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Multi-system sustainability transitions in developing countries: a case study of the electric car in Brazil

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Multi-system sustainability transitions in developing countries: a case study of the electric car in Brazil

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[…] struggling and suffering, as I now saw it, were the essence of a life worth living. If you're not pushing yourself beyond the comfort zone, if you're not constantly demanding more from yourself—expanding and learning as you go—you're choosing a numb existence. You're denying yourself an extraordinary trip. (KARNAZES, 2006, p. 238)

ABSTRACT

The urban mobility socio-technical system still follows a trend of increasing its unsustainable patterns. There are many proposals to achieve sustainable urban mobility, but there is no consensus on its definition and operationalization. Electric mobility may be the easiest of these proposals to implement in Brazil. The transition to electric cars involves many socio-technical systems, such as urban mobility and electricity. Most theories and typologies currently used in the sustainability transitions field were conceived in developed countries and may not be adequate to explain transitions involving multiple socio-technical systems in developing countries. The objective of this thesis is to explain how the electricity socio-technical system influences the transition to the electric car in Brazil. The ontology and epistemology adopted in the research are close to pragmatism and critical realism. The theoretical framework used is the multilevel perspective and the strategy adopted is the case study. The case selected was ANEEL's Strategic Research and Development Project nº 22 from 2019. Two different data collection methods are used: secondary data and semi-structured interviews. The results show that the electricity socio-technical system is interacting with the electric car niche in multiple ways, and these interactions cannot be reduced to a single pattern. Most actors from the electricity socio-technical system are not interested in the transition to electric cars, but some relevant actors from this socio-technical system, notably incumbents, are helping to consolidate the electric car niche. They are collaborating to the creation of a network of actors related to electric cars, helping to create learning processes at multiple dimensions, contributing to articulate expectations and visions on electromobility, improving the electric cars charging infrastructure in Brazil, developing new business models to make electric cars charging a profitable business, and helping to improve the regulation on electric cars. It was also found that the lack of a clear normative orientation is contributing to delaying the transition to electric cars in Brazil. The competition between electric cars and biofuels is leading several actors to postpone investments in electric mobility. In addition, the case study reveals that transnational actors play an important role in ANEEL's project. These actors help local actors to access global resources and serve as a bridge with other sustainability experiments around the world.

Key words: Socio-technical transition. Electric vehicle. Strategic Research and Development Project nº 22.

RESUMO

O sistema sociotécnico de mobilidade urbana ainda segue uma tendência de aumento de seus padrões não sustentáveis. Existem muitas propostas para tornar a mobilidade urbana sustentável, mas não há consenso sobre a sua definição e operacionalização. Destas propostas, a mobilidade elétrica pode ser a mais fácil de ser implementada no Brasil. A transição para carros elétricos envolve muitos sistemas sociotécnicos, como mobilidade urbana e eletricidade. A maior parte das teorias e tipologias usadas atualmente no campo das transições para a sustentabilidade foram elaboradas em países desenvolvidos e podem não ser adequadas para explicar transições envolvendo múltiplos sistemas sociotécnicos em países em desenvolvimento. O objetivo desta tese é explicar como o sistema sociotécnico de eletricidade influencia a transição para o carro elétrico no Brasil. A ontologia e a epistemologia adotadas na pesquisa estão próximas do pragmatismo e do realismo crítico. O framework teórico utilizado é a perspectiva multinível e a estratégia adotada é o estudo de caso. O caso selecionado foi a Chamada 22 da ANEEL de 2019. Dois métodos diferentes de coleta de dados são usados: dados secundários e entrevistas semiestruturadas. Os dados coletados mostram que o sistema sociotécnico de eletricidade está interagindo com o nicho do carro elétrico de diversas maneiras e estas interações não podem ser reduzidas a um único padrão. A maior parte dos atores do sistema sociotécnico de eletricidade não está interessada na transição para carros elétricos, mas alguns atores relevantes deste sistema sociotécnico, notadamente incumbentes, estão ajudando a consolidar o nicho do carro elétrico. Eles estão colaborando com a criação de uma rede de atores em torno dos carros elétricos, ajudando a criar processos de aprendizado em múltiplas dimensões e contribuindo para a articular expectativas e visões sobre mobilidade elétrica, melhorando a infraestrutura de recarga de carros elétricos no Brasil, desenvolvendo novos modelos de negócios para tornar a recarga de carros elétricos lucrativa, e ajudando a melhorar a regulação sobre carros elétricos. Verificou-se também que a falta de uma orientação normativa clara está contribuindo para retardar a transição para carros elétricos no Brasil. A competição entre carros elétricos e biocombustíveis está levando vários atores a postergar investimentos em mobilidade elétrica. O estudo de caso revelou também que atores transnacionais têm papel importante na Chamada 22. Estes atores ajudam os atores locais a ter acesso a recursos globais, e servem como uma ponte com outros experimentos sustentáveis ao redor do mundo.

Palavras-chave: Transição sociotécnica. Veículo elétrico. Projeto Estratégico de Pesquisa e Desenvolvimento – P&D nº 22.

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LIST OF ACRONYMS & ABBREVIATIONS

ABVE	*Associação Brasileira do Veículo Elétrico*
ACEA	European Automobile Manufacturers' Association
ACL	*Ambiente de contratação livre*
ACR	*Ambiente de contratação regulada*
APINE	*Associação Brasileira dos Produtores Independentes de Energia Elétrica*
ANEEL	*Agência Nacional de Energia Elétrica*
ANFAVEA	*Associação Nacional dos Fabricantes de Veículos Automotores*
ANP	*Associação Nacional do Petróleo*
ANTP	*Associação Nacional de Transportes Públicos*
AV	Automated vehicles
Baesa	*Energética Barra Grande*
BATLAB	*Laboratório de Inteligência Artificial, Eletrônica de Potência e Sistemas Digitais*
BEIS	UK Department for Business, Energy & Industrial Strategy
BEV	Battery electric vehicle
BRT	Bus Rapid Transit
CARB	California Air Resources Board
CAV	Connected and automated vehicles
CCEE	*Câmara de Comercialização de Energia Elétrica*
CEAMAZON	*Centro de Excelência em Eficiência Energética da Amazônia*
CEB	*Companhia Energética de Brasília*
CEB-D	*CEB Distribuição*
CEC	*Companhia Energética Candeias*
CEEE-D	*Companhia Estadual de Distribuição de Energia Elétrica*
CEEE-GT	*Companhia Estadual de Geração e Transmissão de Energia Elétrica*
CEESP	*Centro de Excelência em Energia e Sistemas de Potência*
Celpe	*Companhia Energética de Pernambuco*
Celesc	*Centrais Elétricas de Santa Catarina*
Celesc D	*Celesc Distribuição*
CEM	*Companhia Energética Manauara*

CEMIG	*Companhia Energética de Minas Gerais*
CEMID D	*CEMIG Distribuição*
CEMIG GD	*CEMIG Geração Distribuída*
CEMIG GT	*CEMIG Geração e Transmissão*
CEMIG SIM	*CEMIG Soluções Inteligentes em Energia*
CEP	*Companhia Energética Potiguar*
CEP/CHS	*Comitê de Ética em Pesquisa em Ciências Humanas e Sociais da Universidade de Brasília*
CESPE	*Companhia Energética de São Paulo*
CESTE	*Consórcio Estreito Energia*
CERTI	*Fundação Centros de Referência em Tecnologias Inovadoras*
CGEE	*Centro de Gestão e Estudos Estratégicos*
CIBiogás	*Centro Internacional de Energias Renováveis e Biogás*
CIMATEC	*Campus Integrado de Manufatura e Tecnologia*
CMSE	*Comitê de Monitoramento do Setor Elétrico*
CNPE	*Conselho Nacional de Política Energética*
Coelba	Companhia de Eletricidade do Estado da Bahia
COPEL	*Companhia Paranaense de Energia*
Cosern	*Companhia Energética do Rio Grande do Norte*
CPFL Jaguari	*Companhia Jaguari de Energia*
CPFL Paulista	*Companhia Paulista de Força e Luz*
CPFL Piratininga	*Companhia Piratininga de Força e Luz*
CPFL Santa Cruz	*Companhia Luz e Força Santa Cruz*
CTG	China Three Gorges Corporation
CO	Carbon monoxide
DME	DME Poços de Caldas Participações
DMED	*DME Distribuição*
DMEE	*DME Energética*
EDP	Energias de Portugal
Eletrobras	*Centrais Elétricas Brasileiras*
Eletronorte	*Centrais Elétricas do Norte do Brasil*
EAC	*Energisa Acre Distribuidora de Energia*
EBO	*Energisa Borborema Distribuidora de Energia*
EMG	*Energisa Minas Gerais Distribuidora de Energia*

EMS	*Energisa Mato Grosso do Sul Distribuidora de Energia*
EMT	*Energisa Mato Grosso Distribuidora de Energia*
ENF	*Energisa Nova Friburgo Distribuidora de Energia*
EQTL Alagoas	*Equatorial Energia Alagoas*
EQTL Maranhão	Equatorial Energia Maranhão
EQTL Pará	*Equatorial Energia Pará*
EQTL Piauí	*Equatorial Energia Piauí*
ERO	*Energisa Rondônia Distribuidora de Energia*
ESE	*Energisa Sergipe Distribuidora de Energia*
ESS	*Energisa Sul-Sudeste Distribuidora de Energia*
EPB	*Energisa Paraíba Distribuidora de Energia*
ETO	*Energisa Tocantins Distribuidora de Energia*
EPE	*Empresa de Pesquisa Energética*
EU	European Union
EV	Electric vehicles
FACEPE	*Fundação de Apoio à Cultura, Ensino, Pesquisa e Extensão de Alfenas*
FEESC	*Fundação Stemmer para Pesquisa, Desenvolvimento e Inovação*
FENABRAVE	*Federação Nacional da Distribuição de Veículos Automotores*
FCA	Fiat Chrysler Automobiles
FCEV	Fuel cell electric vehicles
FUJB-UFRJ	*Fundação José Bonifácio*
FV-UFSC	*Grupo de Pesquisa Estratégica em Energia Solar*
GASMIG	*Companhia de Gás de Minas Gerais*
GDP	Gross domestic product
GEPAI	*Grupo de Pesquisas em Eletrônica de Potência e Acionamentos Industriais*
GESEL	*Grupo de Estudos do Setor Elétrico*
GIZ	*Deutsche Gesellschaft für Internationale Zusammenarbeit*
GHG	Greenhouse gas
GM	General Motors
GPR	*Global Participações em Energia*
HEV	Hybrid electric vehicle
IATI	*Instituto Avançado de Tecnologia e Inovação*

ICEV	Internal combustion engine vehicle
ICT	Information and communication technologies
IEA	International Energy Agency
IFSULDEMINAS	*Instituto Federal do Sul de Minas Gerais*
ICT	Information and communication technologies
ICT Inova Brasil	*Instituição Científica e de Inovação Tecnológica Brasil*
IPCC	Intergovernmental Panel on Climate Change
ITA	*Instituto Tecnológico de Aeronáutica*
ITAQUI	*Itaqui Geração de Energia*
ITEMM	*Instituto Edson Mororó Moura*
Itapebi Geração	*Itapebi Geração de Energia Elétrica*
LABNAV	*Laboratório de Engenharia Naval*
Lactec	Instituto de Tecnologia para o Desenvolvimento
LAPEE	*Laboratório Aplicado de Pesquisas em Eficiência Energética*
LASSE	*Núcleo de Pesquisa e Desenvolvimento em Telecomunicações, Automação e Eletrônica*
LASUP	*Laboratório de Aplicações de Supercondutores*
LCA	Life cycle assessment
LCPE	*Laboratório de Combustão, Propulsão e Energia*
LCT	*Laboratório de Computação e Telecomunicações*
LEVE	*Laboratório de Estudos do Veículo Elétrico*
MAN	*Man Latin América Indústria e Comércio de Veículos*
MME	*Ministério de Minas e Energia*
MLP	Multi-Level Perspective
NDC	Nationally Determined Contribution
NGO	Non-governmental organization
NMVOC	Non-methane volatile organic compounds
NOx	Nitrogen oxides
NTU	*Associação Nacional das Empresas de Transportes Urbanos*
OECD	Organization for Economic Co-operation and Development
ONS	*Operador Nacional do Sistema Elétrico*
PARNA I	*Paranaíba I Geração de Energia*
PARNA II	*Paranaíba II Geração de Energia*
PECÉM II	*Pecém II Geração de Enegia*

Petrobras	*Petróleo Brasileiro S.A.*
PHEV	Plug-in hybrid electric vehicle
$PM_{2.5}$	Particulate matter with a diameter of 2.5 µm or less
PM_{10}	Particulate matter with a diameter of 10 µm or less
PUC Minas	*Pontifícia Universidade Católica de Minas Gerais*
PUC Rio	*Pontifícia Universidade Católica do Rio de Janeiro*
RGE Sul	*RGE Sul Distribuidora de Energia*
RISE	*Rede de Inovação no Setor Elétrico*
R&D	Research and development
SDG	Sustainable Development Goal
SENAI	*Serviço Nacional de Aprendizagem Industrial*
SHP	Small hydroelectric plant
SMC	*Sociedade Mineira de Cultura*
SNM	Strategic Niche Management
SPE	*Superintendência de Pesquisa e Desenvolvimento e Eficiência Energética da ANEEL*
SOx	Sulfur oxides
SRDP-22	Strategic Research and Development Project nº 22
STRN	Sustainability Transitions Research Network
ST-regime	Socio-technical regime
ST-system	Socio-technical system
ST-transition	Socio-technical transition
SuM4All	Sustainable Mobility for All
TIS	Technological Innovation System
TM	Transition Management
UFABC	*Universidade Federal do ABC*
UFMG	*Universidade Federal de Minas Gerais*
UFPA	*Universidade Ferderal do Pará*
UFPB	*Universidade Federal da Paraíba*
UFPE	*Universidade Federal de Pernambuco*
UFSC	*Universidade Federal de Santa Catarina*
UFRJ	*Universidade Federal do Rio de Janeiro*
UFSM	*Universidade Federal de Santa Maria*
UK	United Kingdom

UN	United Nations
UnB	*University of Brasília*
UNFCC	United Nations Framework Convention on Climate Change
Unicamp	*Universidade Estadual de Campinas*
UNIFAL	*Universidade Federal de Alfenas*
USA	Unites States of America
UTFPR	Universidade Tecnológica Federal do Paraná
V2G	vehicle-to-grid
WBCSD	World Business Council for Sustainable Development
WHO	World Health Organization
ZEV	Zero-emission vehicle

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1. INTRODUCTION

The increasing concerns about climate change, considered by many researchers as the most significant environmental threat of the 21st Century, made many scholars focus on a particular research area: sustainability transitions. These are systemic changes that can only be achieved through deep-structural modifications in socio-technical systems (ST-system), i.e., interconnected elements (e.g., technologies, infrastructure, organizations, policies) that fulfill a societal function, such as, transport, energy, and agri-food (GEELS, 2004). Changes in ST-systems go beyond new technologies, entailing economic, socio-cultural, institutional and political aspects (GEELS, 2004; VAN DEN BERGH; TRUFFER; KALLIS, 2011).

The urban mobility ST-system, i.e., all movements of people and goods within the urban space (BRAZIL, 2012), is particularly relevant to climate change. Considering that the transport ST-system was responsible for the discharge of 8.2 $GtCO_2eq$ in 2018 (IEA, 2019a) and that the urban mobility ST-system accounts for approximately 40% of these emissions (IPCC, 2014), urban mobility emitted about 3.3 $GtCO_2eq$. Therefore, this ST-system accounted for 5.9% of the 55.6 $GtCO_2eq$ global Greenhouse gas (GHG) emissions in 2018 (OLIVIER; PETERS, 2020). In Brazil, the urban mobility ST-system was responsible for 5.2% of the country's GHG emissions in 2018 (ANGELO; RITTL, 2019).

Nonetheless, the urban mobility ST-system is not on a transition pathway that would allow achieving the Paris Agreement goal (UNFCCC, 2015) of limiting global warming to 1.5º C[1] (ROGELJ et al., 2016; GEIGES et al., 2019). This ST-system still follows trends of using increasing amounts of fossil fuels (DOMINKOVIĆ et al., 2018; IEA, 2019a). GHG emissions of the urban mobility ST-system have increased by 44% between 2000 and 2018 (IEA, 2019a). This same pattern was seen in Brazil, where the annual emissions of this ST-system has steadily increased between 2000 and 2014, from 61.8 $MtCO_2eq$ to 112.4 $MtCO_2eq$ in 2014 (ANGELO; RITTL, 2019). There was a reduction in emissions from this ST-system after 2014, reaching 99.5 $MtCO_2eq$ in 2018. However, this reduction seems more related to Brazil's economic recession in 2015 and 2016 and low economic growth in 2017 and 2018 than to efforts to achieve the Paris Agreement targets.

[1] The self-determined targets for the reduction of GHG emissions submitted by the countries who ratified the Paris Agreement is insufficient to achieve the goal of limiting global warming to 1.5º C and may not be enough even to limit it to 2º C (SCHLEUSSNER et al., 2016)

Therefore, reducing GHG emissions in the urban mobility ST-system is essential to achieve the Paris Agreement goal (LAH, 2019a). The United Nations (UN) Sustainable Development Goals (SDG)[2] have targets explicitly aimed at this ST-system. SDG 9 focus on developing sustainable and resilient infrastructures, which include the urban mobility ST-system, and SDG 11's target 11.2 aim to make the transport ST-system (encompassing the urban mobility ST-system) sustainable, affordable, accessible, and safe.

The Intergovernmental Panel on Climate Change (IPCC) also considers the urban mobility ST-system key for addressing climate change, with great potential to reduce GHG emissions. Switching to low-carbon transportation is among the main strategies recommended by the IPCC (2014). Most countries that ratified the Paris Agreement, including some of the major GHG emitters, like China, the European Union (EU), India, Brazil, and Japan, informed in their National Determined Contribution (NDC) targets for decreasing GHG emissions by the urban mobility ST-system.

Moreover, the urban mobility ST-system have many other negative impacts on society and the environment (HOLDEN et al., 2020). It is a major consumer of non-renewable resources, such as fossil fuels, steel and aluminum (BLACK, 2010). It is a great contributor to local air and noise pollution. Traffic-related accidents leads 1.35 million people to death every year (WHO, 2018). The development of urban mobility infrastructure has many negative impacts in the environment (EUROPEAN ENVIRONMENT AGENCY, 2004; ASHER; GARG; NOVOSAD, 2018). The unequal access to mobility services is increasing inequality and social exclusion (HOLDEN; GILPIN; BANISTER, 2019). Traffic congestions have considerable negative impact on the economy (SWEET, 2011, 2014).

There are many proposals to make urban mobility sustainable. The main ones are: (i) biofuels, (ii) shared vehicles; (iii) integrated public transport; (iv) compact cities; (v) communication and information technologies; (vi) automated vehicles; and (vii) electric vehicles (NYKVIST; WHITMARSH, 2008; BLACK, 2010; XENIAS; WHITMARSH, 2013; MARLETTO, 2014; MORADI; VAGNONI, 2018; HOLDEN et al., 2020). However, there is no consensus about the definition and the operationalization of sustainable mobility (HODSON; GEELS; MCMEEKIN, 2017). Besides, the

[2] For more information on the SDG see https://sdgs.un.org/goals.

sustainability transition in the urban mobility ST-system involves broader changes in the economy, consumer's behavior, and infrastructure (SHAFIEI et al., 2017).

The transition to electric cars might be easier to implement in Brazil than the other proposals for achieving sustainable urban mobility, since most constituent elements of a car-dependent transport ST-system[3] are present in the country. The current configuration of the Brazilian urban mobility ST-system places the country in a hard to break car-dependence lock-in, i.e., institutional, technological, and social forces act to maintain and promote cars in detriment of other alternatives.

Besides, Brazil has abundant renewable energy resources (e.g., hydro, wind, and solar), which have potential synergies with electric vehicles. These technologies could reduce costs and carbon emissions if combined (SHAFIEI et al., 2017; CALVILLO et al., 2018). Cars are responsible for 67% of all GHG emissions in urban transportation in Brazil, although they only account for 31% of total distance travelled[4] (ANTP, 2020a). In 2021, there were approximately 37.9 million cars in Brazil. 99.9% of them were internal combustion engine vehicles (ICEV), and only 0.1% (34,990 units) were battery electric vehicles (BEV), plug-in hybrid electric vehicles (PHEV) or hybrid electric vehicles (HEV) (ANFAVEA, 2022).

Moreover, the COVID-19 pandemic significantly impacted the urban mobility ST-system. This pandemic has great human cost. At this time (December-2022), more than 6.6 million people have died and almost 650 million have been infected by the virus all over the world (JOHNS HOPKINS UNIVERSITY & MEDICINE, 2022). Restricting human mobility is one of the most effective measures to control the spread of the disease (KRAEMER et al., 2020; TIAN et al., 2020) and it was implemented in many countries, including Brazil. These restrictions had significant impacts on the urban mobility ST-system, notably the automotive sector, which created opportunities for new technologies and practices (sustainable or not) to emerge in this ST-system. In the short term, it have reinforced automobility, especially electric cars (WANG; WELLS, 2020). In the long term, the combination of fewer and shorter trips, a shift to individual transportation and the need to reduce GHG emissions may be the necessary conditions for electric cars to break through from niche and challenge the private car ST-regime.

---

[3] These elements are: i) strong automotive industry; ii) the provision of car infrastructure; iii) the political economy of urban sprawl; iv) poor provision of public transport; v) cultures of car consumption (MATTIOLI et al., 2020).

[4] Includes non-motorized transport (walking and bicycle).

A transition from ICEVs to electric vehicles (EV) in Brazil would have many implications, besides reducing GHG emissions, such as: (i) increasing the demand for electricity, mainly from renewable sources, which would impact the electricity system; (ii) reducing the consumption of fossil fuels; (iii) creating pressure in the automobile industry to change its production lines; (iv) requiring a change in consumer behavior, as owning and using an EV is not the same as an ICEV in many aspects (BAUER, 2018; PHILIPSEN et al., 2018); (v) reducing other impacts from ICEV, such as local noise and air pollution (HOLDEN et al., 2020); (iv) increasing the demand for rare elements, including lithium, cobalt, and rare earths used in the some electric motors and batteries (HIRST et al., 2020; SILVESTRI et al., 2021).

Although there is some research on how electric cars could impact the Brazilian urban mobility ST-system, their focus is usually on technological alternatives and environmental impacts (CHOMA; UGAYA, 2017; DE SOUZA et al., 2018; GLENSOR; MUÑOZ, 2019). There is little consideration of institutional, political, and socio-cultural factors that impact the adoption of electric cars in Brazil. Moreover, few researchers have considered sustainability transitions theoretical frameworks when studying electric cars in Brazil (e.g., Marx et al., 2015; Coelho and Abreu, 2019)

The transition to electric cars is a sustainability transition that involves many ST-systems, such as urban mobility, electricity, and fossil fuels. Transitions involving interactions between multiple socio-technical regimes (ST-regimes) and niches[5] from different ST-systems have been understudied in the transitions field (HASSINK; GRIN; HULSINK, 2018; KÖHLER et al., 2019; ROSENBLOOM, 2019, 2020). The main theoretical frameworks used in this field focus on transitions in a single ST-system (BERKHOUT; SMITH; STIRLING, 2004; RAVEN; VERBONG, 2007; GEELS, 2011).

Moreover, most research on sustainability transitions was done in developed countries. There are much fewer studies on transitions in developing countries. (HANSEN; COENEN, 2015; VAN WELIE et al., 2018; BINZ et al., 2020). There is uncertainty about how geographic aspects impact transitions and how the spatial dimension should be incorporated to the theoretical frameworks (RAVEN; SCHOT; BERKHOUT, 2012; KÖHLER et al., 2019). The theories and typologies currently used, for example, Raven and Verbong (2007) and Papachristos, Sofianos, and Adamines

[5] The conceptualization of ST-regimes and niches in transitions theory is detailed in Section 2.1.1.4.

(2013), have been developed based on case studies from developed countries and may not be suited for explaining sustainability transitions in developing countries.

For example, the role of incumbents in sustainability transitions is often oversimplified in transitions literature (KÖHLER et al., 2019). This simplification is particularly problematic in developing countries, where incumbents often have relevant roles in promoting sustainability transitions (GHOSH; SCHOT, 2019). Moreover, the sustainability transitions theoretical frameworks still need a more comprehensive conceptualization of ST-regimes, which could be properly applied to developing countries (KÖHLER et al., 2019).

Another relevant issue is assessing how different visions of sustainability impact the governance and outcome of sustainability transitions. Economic and political elites often try to coopt sustainability transitions to preserve the existing distributions of power in developing countries such as Brazil (HANSEN et al., 2018; RAMOS-MEJÍA; FRANCO-GARCIA; JAUREGUI-BECKER, 2018). Moreover, this is a real possibility in the transition to electric cars. If not properly governed, this transition can increase the unequal access to mobility, heightening economic inequality and social exclusion (SPERLING, 2018; HOLDEN; GILPIN; BANISTER, 2019).

Therefore, the research gap addressed in this thesis is multi-system sustainability transitions in developing countries. Research on sustainability transitions involving multiple ST-systems in developing countries, such as the study of the transition to electric cars in Brazil, can provide empirical elements to advance the sustainability transitions theoretical frameworks.

The research is guided by the following research question. “How does the electricity ST-system influence the sustainability transition to the electric car in the Brazilian urban mobility ST-system?”

Many actors of different ST-systems are interested in supporting, delaying or blocking a transition to the electric car in Brazil. For example, the fossil fuel and the biofuel ST-systems can be negatively impacted by this transition, due to the consequently reduced demand for fossil fuels and biofuels. Therefore, key actors within these ST-systems may try to delay or block this transition. On the other hand, the electricity ST-system can significantly benefit from a transition to EVs. This transition could considerably increase electricity consumption and would offer other advantages, such as vehicle-to-grid applications.

However, an accelerated transition could also cause problems to the Brazilian electricity system, which is already struggling to meet demand in years with low rain, when the operation of the hydroelectric plants is restricted. Increasing the electricity generation infrastructure usually involves significant investments and large construction works that can take many years. Therefore, there may be some actors resisting the transition to electric cars even in the electricity ST-system.

Nonetheless, the electricity ST-system is at the core of the sustainability transition to electric cars in Brazil (CONSONI et al., 2018). The support from actors from this ST-system can be essential for this transition to unfold, given the significant political power and the great financial resources of this ST-system. For example, the support of key actors from the electricity ST-system was fundamental to the consolidation of the electric car in Norway (SKJØLSVOLD; RYGHAUG, 2020).

Therefore, the main objective of this thesis is to explain how the electricity ST-system influences the sustainability transition to the electric car in Brazil. The focus of the research is the sustainability experiments that are part of the Strategic Research and Development Project nº 22 (SRDP-22) from the *Agência Nacional de Energia Elétrica* (ANEEL, National Electrical Energy Agency). The main objective of SRDP-22 is to prepare the Brazilian electricity ST-system for the transition to EVs, and its sustainability experiments involve actors from both the electricity and the urban mobility ST-systems.

The following set of specific objectives were defined to achieve the thesis' main objective:

(i) To characterize the urban mobility ST-system, electricity ST-system and electric car niche in Brazil.

(ii) To identify the main sustainability experiments in the Brazilian electric car niche that involve actors from the electricity and the urban mobility ST-systems prior to the Strategic Research and Development Project nº 22 from ANEEL.

(iii) To characterize the sustainability experiments that are part of the Strategic Research and Development Project nº 22 from ANEEL.

(iv) To assess how sustainability experiments in the electric car niche that involve actors from the electricity and the urban mobility ST-systems influence the sustainability transition to the electric car in Brazil.

(v) To analyze the role of incumbents (actors of the existing ST-regimes) in the sustainability transition to the electric car in Brazil.

(vi) To assess how different visions of sustainability impact the governance and outcome of sustainability transitions.

(vii) To evaluate how the COVID-19 pandemic impacted the electric car niche in Brazil.

(viii) To make policy recommendations to help accelerate the sustainability transition to electric cars in Brazil.

The thesis is divided into 7 chapters, including the Introduction and Conclusion. The Introduction (Chapter 1) presents the research problem and introduces the research question and the objectives of the thesis.

Chapter 2 presents the theories, frameworks, and concepts used in the thesis. This chapter gives an overview of the sustainability transitions field and its main theoretical frameworks, paying special attention to the multi-level perspective (MLP), which is the framework that is mainly used in the thesis. Besides, two themes are discussed in detail: multi-system sustainability transitions and sustainability transitions in developing countries. This chapter also provides a review of sustainable urban mobility and discusses the role of the electric car in it.

Chapter 3 details the research design of the thesis, which follows the 'transition research onion' developed by Zolfagharian et al. (2019). The choices made in each layer of the 'research onion' are explained and justified. Thus, the research philosophy, the theoretical framework, and the strategy used in thesis are detailed. Moreover, the reasons for selecting SRDP-22 as the case for the case study and the rationale behind the option for using a multi-method qualitative approach are presented in this chapter. There is also a description of the two data collection methods used in the research, secondary-data and semi-structured interviews, including an explanation of the sampling method adopted. In addition, the analytical framework used in the analysis of the case study results is detailed. Finally, this chapter also explains the strategies used to manage, minimize, and eliminate bias from the research and the ethical considerations of the research design.

Chapter 4 presents the contextualization of the case study. The two ST-systems, electricity and urban mobility, involved in the case study and their ST-regimes and niches are detailed. Regarding the urban mobility ST-system, the focus is on the private car ST-regime and the electric car niche, which are detailed in greater depth. Besides, there is an analysis of the sustainability experiments with electric cars involving actors from the electricity ST-system prior to SRDP-22. Finally, this chapter also presents how SRDP-22 was conceived, its main goals, and the sustainability experiments that are part of the program.

Chapter 5 shows a compilation of the primary and secondary data collected during the research. The data is presented following the analytical framework detailed in Chapter 2. Thus, there is a characterization of the actors involved in SRDP-22, the detailing of different levels, modes, and value-chain levels of interaction of SRDP-22 experiments, and a description of the resources exchanged in these experiments. In addition, the impact of transnational linkages on SRDP-22 and the interest of the electricity ST-system in electric mobility are presented. Finally, this chapter also details the main impacts of COVID-19 in SRDP-22 experiments.

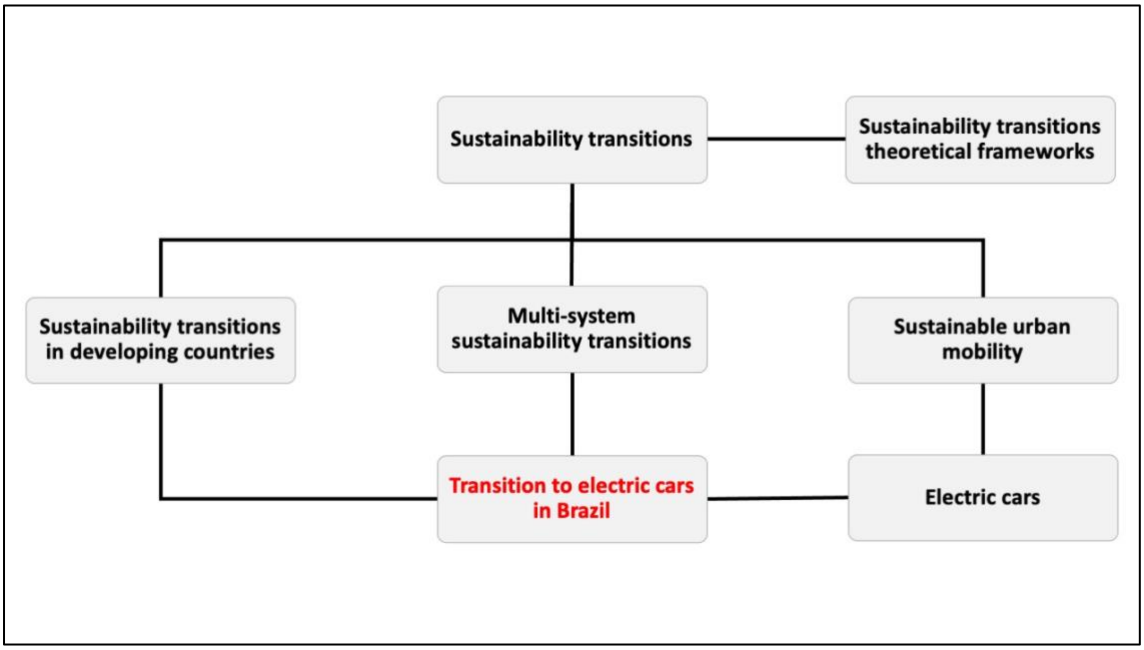
Chapter 6 provides the analysis and discussion of the results presented in Chapter 5. Chapter 6 explores four main themes. First, there is an analysis of the role of the electricity ST-system in the transition to EVs in Brazil, including a discussion of the current conceptualizations of multi-system sustainability transitions. Second, the current normative orientation of sustainability in the urban mobility ST-system in Brazil, and how it is impacting the transition to EVs is analyzed. Then, there is an explanation of the role of incumbents in the transition to EVs, considering how the private car ST-regime and the ST-regimes of the electricity ST-system are interacting with the niches involved in the case study. Finally, the last theme explored is the impact of transnational linkages in the transition to EVs in Brazil.

The Conclusion (Chapter 7) is the last chapter of the thesis. It answers the research question posed in the Introduction and summarizes the main contributions of the thesis to the literature. In addition, this chapter also presents policy recommendations to help accelerate the transition to EVs in Brazil, indicates the main limitations of the research, and suggests future work to advance the sustainability transitions field.

2. THEORY REVIEW

This chapter presents the main theories, frameworks, and concepts that will be used to analyze the transition to electric cars in Brazil. First, an overview of the sustainability transitions field is presented, introducing its main theoretical frameworks. One framework, the MLP is presented in more details because it is the framework that will be mainly used in the analysis. Then, two research themes in sustainability transitions field are discussed in detail because they are significant for the research: multi-system sustainability transitions and sustainability transitions in developing countries. Finally, there is an overview of sustainable urban mobility and a discussion about how electric cars can make urban mobility more sustainable. Figure 2.1 show how each of these topics connect with each other and with the research gap addressed in this research.

Figure 2.1 –Themes discussed in the Theory Review and their link with the research gap



Source: Developed by the author

2.1 Sustainability transitions

Sustainability transitions became an established research topic at the start of the 2000s (PARRIS; KATES, 2003). It has received increasing attention from policymakers and scholars since then (SMITH; STIRLING; BERKHOUT, 2005; MARKARD; RAVEN; TRUFFER, 2012). The emerging field of sustainability transition studies is concerned with the great environmental challenges facing humanity. (e.g., climate change, loss of biodiversity, and resource depletion). There is an understanding among the researchers in this field that incremental improvements and technological fixes will not be sufficient to promote sustainability and address these challenges. Radical changes, combining "technical, organizational, economic, institutional, social-cultural and political changes" (VAN DEN BERGH; TRUFFER; KALLIS, 2011, p. 2), are thus necessary. These radical shifts are the sustainability transitions (ELZEN; GEELS; GREEN, 2004; KÖHLER et al., 2019).

Sustainability transitions are different from other transitions in the past. They are goal-oriented, some of its solutions do not offer clear user benefits, and the involvement of large and established firms that would typically avoid systemic changes will be necessary to achieve it in the required timeline (GEELS, 2011). Köhler *et al.* (2019) listed several characteristics that distinguish sustainability transitions from other topics in social sciences:

(i) They are *multi-dimensional*, involving the *co-evolution* of multiple elements and dimensions.

(ii) They involve *multiple actors* and social groups, as well as many kinds of agency.

(iii) Research in this field is deeply interested in the "*dialectic relationship between stability and change"* (KÖHLER et al., 2019, p. 2);

(iv) They are *long-term processes*, which may take many years or decades to develop.

(v) *Open-endedness* and *uncertainty* are inherent to these transitions.

(vi) They are *contested* by several incumbent actors, who are interested in maintaining their interests and avoid change.

(vii) They demand *normative direction*, i.e., the *directionality* of sustainability transitions must be shaped by public policy (e.g., regulations, taxes, subsidies). There is limited or no incentive for the private actors to change, because sustainability is a public good.

Sustainability transitions involve significant changes in the overall configuration of entire systems, such as the energy, water, and transportation systems (ELZEN; GEELS; GREEN, 2004; GEELS, 2010, 2011). Markard, Raven, and Truffer (2012, p. 956) defined sustainability transitions as "long-term, multi-dimensional, and fundamental transformation process through which established socio-technical systems shift to more sustainable modes of production and consumption."

Therefore, sustainability transitions are socio-technical transitions (ST-transitions), i.e., large-scale and long-term transitions from one ST-system to another (GEELS, 2002; SCHOT; KANGER, 2018). ST-transitions involve deep technological changes in the ST-systems. These changes are not only in technology, but also in other elements of the ST-system, such as regulations, culture and symbolic meanings, markets and user practices, and infrastructures (GEELS, 2002, 2004).

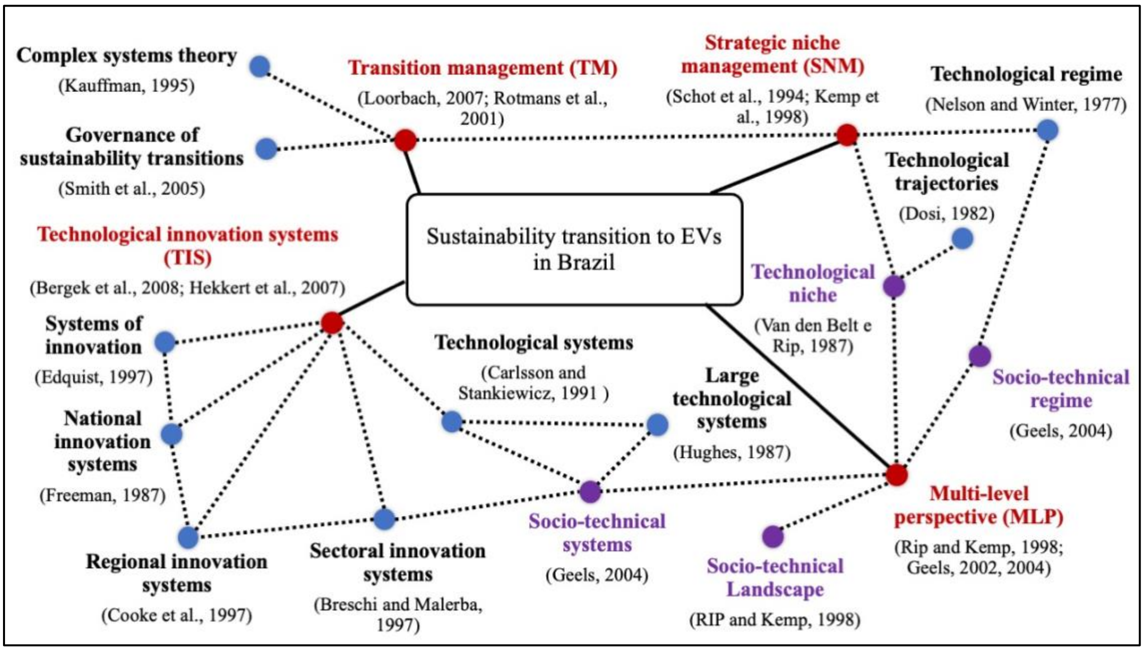
The concept of ST-system was advanced by Geels (2004), building on previous concepts: Breschi and Malerba's (1997) Sectoral Systems of Innovation, Hughes' (1987) Large Technical Systems, and Carlsson and Stankiewicz's (1991) Technological Systems. Geels (2004) argued that these definitions of technological systems focused only on the production side, ignoring the demand side. He proposed a definition of technological system that also included the demand side. Thus, ST-systems are "the linkages between elements necessary to fulfil societal functions" (GEELS, 2004, p. 900). ST-systems focus on the fulfillment of societal functions (e.g., transport, energy, and agri-food) rather than on innovations itself and are formed by artifacts, knowledge, culture, capital, regulations, etc. (GEELS, 2004).

ST-transitions and ST-systems are basic concepts used on all the main theoretical frameworks in the field of sustainability transitions. These frameworks are detailed in the next section.

2.1.1 Sustainability transitions theoretical frameworks

There are four central theoretical frameworks used in sustainability transitions studies: the Technological Innovation System (TIS), the Strategic Niche Management (SNM), the Transition Management (TM) and the MLP (VAN DEN BERGH; TRUFFER; KALLIS, 2011; MARKARD; RAVEN; TRUFFER, 2012; KÖHLER et al., 2019). These frameworks are marked in red in Figure 2.2, which shows the many theoretical linkages and conceptual commonalities between these frameworks, even though they have different focus and levels of analysis (MARKARD; TRUFFER, 2008; MARKARD; RAVEN; TRUFFER, 2012). The concepts marked in purple in Figure 2.2 are the most relevant to the thesis and are presented in more detail than the others in this chapter.

Figure 2.2 – Theoretical linkages between the TIS, the SNM, the TM and the MLP



Source: Developed by the author based on Markard, Raven and Truffer (2012)

The next sections give an overview of the TIS, SNM, and TM. The MLP is presented in more detail because it is the framework that is used in the thesis[6]. However, it is important to describe the other frameworks because some of the MLP shortcomings may be addressed through its use in combination with them (MARKARD; TRUFFER, 2008).

2.1.1.1 Technological Innovation System

The TIS is a technology-centered framework based on ideas from innovation system theory and industrial economics (BERGEK et al., 2015; KÖHLER et al., 2019). This framework was commonly referred to as 'Innovation Systems' approach or 'Technological System' approach in earlier work (MARKARD; RAVEN; TRUFFER, 2012). These first studies conceptualized innovation systems in many different levels (EDQUIST, 1997), including national innovation systems (FREEMAN, 1987; NELSON, 1993; LUNDVALL, 2016), regional innovation systems (COOKE; URANGA; ETXEBARRIA, 1997), and sectoral systems of innovation and production (BRESCHI; MALERBA, 1997; MALERBA, 2002).

[6] The reasons for choosing the MLP as the thesis' theoretical framework are presented in Section 3.2.

The TIS concept can be traced back to the work of Carlsson and Stankiewicz (1991, p. 111) (MARKARD; RAVEN; TRUFFER, 2012; MARKARD; HEKKERT; JACOBSSON, 2015), who defined technological system as

> […] a network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure or set of infrastructures and involved in the generation, diffusion, and utilization of technology. Technological systems are defined in terms of knowledge/competence flows rather than flows of ordinary goods and services. They consist of dynamic knowledge and competence networks.

The term 'Technological Innovation System' was introduced by Bergek, Hekkert, and Jacobsson (2008). Building on Carlsson and Stankiewicz (1991), Bergek *et al.* (2008, p. 408) presented a new definition of TIS: "socio-technical systems focused on the development, diffusion and use of a particular technology (in terms of knowledge, product or both)."

In the TIS framework, an emerging technology is evaluated based on its structural configuration (actors, networks, and institutions) and processes (or functions) that support its formation (WIECZOREK et al., 2015). The success of a TIS is the result of the fulfillment of several functions, which directly impact its development, diffusion, and use (HEKKERT et al., 2007; BERGEK et al., 2008; NEGRO; SUURS; HEKKERT, 2008). Functions of innovation systems are defined as "the contribution of a single component, a set of components or the entire system to the system's (inexplicit) 'goal'" (JOHNSON; JACOBSSON, 2001, p. 5).

Many TIS studies identified different functions of innovation systems over the years (see Bergek et al., 2008, for an overview). The most used set of functions used in TIS studies (e.g., Negro, Suurs, and Hekkert, 2008; and Haley, 2015) was the result of a comprehensive literature review coupled with an inductive aggregation of empirical studies (BINZ; TRUFFER, 2017). This set is composed by seven functions: (i) knowledge development and diffusion; (ii) market formation; (iii) influence on the direction of search; (iv) entrepreneurial experimentation; (v) resource mobilization; (vi) legitimation; and (vii) development of positive externalities (HEKKERT et al., 2007; BERGEK et al., 2008).

Assessing the performance of each of these functions allows the identification of inducement and blocking mechanisms, i.e., processes that favor or hinder the development of TIS functions. The TIS approach can be used to provide policy recommendations aimed at strengthening or adding inducement mechanisms and weakening or removing blocking mechanisms (BERGEK et al., 2008; WIECZOREK et al., 2015). Hence it is a 'technocentric' approach premised on top-down or hierarchal managerial control.

2.1.1.2 Strategic Niche Management

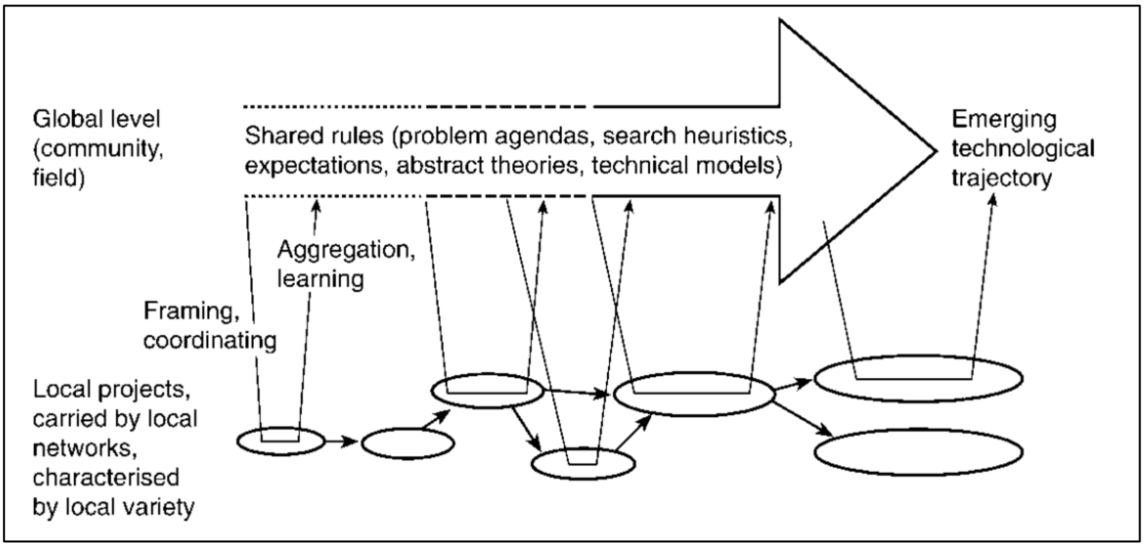
The SNM is a framework based on sociology of innovation and evolutionary economics, which understands that socially desirable innovations can be achieved by modulating technological niches (SCHOT; GEELS, 2008; BERKHOUT; WIECZOREK; RAVEN, 2011; KÖHLER et al., 2019). Van den Belt and Rip (1987) introduced the concept of the niche as a space created to protect a new trajectory from rough selection processes. They built on Dosi's (1982) *technological trajectories*, i.e., the 'normal' pattern of development of a technology. In other words, a niche is a protected space where a new technology can develop shielded from mainstream market selection (GEELS; RAVEN, 2006).

Schot, Hoogma, and Elzen (1994) and Kemp, Schot, and Hoogma (1998) developed the SNM approach using the Van den Belt and Rip (1987) niche concept (SCHOT; GEELS, 2008). SNM can be defined as "the creation, development and controlled phase-out of protected spaces for the development and use of promising technologies by means of experimentation" (KEMP; SCHOT; HOOGMA, 1998, p. 186). In SNM, a new technology is gradually introduced to the existing environment, allowing them to adjust to each other (SCHOT; HOOGMA; ELZEN, 1994).

Successful niche management involves three steps. First, it is necessary to articulate expectations and visions. The promises of the new technology must be credible and coupled to a societal problem which the existing technology is not expected to solve. Sometimes, the new technology can even 'create' a new problem or need that did not exist before, along with the solution. Second, there must be learning processes at multiple dimensions (e.g., technical aspects, government policy, user preferences, and societal and environmental effects). Finally, it must provide a space for interactions between actors and the formation of new social networks (KEMP; SCHOT; HOOGMA, 1998; GEELS; RAVEN, 2006; SCHOT; GEELS, 2008).

Geels and Raven (2006) expanded the analytical core of SNM by proposing to distinguish between the level of local projects and the global niche level. The global level would be articulated from the comparison and the aggregation of learning processes at the local level. They also proposed shifting the focus from single projects to multiple projects. A sequence of successful local experiments and demonstrations generates useful lessons (JOLLY; RAVEN; ROMIJN, 2012). Successful chains of local projects helps to make rules and expectations that were previously dispersed and unstable more articulated and stable in the global niche level, which can lead to new innovation trajectories (see Figure 2.3) (GEELS; RAVEN, 2006; SCHOT; GEELS, 2008).

Figure 2.3 – Technical trajectory carried by local projects



Source: Geels and Raven (2006)

The SNM can be a useful policy instrument, since guiding technological developments is easier than conducting ST-transitions. Creating niches for technologies to develop is in reach of most policymakers. Nonetheless, it is not the definitive instrument to achieve sustainability transitions but rather a steppingstone in these processes. It is a useful addition considering that the value of experiments is often neglected by other policy instruments (KEMP; SCHOT; HOOGMA, 1998; RIP; KEMP, 1998; SCHOT; GEELS, 2008). Schot and Geels (2008) warned that care must be taken to avoid a push bias towards certain technologies when using the SNM. The required co-evolutionary dynamics of the SNM must not be overlooked.

2.1.1.3 Transition Management

Another important framework in sustainability transitions studies is TM. This policy-oriented approach integrates insights and principles from technological transitions studies with complexity science and governance theory at the level of the ST-system. Its goal is to produce policy-relevant knowledge to enable, facilitate and guide sustainability transitions (LOORBACH, 2007; MARKARD; TRUFFER, 2008; KÖHLER et al., 2019).

TM basic elements are (ROTMANS; KEMP; VAN ASSELT, 2001; LOORBACH, 2007):

- Systems-thinking, considering multiple domains (multi-domain), phases (multi-phase) and levels (multi-level).
- Long-term sustainability visions as a framework for shaping short-term policy.
- Focus on learning.
- Orientation towards system transition and innovation.
- Creating and managing niches.
- Involving relevant societal perspectives through multi-actor participatory approach.

Smith, Stirling and Berkhout (2005) stressed that the TM's sustainability visions have several essential functions: (i) mapping plausible alternatives for ST-transitions; (ii) acting as a problem-defining tool; (iii) establishing a stable frame for target-setting and monitoring; (iv) creating a metaphor for building networks; and (v) serving as a narrative for focusing resources.

The TM framework consists of four stages that can be used by policymakers to shape transitions (KÖHLER et al., 2019). It helps policymakers decide which instrument to use, which actors to involve and which step to take next. The framework distinguishes between different types or levels of governance activities that are relevant to ST-transitions. There is no hierarchy between these levels, they exist in parallel, and they mutually influence each other (LOORBACH, 2007, 2010).

The first stage or level involves strategic activities. The strategic level encompasses all activities related to problem structuring and envisioning: vision development, strategic discussions, formulating long-term goals (25 years or more), setting collective goals and norms, and long-term anticipation. It is a time of high uncertainty about the future when innovative individuals can present alternative transition pathways. Tactical activities are the next stage. At this level, actors are focused on translating visions into goals and concrete actions with a shorter time-horizon (5 to 15 years) than at the strategic level. The aim is to identify steering activities, including actions and institutions, that are driven by interests in perpetuating the current ST-system. It is the level at which transition agendas are built, and policymaking happen (LOORBACH, 2007, 2010).

Operational activities, such as experiments and demonstration projects, constitute the third stage. These are short term (less than five years) activities focused on practice, innovation, and learning. At the operational level, policies are implemented and tested, and actors try to scale-up innovations. It also the level at which visions (strategic level) and agendas (tactical level) are downscaled, influencing the selection environment. The last stage involves reflexive activities. These are monitoring, assessment, and evaluation processes, which aim at reflecting upon the activities of the other three stages. They can lead to adjustments and adaptation of visions, agendas, and projects. Social learning happens through these reflexive activities (LOORBACH, 2007, 2010).

The TM framework can be implemented through the transition arena model, a meta-instrument for transition management based on a network approach. It aims to create room for the development of innovations that may lead to a new ST-system (LOORBACH, 2007, 2010). However, it must be stressed that this model is not a blueprint for transition management, although it enhances the chances of success. Besides, TM should not be seen as a substitute for current policy, but rather as a complement to it (ROTMANS; KEMP; VAN ASSELT, 2001; LOORBACH, 2007).

Moreover, Shove and Walker (2007, 2010) argued that TM neglects the political aspects involved on deciding when and where to intervene, concealing conflicts and inequalities. TM ignores the ambivalence of sustainability as a normative objective and the politics and power dynamics related to it (WALKER; SHOVE, 2007). It presupposes that a shared vision of sustainability will emerge from transition arenas and will be considered legitimate by the public (HENDRIKS, 2009). Besides, important types and agents of change are ignored in TM literature. Many relevant groups and interests are often disregarded (SHOVE; WALKER, 2007, 2010), raising questions about the democratic aspects of TM (HENDRIKS, 2009).

2.1.1.4 Multi-Level Perspective

The MLP framework is a middle range theory[7] (GEELS, 2007a) that combines ideas from evolutionary economics, sociology of innovation, and neo-institutional theory.

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[7] Middle range theories "lie between the minor but necessary working hypotheses that evolve in abundance during day-to-day research and the all-inclusive systematic efforts to develop a unified theory that will explain all the observed uniformities of social behavior, social organization and social change" (MERTON, 1968, p. 39).

It conceptualizes the general patterns in ST-transitions as non-linear process that results from the dynamic interplay between three analytical levels: technological niches (micro level), ST-regimes (meso level) and exogenous socio-technical landscape (macro level) (GEELS, 2002, 2004, 2010, 2011). This framework provides a straightforward method to order, simplify and analyze complex ST-transitions (SMITH; VOSS; GRIN, 2010).

The MLP was developed by Geels building on the quasi-evolutionary theory developed by Kemp, Rip, and Schot (SCHOT; HOOGMA; ELZEN, 1994; KEMP; SCHOT; HOOGMA, 1998; RIP; KEMP, 1998; GEELS, 2010; MARKARD; RAVEN; TRUFFER, 2012). This framework tries to reconcile two different views of technological evolution in evolutionary economics: one that sees evolution as a process of variation, selection and retention; and another in which evolution is a process of creating new combinations, resulting in new paths and trajectories (GEELS, 2002).

The MLP assumes that ST-transitions are possible when landscape factors put pressure in the ST-regime, creating an opportunity for niches to break through, which can result in different transition pathways, including the technological substitution of the existing ST-regime by the emergent technology (GEELS; SCHOT, 2007). This dynamic and the three analytical levels are detailed in the next sections.

2.1.1.4.1 Technological niches

As already detailed in Section 2.1.1.2, niches are protected spaces where radical innovations can develop shielded from "normal" market selection (RIP; KEMP, 1998; GEELS, 2002). This protection is necessary because new technologies may have low initial price/performance ratios and can only mature when insulated from selection pressures. The protection can be provided in the form of funding, subsidies, legitimation, or other resources (KEMP; SCHOT; HOOGMA, 1998; SCHOT; GEELS, 2008). Bakker, van Lente, and Engels (2012) stressed that technological or market niches considered in ST-transitions studies[8] must not be confused with market niches in marketing studies, i.e., specialized markets for a specific group of consumers.

2.1.1.4.2 Socio-technical regimes

The ST-regime is an extended version of 'technological regimes' (GEELS; SCHOT, 2007). Nelson and Winter's (1977) defined technological regimes as cognitive routines shared by a group of technicians or engineers. These shared routines direct research and innovation (NELSON; WINTER, 1977; KEMP; SCHOT; HOOGMA, 1998;

[8] See Schot and Geels (2007) for a detailed account of niches in ST-transition studies.

GEELS, 2002). Rip and Kemp (1998, p. 338) broadened the technological regime concept, defining it as

> the rule-set or grammar embedded in a complex of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artifacts and persons, ways of defining problems—all of them embedded in institutions and infrastructures.

Building on Rip and Kemp (1998), Geels (2004) proposed the broader notion of ST-regimes to encompass relevant social groups other than engineers and technicians, such as users, policymakers, and civil society (BIJKER; HUGHES; PINCH, 1989; BIJKER, 1995; GEELS; KEMP, 2012). According to Geels (2004, p. 905), "ST-regimes can be understood as the 'deep-structure' or grammar of ST-systems, and are carried by the social groups". It is the 'deep-structure' (e.g., shared beliefs, heuristics, vested interests, and sunk capital) that lock-in and stabilize the ST-regime. This stability is dynamic, which means that there is innovation within the ST-regime[9]. However, this innovation is incremental rather than radical[10] (GEELS, 2002, 2004, 2007a, 2010, 2011).

A ST-regime is composed of an alignment between regimes (e.g., policy regime, user and market regime, and science regime). However, it does not encompass other regimes entirely, but only the 'semi-coherent' set of rules shared by them. These rules guide and coordinate the different regimes and stabilize the ST-regime. Different regimes are relatively autonomous and interdependent at the same time, co-evolving with each other (GEELS, 2004, 2007a, 2011; GEELS; KEMP, 2012).

2.1.1.4.3 Socio-technical landscape

Rip and Kemp (1998) argue that the socio-technical landscape can be used to capture the anthropological concept of technology. It has both a literal meaning, i.e., '*something around us*,' and a metaphorical meaning, i.e., '*something that we are part of.*' These meanings are inherently linked to each other. The landscape is the wider exogenous

[9] This dynamic stability also means that there are inconsistencies, irregularities and conflicts inside ST-regimes (SPÄTH; ROHRACHER, 2012).

[10] Incremental innovation refines, improves and strengths established designs or structures, reinforcing existing skills, knowledge, and methods. It makes the existing technology more attractive to established costumers, raising barriers to entry, and reducing the threat of substitution by alternative technologies. On the other hand, radical innovation presents a new design, which makes the existing technology obsolete and demand new skills and methods. It disrupts existing markets and distribution networks, creating new ones and attracting new customers (ABERNATHY; CLARK, 1985).

environment or context in which a variety of ST-regimes and niches are nested (GEELS, 2004, 2011; SMITH; VOSS; GRIN, 2010; GEELS; KEMP, 2012).

Landscape comprises a set of deep structural trends which consists of both slow-changing trends (e.g., demographics, political ideologies, cultural developments, and macro-economic patterns); exogenous shocks (e.g., war, economic and political crises, pandemics); and factors that do not change or that change very slowly (e.g., topography and climate) (GEELS, 2002, 2018a; VAN DRIEL; SCHOT, 2005; GEELS et al., 2017).

The landscape is even harder to change than ST-regimes and, therefore, it provides even more structuration (GEELS, 2002). Actors at the ST-regime and niche levels cannot directly influence the landscape, nor can it be changed by will (GEELS, 2004). Nonetheless, ST-regimes can influence the landscape in the long term (HOFFMANN; WEYER; LONGEN, 2017). For example, carbon emissions from the automobility ST-regime are influencing the climate. Therefore, changes do happen at the landscape level. Nevertheless, they are much slower (decades) and gradual than changes in the ST-regime[11] (GEELS; SCHOT, 2007; GEELS, 2011; GEELS; KEMP, 2012).

Although ST-regimes and niches are nested in the landscape, this does not mean that landscape developments necessarily impact them, nor do they determine how ST-regime and niche actors behave. These developments only make some actions, or paths, more straightforward than others for these actors (SMITH; STIRLING; BERKHOUT, 2005; GEELS; SCHOT, 2007). How this and other dynamics of ST-transitions are understood in the MLP framework is detailed in the next section.

2.1.1.4.4 Socio-technical transitions

The MLP considers that niches, ST-regimes, and landscape have a nested hierarchy, which means that niches are embedded within ST-regimes, and ST-regimes within the landscape. Although embedded, these analytical levels are separated from each other. There are different levels of structuration between the three levels, with the niche having the weakest structuration and the landscape the strongest. Innovations in ST-regimes are incremental, due to its stability, lock-in and path dependence characteristics. Radical innovations are developed in the niches, protected from the ST-regimes. These new technologies aim to solve problems in the existing ST-regime. However, these innovations cannot break through unless there is some pressure in the ST-regime, which

[11] Although the landscape generally changes slowly, some changes (exogenous shocks) can be sudden and rapid. This topic is detailed in section 2.1.1.4.6.

generates cracks, tensions, and misalignments between the ST-regime rules (GEELS, 2002, 2004, 2007a, 2010).

There are different sources of pressure. For example, landscape developments may put pressure in the ST-regime, momentarily destabilizing it; internal problems may lead regime actors to search for new technical pathways; or negative externalities from other ST-systems may affect the ST-regime (GEELS, 2004). These pressures usually are weak and incoherent, not causing problems to the ST-regime. However, sometimes they can become strong and coherent enough to cause instability (SMITH; STIRLING; BERKHOUT, 2005). The MLP argues that radical innovation can only break through when there is instability in the ST-regime. When pressure causes cracks in the ST-regime, radical novelties can break out from the niche to the regime level, diffuse and compete with the existing mainstream technology. It is a period of significant restructuring (GEELS, 2002, 2004, 2007a).

However, this does not mean that a niche technology will breakthrough whenever there is pressure in the ST-regime. ST-regimes have adaptative capacity, i.e., capacity and resources to respond to pressures (SMITH; STIRLING; BERKHOUT, 2005; SMITH; VOSS; GRIN, 2010). For example, successive and gradual changes from within the regime, carried out by regime actors, may resolve the ST-regime destabilization (GEELS, 2018a). Or regime actors can capture the innovations developed in niches (GEELS; SCHOT, 2007). Besides, the breakthrough also depends on niche internal dynamics, such as a dominant design, improved price/performance, economies of scale, and support from powerful actors (GEELS, 2007a, 2018a). The tensions and misalignments in the ST-regime only create a “window of opportunity” for the innovation to break through. If it is successful, the new technology may eventually substitute the existing one, establishing a new ST-regime. This new ST-regime may even trigger other landscape developments (GEELS, 2002, 2004).

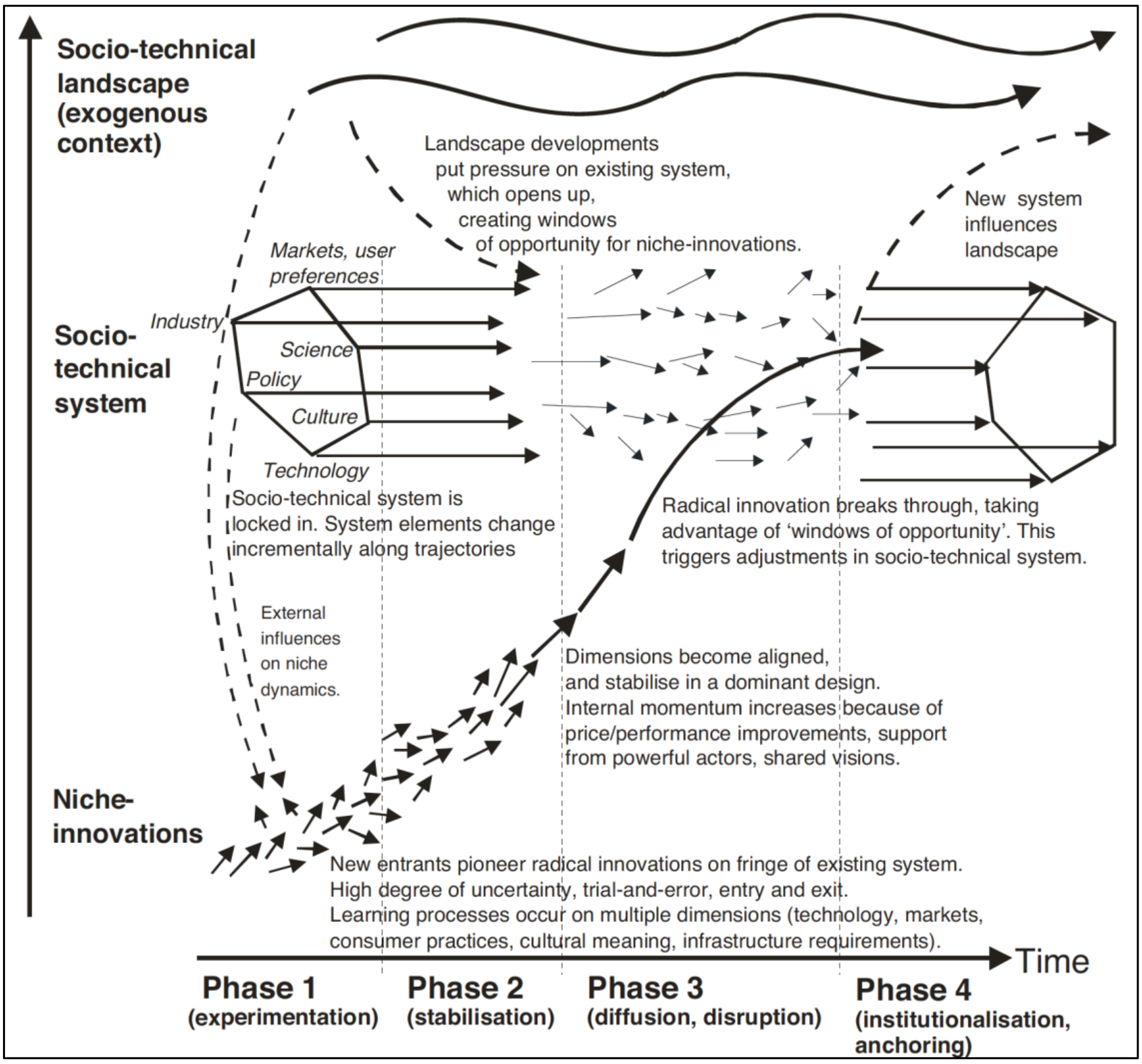
The main point of the MLP is that ST-transitions only happen when there is an alignment between development in the three levels. There is no single cause or driver for the transition (GEELS, 2002; GEELS et al., 2017). It is the way that niches, ST-regimes, and landscape interact with each other that defines how and if a ST-transition will unfold (SMITH; VOSS; GRIN, 2010). Struggles between niches and ST-regimes take place on multiple levels and dimensions (GEELS, 2011; GEELS; KEMP, 2012). Economic competition, political dispute over regulations and standards, and conflicts between new and old users’ practices are examples of these struggles (GEELS, 2018a). They are enacted by actors in both levels, which interact in many different ways (e.g., negotiating, fighting, allying, and learning) (GEELS, 2007a, 2010, 2018a).

Elzen, van Mierlo, and Leeuwis (2012) distinguished three different types of anchoring, i.e., emerging forms of linking, between niches and ST-regimes: *technological anchoring* (further developing the characteristics of the innovation central to the niche), *institutional anchoring* (creating the rules related to the new technology) and *network anchoring* (recruitment of new actors). These three types of anchoring can occur independently of each other and in any sequence. However, the three forms have to align to the anchoring to become a strong link between the niche and the ST-regime, a necessary step for a ST-transition to unfold (ELZEN; VAN MIERLO; LEEUWIS, 2012; DARNHOFER; SUTHERLAND; PINTO-CORREIA, 2014; DARROT et al., 2014).

Geels (2005) identified four phases of ST-transitions. In the first phase, a radical innovation starts to develop in a peripheral niche, with no stable rules, a weak network of supporting actors, and many competing designs and experiments. During the second phase, rules begin to stabilize, a dominant model starts to consolidate, and the network of supporting actors gets stronger. The innovation may begin to be used in small market niches, attracting some dedicated users. If there is no pressure in the ST-regime, the innovation may stay for an extended period in the niche.

In phase three, the innovation can break through due to instability in the ST-regime. The new technology starts to diffuse. More elements to support this new technology are created (e.g., infrastructure, regulations, user practices) as the diffusion increases. The innovation then gains momentum and competes with the existing ST-regime. The fourth phase is when the new technology starts to replace the older one, which leads to broader socio-technical changes. These are gradual changes, and the new ST-regime may take some time to consolidate (GEELS, 2005). Figure 2.4 illustrates these phases and other dynamics of the MLP.

Figure 2.4 – A dynamic multi-level perspective on system innovations



Source: Adapted by the author from Geels (2019)

Geels (2005) stressed that, although the processes illustrated in Figure 2.4 may appear mechanical and linear, it is because actors and social groups are not represented. The linkages between processes in different levels and phases of the MLP are made by actors and social groups (e.g., companies, NGOs, representative bodies) in their cognitions and activities. Therefore, the processes represented in Figure 2.4 are socially constructed rather than mechanical. Besides, these processes are not linear because actors change their perceptions and strategies over time. Struggles between niche and regime actors means that these processes are rough and contested. In other words, the MLP understanding of ST-transitions dynamics is complex and cannot be represented in a figure without some simplifications.

Schot and Kanger (2018) suggested that after phase 4, the new ST-regime becomes a new layer in the landscape, which they understand as "*a layered web of mature ST-*

systems." This new layer is added without removing the existing ones but starts to influence further interactions in the ST-system. They call this process the *sedimentation mechanism.*

What happens to the existing ST-regime during its decline in phase 4 and afterward often receives less attention than innovations in ST-transition studies. ST-regime's destabilization dynamics and drivers, other than niche emergence and landscape pressure, are frequently ignored (SMITH; VOSS; GRIN, 2010; TURNHEIM; GEELS, 2012, 2013; PAPACHRISTOS, 2014; HOFFMANN; WEYER; LONGEN, 2017; GEELS, 2019). This topic is discussed in the next section.

2.1.1.4.5 Destabilization of ST-regimes

Turnheim and Geels (2012, p. 35) defined the destabilization of a ST-regime as "the processes of weakening reproduction of core regime elements," which is the result of incumbents reorienting towards a new ST-regime or because the incumbents themselves were replaced by new entrants. Based on the triple embeddedness framework (GEELS, 2014a)[12], Turnheim and Geels (2012, 2013) suggested that destabilization of industry regimes encompass interactions between three processes. First, pressures from the economic (e.g., shrinking markets and supply problems) and the socio-political (e.g., change in public opinion and policy) selection environments weaken the performance of the industry. Second, these performance problems trigger responses from incumbents. Finally, if the responses are not sufficient to improve performance and alleviate pressures, the incumbents' commitment towards the regime weakens, eventually leading to the destabilization of the regime (TURNHEIM; GEELS, 2012, 2013).

The weaking of the regime's support happens in phases, which are dispersed in the three processes previously described. First, incumbents tend to deny and ignore the pressures on the regime. Then, if pressures increase, they look for incremental innovations and local solutions. If these solutions are not enough to improve the regime's performance, incumbents start questioning the regime's viability and searching for solutions outside it. In a later stage, incumbents try to change the regime's elements (reorientation process), including, deep change to core elements (recreation process) if

[12] The triple embeddedness framework (TEF) states that firms are embedded in two external selection environments: economic and socio-political, and are shaped by industry regimes, i.e., field-specific institutions that mediate perceptions and actions of firms regarding external environments (GEELS, 2014a).

necessary. If these processes fail, incumbents finally abandon the regime (TURNHEIM; GEELS, 2012, 2013).

Turnheim and Geels (2012, 2013) highlighted some relevant aspects of the destabilization process based on a case study of the decline of the coal industry in Britain:

- Destabilization of a ST-regime is the result of the alignment of multiple pressures in different environments. Besides, pressures in one environment can spillover to another one reinforcing or creating pressures in this other environment.
- External shocks and extreme events (e.g., wars) can both accelerate or stop destabilization of a ST-regime.
- There is bi-directionality between novelties and destabilization, i.e., technical innovations may contribute to ST-regimes' destabilization, while destabilization processes create opportunities for novelties to emerge.
- Lock-in mechanisms make incumbents resist change and underestimate pressures.

Kuokkanen *et al.* (2018) and Yazar *et al*. (2020) criticized this conceptualization, arguing that destabilization does not occur in well-defined and linear steps as suggested by Turnheim and Geels (2012, 2013). Instead they suggested that there are many overlaps between the steps and the whole process is unpredictable, i.e., it can follow many different directions depending on how incumbents translate pressures and react to them (KUOKKANEN et al., 2018; YAZAR et al., 2020).

Geels (2014b) pointed out that incumbents have four different ways to resist ST-transitions. Incumbents can use *instrumental* power (e.g., financial resources and media influence) to influence other actors, such as government officials and civil society, in favor of the existing ST-regime. Incumbents can also use *discursive* strategies to shape what issues are discussed and how they are discussed. Incumbents can also use their *institutional* power to influence policy, cultures, and governance to favor the maintenance of the ST-regime and hinder technological alternatives. Finally, another option is to use the ST-regime's financial and technical capabilities to improve the regime's own performance (*material* strategy) (GEELS, 2014b).

Kuokkanen *et al.* (2018) criticized the assumption that incumbents only resist changes (TURNHEIM; GEELS, 2012, 2013; GEELS, 2014b). Regime actors can try to shape changes to their own interests. Incumbents have multiple identities and adopt many strategies, which may include destabilizing the existing ST-regime instead of defending it (KUOKKANEN; YAZAR, 2018).

Bergek *et al*. (2013) argued that the improvement of the ST-regime can go beyond incremental innovation, in contrast to the usual assumption in the MLP (GEELS, 2002, 2004; GEELS; SCHOT, 2007). Incumbents can significantly change components and architecture of existing technologies, improving cost, performance and quality, without destabilizing the regime or creating opportunities for the diffusion of new technologies (BERGEK et al., 2013). Besides, Darnhofer, Sutherland and Pinto-Correia (2014) argued that radical versus incremental change is not a binary judgment. Incremental change may add-up to a radical change.

Kuokkanen *et al.* (2018) proposed a different conceptualization of ST-regimes destabilization, emphasizing the importance of agency. They argued that this process is not simply a matter of external pressure accumulation followed by the weakening of incumbents' commitment to the ST-regime. First, actors inside and outside the ST-regime internalize, translate, and frame pressures according to their strategic response. Then, these actors try to influence the selection environments' formulation and benefit from it. They do this by building up networks and coalitions, as no actor alone can shape the whole selection environment. Destabilization happens when competing visions, and alignments and misalignments of these networks and coalitions, change crucial factors of the selection environment (KUOKKANEN et al., 2018).

Also focusing on agency, Kivimaa (2014) and Matschoss and Heiskanen (2018) argued that intermediaries[13] can have a relevant role in destabilizing ST-regimes. In the MLP, intermediaries are generally considered niche aggregators (GEELS; DEUTEN, 2006; MATSCHOSS; HEISKANEN, 2018). However, Kivimaa (2014) and Matschoss and Heiskanen (2018) showed through case studies that intermediaries can also destabilize ST-regimes by: (i) empowering niches; (ii) gaining acceptance and legitimacy to new visions; (iii) enabling changes in the ST-regime cognitive rules by bringing together incumbent firms, niche innovators and civil society; (iv) renegotiating ST-regimes rules; and (v) disrupting existing incumbent networks and coalitions.

The governance of destabilization has also been studied by some authors (KUOKKANEN et al., 2018). The literature on MLP, and more broadly on sustainability transitions, focused its policy discussion on creating protected spaces (niches) for

[13] Intermediaries can be defined as actors who work between developers and users, creating spaces and opportunities for the emergence of technical and cultural products (STEWART; HYYSALO, 2008).

technologies to develop (e.g., Strategic Niche Management literature), or on facilitating the emergence of niche's innovation (e.g., Bergek *et al.,* 2008). Using policy to destabilize ST-regimes has been much less researched (KIVIMAA; KERN, 2016). However, Geels (2014b) argued that destabilizing ST-regimes policies may be necessary to enable sustainability transitions.

Stegmaier, Kuhlmann and Visser (2014) distinguished six dimensions of dedicated discontinuation governance necessary to destabilize ST-regimes. They use the term *discontinuation* instead of *destabilization* to emphasize the focus on the process. The six dimensions are (STEGMAIER; KUHLMANN; VISSER, 2014):

(i) Aligning problem perception through increasingly structured interaction.
(ii) Setting and keeping the problem in the political agenda.
(iii) Building, maintaining, and changing advocacy coalitions.
(iv) Mobilizing existing and new governance instruments.
(v) Politically binding and legitimate decision-making.
(vi) Governing socio-technical aftercare.

Stegmaier, Kuhlmann and Visser (2014) stressed three particular points. First, the change in perception is a primary and fundamental step. Discontinuation happens in a highly complex and contested environment. Changing an actor's perception, especially an incumbent, is necessary to overcome resistance from institutional inertia and vested interests. Second, aftercare is not a consequence, but a prerequisite for change. Substituted ST-regimes do not vanish, and some level of continued governance is necessary to deal with it. The aftercare allows controlling 'loose ends' of the old ST-regime (STEGMAIER; KUHLMANN; VISSER, 2014). Otherwise, there can be significant negative repercussions, for example, communities impacted by the phase out of coal mines in the UK and the USA. Finally, policymakers must realize that governance efforts to discontinue ST-regimes may last longer than the existing governance (STEGMAIER; KUHLMANN; VISSER, 2014).

Kivimaa and Kern (2016) stated that a policy mix to enable sustainability transitions must focus both on "creating" the new ST-regime and "destroying" the existing one. Building on Schumpeter's *creative destruction*[14] and Bergek, Berggren and Magnusson's

[14] According to Schumpeter (2003, p. 83), creative destruction is a process "that incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one."

(2011) *creative accumulation*[15], Kivimaa and Kern (2016) developed an analytical framework to ally niche creation and development with the destabilization of ST-regimes. They proposed four destabilizing policies that can be combined with the policies focused on promoting the seven TIS functions (see Section 2.1.1.1). These policies are (KIVIMAA; KERN, 2016): (i) control policies (e.g., taxes, environmental regulations, and import restrictions); (ii) significant change in regime rules (e.g., structural reforms in legislation); (iii) reduced support for dominant regime technologies (e.g., removing subsidies and cutting R&D funding); and (iv) changes in social networks, i.e., replacing key actors (e.g., substituting incumbents by niche actors in advisory councils).

The role of policymakers in destabilizing the ST-regime must also be considered. Although many studies (implicitly) consider policymakers as neutral outsiders of the ST-regime, most times they are incumbents of the existing ST-regime. Therefore, they should be regarded as participants of the networks and coalitions of actors actively trying to influence the selection environments' formulation accordingly to their own strategies, rather than impartial actors in the destabilization process (KUOKKANEN et al., 2018).

2.1.1.4.6 Transition pathways

The MLP was advanced by Geels and Schot (2007), who developed a typology of transition pathways. They aimed to overcome the presumed bottom-up and niche-driven bias towards ST-transitions in the MLP (BERKHOUT; SMITH; STIRLING, 2004). The pathways developed were distinguished based on the *timing* and the *nature* of the multi-level interactions.

Timing is related to whether the niche innovations are fully developed. Since this is a subjective definition, they recommended four criteria to establish if the innovation is developed or not[16]: (i) the niche has stabilized rules and a dominant design; (ii) powerful actors are present in the supporting network; (iii) price/performance has improved, and the actors' perception is that it can be further enhanced; (iv) the innovation is used in market niches, accounting for 5% of the total market share[17] (GEELS; SCHOT, 2007).

[15] Bergek, Berggren and Magnusson's (2011, p. 252) "have defined creative accumulation as a process in which existing knowledge continues to develop but is complemented and integrated with knowledge from new sources in order to develop novel products or processes with major improvements in performance."

[16] Determining if a niche innovation is fully developed is not an objective process. The criteria presented by Geels and Schot (2007) are subjective proxies based on transition and diffusion research.

[17] Based on the diffusion of innovation theory, which indicates that the diffusion of an innovation becomes self-sustaining once it achieves between 5 and 20% of cumulative adoption (ROGERS, 2003).

Nature refers to how the three analytical levels interact. It analyzes if niche innovation and landscape developments have a reinforcing or a disruptive relationship with the ST-regime and if the relationship between niche innovation and the ST-regime is competitive or symbiotic (GEELS; SCHOT, 2007).

Geels and Schot (2007) also used the Suarez and Oliva (2005) typology of environmental change to differentiate landscape pressures, which were distinguished based on four dimensions: frequency, amplitude, speed and scope (see Table 2.1). The first type is *regular change*, characterized as low intensity and gradual. *Hyperturbulence* corresponds to high intensity of high-speed change. The third type, *specific shocks*, are rare, rapid, and high intensity changes. *Disruptive changes* are changes that occur infrequently, develop rapidly, and have a highly intense effect. The last type of change, *avalanche*, takes place very infrequently, but with high intensity, high speed and affecting multiple dimensions of the environment simultaneously (SUAREZ; OLIVA, 2005).

Table 2.1 – Attributes of change and resulting typology

Type of environmental change	Frequency	Amplitude	Speed	Scope
Regular	Low	Low	Low	Low
Hyperturbulence	High	Low	High	Low
Specific shock	Low	High	High	Low
Disruptive	Low	High	Low	Low
Avalanche	Low	High	High	High

Source: Suarez and Oliva (2005)

One issue with this typology is that neither Suarez and Oliva (2005), neither Geels and Schot (2007), established objective parameters to differentiate low and high frequencies, amplitudes, speeds and scopes. Therefore, that is a subjective decision when using this typology.

Geels *et al.* (2016) further developed Geels and Schot's (2007) typology. They wanted to make agency and institutions explicit in the typology. Geels *et al.* (2016) reformulated the typology, differentiating actors and social groups, rules and institutions, and technologies and broader ST-systems. They also developed a new understanding of shifts between transition pathways.

The first possible pathway is when the existing ST-regime remains dynamically stable. Geels and Schot's (2007) called it a *reproduction process*. In this pathway, there is little or no pressure from the landscape (regular change) onto the ST-regime. Therefore, there is no opportunity for niche innovations to emerge. Although there may be internal problems in the ST-regime, the perception shared by incumbents, niche actors and outsiders is that these problems can be solved without changing any of the regime's core rules.

One possible transition pathway is *substitution*. In this pathway, niche innovation is well developed when the ST-regimes suffers high-intensity pressure (specific shock, avalanche change or disruptive change) from landscape developments. This pressure creates an opportunity for the innovation to diffuse, compete and eventually substitute the existing ST-regime, leading to broader socio-technical changes (GEELS; SCHOT, 2007). Incumbents initially resist change, but their commitment to the regime weakens as pressure increases. Incumbents may eventually start supporting a niche innovation or be substituted by niche actors (GEELS, 2004; TURNHEIM; GEELS, 2012). Innovation does not come only from niches within the ST-regime, but also from outsiders. For example, incumbents from other regimes may see the ST-regime instability as an opportunity to diversify. There are also two patterns for institutions. There is little or incremental institutional change if the innovation functionalities are like the older technology. Otherwise, institutions and rules need to adapt to the innovation requirements (GEELS et al., 2016).

Another pathway is *transformation*. It occurs when moderate landscape pressure impacts the ST-regime (disruptive change), and the niche innovation is not fully developed. Then the regime actors can gradually reorient the ST-regime. Although some societal groups may demand quick solutions to the existing problems, there is no radical alternative. Incumbents use their adaptative capacity to redirect the development trajectory, adopting symbiotic niche innovations that add to the existing ST-regime (GEELS; SCHOT, 2007). However, incumbents can also seek deeper reorientation, reaching to more radical niche innovations, breaking the ST-regime lock-in and leading to broader changes. The degree of institutional change will be directly related to the depth of this reorientation (GEELS et al., 2016).

A fourth possible pathway is *reconfiguration*. Symbiotic niche innovations are adopted by the ST-regime as add-on to solve local problems under low-intensity landscape pressure (regular change). There are minor changes, including in rules and institutions, which create opportunities or the need for more changes. Incumbents and new entrants (sometimes in alliance) explore these opportunities and add other symbiotic niche innovations to the ST-regime. These new add-ons trigger more profound changes to rules and institutions, leading to a gradual but substantial reconfiguration of the ST-regime architecture (GEELS; SCHOT, 2007; GEELS et al., 2016).

The last transition pathway is *de-alignment and re-alignment*. A high-intensity and rapid landscape pressure (avalanche change) causes so many internal problems in the ST-regime that it collapses, causing the de-alignment. Incumbents lose faith in the ST-regime's viability and do not defend it. In this pathway, no niche innovation is fully developed and able to substitute the ST-regime, creating space for multiple niche innovations, some of them carried by diversifying incumbents and outsiders, to emerge and compete. They compete more with each other than with the collapsed ST-regime. Institutions and rules become very unstable, leading the regime and various niche actors to struggle over the new development trajectory and the shape of new institutions. There is a prolonged time of uncertainty and co-existence before one niche innovation gains momentum and gradually becomes dominant. Then there is re-alignment and stabilization in a new ST-regime (GEELS; SCHOT, 2007; GEELS et al., 2016).

The transitions pathways developed by Geels and Schot (2007) and Geels *et al.* (2016) are not deterministic nor linear. ST-transitions may start in one pathway and shift to another because of changes in the landscape pressure, new landscape developments, or changes in actors' alliances and strength[18]. Besides, an analytical issue is that determining the transition pathway of a transition is easier when analyzing past transitions than those that are happening in the present.

All the pathways proposed by Geels and Schot (2007) and Geels *et al.* (2016) have one thing in common, they end with a certain technology becoming dominant, constituting a new or reconfigured ST-regime. Indeed, this is one of MLP's premises (FURLONG, 2014). However, this may not be necessarily true in all cases.

Dumont, Gasselin and Baret (2020) showed that two socio-technical configurations of production can coexist in agriculture: an old configuration focused on the autonomy of producers and a new one, focused on agroecology. Gasselin *et al.* (2020) argued that conventional and alternative agri-food models can coexist. Schmid, Knopf and Pechan (2016) showed that two technological infrastructures of renewable energy can substitute fossil fuel and coexist without one of them becoming dominant: centralized and decentralized solutions. Krätzig, Franzkowiak and Sick (2019) proposed that different

[18] See Geels *et al.* (2016) for some pathway shifts examples.

driving technologies (internal combustion engines, electric and fuel cell vehicles) could coexist in the future.

Moreover, Papachristos (2017) suggested that not having a single dominant technology may not be detrimental to ST-transitions. On the contrary, different technologies can destabilize different parts of the existing ST-regime, in a decentralized and cumulative process leading to a new ST-regime where these different technologies coexist.

Næss and Vogel (2012) proposed the concept of *multi-segmented regimes*, i.e., compromises between different technologies where none is completely dominant. They argue that in some cases, especially in cities, it is difficult to distinguish one dominant technology. Instead, there is a multi-modal ST-regime with different solutions for different users or consumers. They argued that is the case of urban mobility, where private cars, metro, buses, among others, coexist and integrate with each other (NÆSS; VOGEL, 2012).

Papachristos, Sofianos, and Adamines (2013) showed that a niche innovation can lead to the creation of a new ST-system without substituting any of the existing ones. It is the case of *functional foods*, that emerged from interactions between the food and pharmaceutical ST-systems but have not substituted any of them (PAPACHRISTOS; ADAMIDES, 2016).

In many cases the issue is defining the analytical levels. For example, is the electric car a niche innovation that will substitute internal combustion engine cars in the 'private car' ST-regime, or is it a novelty that will develop into a different ST-regime, which will coexist with the existing ST-regime (internal combustion engine cars) in a 'private car' ST-system, as suggested by Krätzig, Franzkowiak and Sick (2019)? Moreover, is 'private car' even an ST-regime? Or is it one mode that coexists with other ones in the 'urban mobility' *multi-segmented* ST-regime proposed by Næss and Vogel (2012)? These same questions are valid in other fields: are decentralized and centralized renewable energies two technologies disputing to be the dominant technology in the 'energy' ST-regime, or are they two different ST-regimes in an 'energy' ST-system? Thus, defining the boundaries of ST-systems and ST-regimes becomes the central issue, which is discussed in the next section.

2.1.1.4.7 Defining the boundaries of ST-systems and ST-regimes

One fundamental step when using the MLP is to delineate ST-systems and ST-regimes. The understanding of a ST-transition depends on how these boundaries are defined (GEELS; KEMP, 2012; MARKARD; RAVEN; TRUFFER, 2012; PAPACHRISTOS, 2014). For example, what seems to be a regime shift at one level, may be understood as an incremental change at a different level (BERKHOUT; SMITH; STIRLING, 2004). However, delimiting these system and regime boundaries is not a simple task, and there is no objective method for doing so (GEELS, 2002; PAPACHRISTOS, 2014).

Genus and Nor (2007) stressed that the delineation of ST-regimes' limits is a part of the MLP framework that is difficult to operationalize. Genus and Coles (2008) affirmed that delimiting the boundaries between MLP levels is not done rigorously enough in most MLP studies. ST-regimes are often used to refer to ST-systems in studies that use the MLP, mixing the two concepts (MARKARD; TRUFFER, 2008; JENSEN; FRATINI; CASHMORE, 2016). Smith, Voss, and Grin (2010) argued that boundaries between niches and regimes might become less clear empirically than theoretically. Korad, Truffer, and Voss (2008) explained that when using the ST-regime concept, it is not *a priori* obvious at which level it should be identified. Besides, boundaries shift over time (KONRAD; TRUFFER; VOSS, 2008; PAPACHRISTOS, 2014).

Sorrell (2018) argued that the MLP lacks consistency in distinguishing between the ST-regime and the ST-system. Sometimes the ST-regime is defined as the semi-coherent set of rules that structure the ST-systems, while other times this set of rules is presented as what forms part of the ST-regime and encompass the ST-system. He also affirmed that the boundaries of ST-systems and ST-regimes are ambiguous. This ambiguity makes the delimitation of these boundaries rather arbitrary, which decreases the MLP's explanatory capability. Sorrell (2018) suggested abandoning the distinction between ST-regime and ST-system and focusing only on the "nature, structure and properties of sociotechnical systems" (SORRELL, 2018, p. 47).

The main issue is that delineating systems boundaries is a subjective task (PAPACHRISTOS; SOFIANOS; ADAMIDES, 2013). Some methods to overcome this have been proposed in the literature, such as using simulations to test and define the ST-system limits (PAPACHRISTOS, 2014), and drawing the boundaries based on the density and strength between the elements of socio-technical configurations (KONRAD;

TRUFFER; VOSS, 2008). However, these methods are also hard to operationalize and subject to some degree of subjectivity.

Geels (2004) argued that delineating ST-regimes and ST-systems is an empirical issue rather than a theoretical one. Markard and Truffer (2008) suggested that systems should be delimited based on the research question and objectives and adjusted as the research progressed, and the understanding of the system increased (*descriptive delineation*). A complementary approach would be to empirically identify systems and regimes' limits based on the analysis of the interaction of the components (*conceptual delineation*).

Markard and Truffer's (2008) approach is aligned to Vayda's (1983) *progressive contextualization* method. He argued that defining the appropriate unit of research is a persistent issue in human ecology studies and related fields. Therefore, he proposed focusing on specific human activities and interactions and then explain these interactions by placing them within wider contexts gradually. This method allows researchers to avoid *a priori* boundaries definitions, which are delimited as researchers understating of the subject increases (VAYDA, 1983). Thus, *progressive contextualization* could be used in ST-transitions studies when it is hard distinguishing between systems and regimes boundaries.

Another relevant aspect is that there are many organizational levels in institutional theories (GEELS; SCHOT, 2007). According to Geels and Schot (2007), the ST-transitions should be placed at the organizational field level. Nonetheless, "the regime notion is an analytical concept that can be applied to empirical topics of different scope" (GEELS, 2011, p. 31). Therefore, Geels (2011) suggested first to define the object of analysis, and afterward operationalize the MLP analytical levels.

Defining ST-regime membership is another important aspect of setting systems boundaries (PAPACHRISTOS; SOFIANOS; ADAMIDES, 2013). However, this step is also tricky because regime actors have many different levels of interdependency and influence within the ST-regime (and across to other ST systems). Therefore, some actors are more interested and invest more time and agency in maintaining the ST-regime than others (SMITH; STIRLING; BERKHOUT, 2005). Smith, Stirling, and Berkhout (2005) argued that membership could be determined based on the degree to which the actors contribute to the maintenance of the ST-regime. Those who contribute more are core members, those who contribute less are peripheral members, and those who do not contribute at all are outsiders (SMITH; STIRLING; BERKHOUT, 2005). Nonetheless, what is a significant contribution and what is not is another subjective decision that must be taken by the researcher when analyzing a ST-regime.

Nonetheless, McDowall and Geels (2017) argued that the subjective aspect of the MLP, which includes defining ST-systems and ST-regimes boundaries, is actually one of the strengths of this framework. Simplicity and standardization are traded-off with real-world accuracy and detailedness. The MLP avoids oversimplification of reality and pays attention to different levels and temporalities, multiple actors and behavior types and the many socio-technical dimensions (GEELS; BERKHOUT; VAN VUUREN, 2016).

Therefore, defining the boundaries of ST-systems and ST-regimes is a subjective task rather than a structured procedure in the MLP. These definitions are influenced by the research question and the characteristics of the system being analyzed. The task of delineating systems boundaries becomes even more relevant and complex when dealing with multiple ST-system interactions. Multi-system interactions are discussed in the next section.

2.1.2 Multi-system sustainability transitions

Multi-system interaction is an issue that is particularly relevant to sustainability transitions. Many of the technologies proposed to solve sustainability problems link multiple ST-systems (e.g., electric cars links transportation and electricity systems, and biofuels combine the agri-food, transportation, and energy systems) (GEELS, 2011; ROSENBLOOM, 2020).

The MLP has long been criticized for not paying attention to multi-system interactions (BERKHOUT; SMITH; STIRLING, 2004; RAVEN; VERBONG, 2007; GEELS, 2011). However, this is an aspect in which the framework still needs to be further advanced (HASSINK; GRIN; HULSINK, 2018; KÖHLER et al., 2019; ROSENBLOOM, 2019, 2020). It is necessary to look beyond single innovations towards interactions between multiple niches and ST-regimes (KÖHLER et al., 2019). Including these interactions in the framework would enhance the MLP, giving it some more complexity and helping maintain relevance (SMITH; VOSS; GRIN, 2010; PAPACHRISTOS; SOFIANOS; ADAMIDES, 2013; PAPACHRISTOS; ADAMIDES, 2016). This section presents the current state-of-the-art of research on this topic.

Geels (2007b) was the first to study how different ST-regimes interact in a case study of the creation of ‘rock ‘n’ roll’. He used the MLP to explain how ‘rock ‘n’ roll’ emerged from the interaction between the radio and recordings ST-regimes and their respective niches. However, Geels (2007b) gave little theoretical contribution other than showing that the relationship between ST-regimes can be competitive or symbiotic and that it can change over time.

Raven and Verbong (2007) investigated the case of combined heat and power production in the Netherlands and how two ST-regimes, electricity and natural gas, interacted during the development of this technology. Based on this case study, they developed a typology of interactions between ST-regimes for the MLP. They distinguished four types of interactions (RAVEN; VERBONG, 2007):

(i) *Competition* happens when two ST-regimes start to fulfil similar societal functions (e.g., electricity and natural gas regimes in the Netherlands can both provide heat and power). In this case, actors from each ST-regime struggle over resources, infrastructures, and regulations. It can eventually lead to one ST-regime substituting the other.

(ii) *Symbiosis* occurs when two ST-regimes start cooperating to reap mutual benefits (e.g., the radio and the recording regimes in the USA in the 1950s; Geels, 2007b). It can make both ST-regimes even more stable and mutually dependent.

(iii) *Integration* refers to the process in which two distinct ST-regimes become one (e.g., the merge of gas and electricity utilities in some European countries in the 1980s and 1990s). The integration process can be partial. For example, some rules and infrastructure are shared, while others remain separated. Disintegration is also a possibility, when a ST-regime split in two or when a new ST-regime emerges from another, without the new regime substituting the older.

(iv) *Spill over* is the transfer of rules from one ST-regime to another (e.g., the process of liberalization and deregulation of the telecom ST-regime in some European countries was a model for the same process in the electricity ST-regime). It can also include other forms of knowledge transfer from one regime to another.

Raven and Verbong (2007) stressed that these four types of interaction between ST-regimes are not exclusive. They can happen simultaneously or change over time[19].

[19] See Hiteva and Waston (2019) for an example.

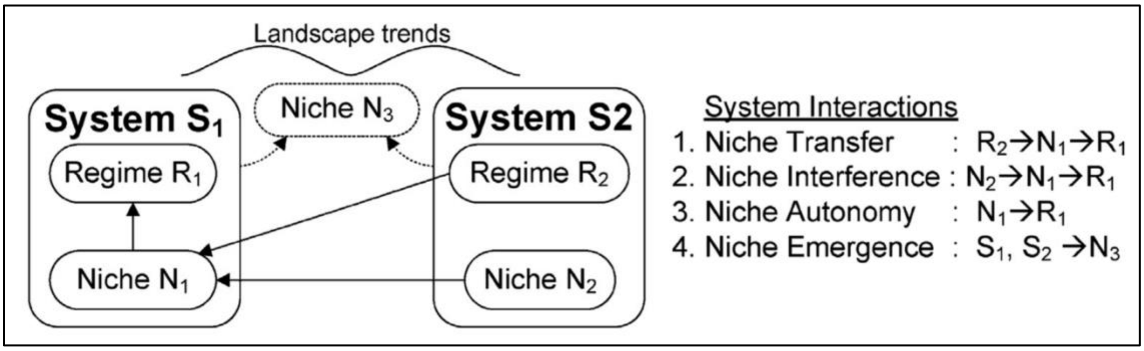
Besides, the interaction between the regimes can both favor or block niche innovations, depending on whether it reinforces or destabilizes the ST-regimes.

Konrad, Truffer, and Voß (2008) analyzed interactions between ST-regimes, considering different utilities (e.g., electricity, water, and gas) in Germany. They pointed out that ST-regimes boundaries shift and blur as they interreact. They also identified three types of interaction (KONRAD; TRUFFER; VOSS, 2008): (i) between *regimes fulfilling the same societal function* (competing or cooperating); (ii) between *regimes on the basis of complementary relations*; (iii) and between *regimes showing structural similarities*.

There is a substantial similarity between Konrad, Truffer, and Voß (2008) and Raven and Verbong (2007) typologies. Konrad, Truffer, and Voß's (2008) first type of interaction is closely related to *competition* and *symbiosis*, while the second and the third types are similar to *integration* and *spill-over*, respectively. Nonetheless, Konrad, Truffer, and Voß (2008) considered the possibility of interactions between multiple (more than two) ST-regimes in their typology, while Raven and Verbong (2007) focused on interactions between only two ST-regimes.

Papachristos, Sofianos, and Adamines (2013) looked at how ST-systems interact during ST-transitions. They developed a typology for transition pathways that include ST-systems interaction, building on Geels and Schot (2007). Papachristos, Sofianos, and Adamines (2013) identified four types of transition systems interactions, based on the review of several ST-transition cases: (i) *niche transfer*; (ii) *niche interference*; (iii) *niche autonomy*; and (iv) *niche emergence*. This typology is shown in Figure 2.5.

Figure 2.5 – Types of transition system interactions



Source: Papachristos, Sofianos, and Adamines (2013)

Niche transfer happens when developments in one ST-regime (R_2) influence or contribute to the creation of a niche (N_1) in another ST-system (S_1). Then, there are three possible pathways, depending on the timing and the nature of the interaction: the niche

(N_1) can be absorbed by the ST-regimes (R_1); it can replace the ST-regime (R_1), or it can simply fade away if there is no landscape pressure on the ST-regime (PAPACHRISTOS; SOFIANOS; ADAMIDES, 2013).

The second type of interaction is *niche interference*. In this case, a niche (N_2) influences an existing niche (N_1) in another system (S_1) or leads to the creation of a new niche (N_1) in the other ST-regime (S_1). The three pathways that can happen next are the same that in the *niche transfer* interaction (PAPACHRISTOS; SOFIANOS; ADAMIDES, 2013).

In *niche autonomy*, developments in one ST-system (S_1) are independent from ST-system (S_2). Once more, the three pathways described for the ST-System (S_1) in the *niche transfer* interaction are possible (PAPACHRISTOS; SOFIANOS; ADAMIDES, 2013).

The last type of interaction is *niche emergence*. It happens when the interaction between two or more different ST-systems (S_1 and S_2) leads to the creation of a new niche (N_3) outside any ST-system, which may lead to the emergence of a new ST-system. The new niche (N_3) may develop into a ST-regime that does not replace any existing ST-regimes, i.e., it starts fulfilling a new societal function (PAPACHRISTOS; SOFIANOS; ADAMIDES, 2013). This critical development was previously ignored in the MLP: the interaction between systems may lead to the increase or the decrease of the total number of ST-systems[20] (PAPACHRISTOS; SOFIANOS; ADAMIDES, 2013).

Defining the ST-systems' boundaries is a fundamental step when using Papachristos, Sofianos and Adamines' (2013) typology, because it influences the focus of the analysis. Papachristos, Sofianos, and Adamines (2013) understand that the limits of a ST-system lie on the societal function fulfillment. Therefore, components of the ST-system are those that help it fulfill its societal function. However, core membership in the system cannot be outlined entirely, as many actors contribute to more than one system. Besides, the actors' participation may change during transitions. For example, outsiders may become incumbents, and peripheral members may become core members. (SMITH; STIRLING; BERKHOUT, 2005; PAPACHRISTOS; SOFIANOS; ADAMIDES, 2013).

Sutherland, Peter, and Zagata (2015) argued that the role of landscape pressure and niche development is missing in most typologies of multi-systems interactions. According to them, there can be two types of landscape pressure in ST-transitions involving multi-systems interactions. One possibility is that all systems are under

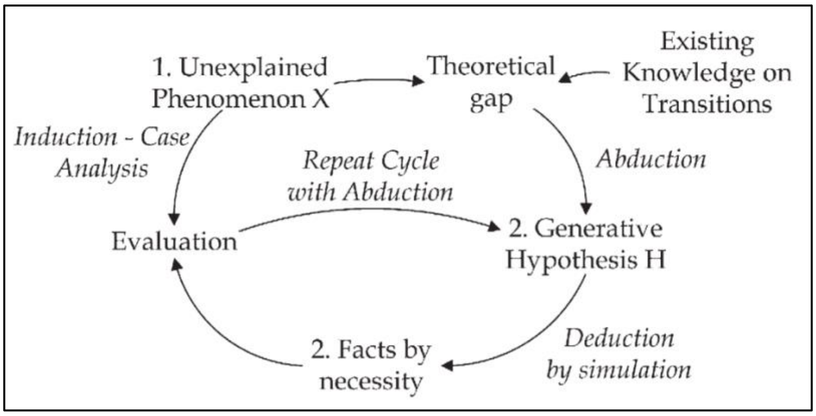
[20] For examples of *niche emergence* and the creation of new ST-systems, see Papachristos and Adamides (2016) and Hassink, Grin and Hulsink (2018).

pressure from the same landscape development. For example, the oil crisis in the 1970s put pressure on many different ST-systems, such as electricity and transportation, and the COVID-19 pandemic is pressuring several ST-systems. Another possibility is that each ST-system is under pressure from a different landscape event (SUTHERLAND; PETER; ZAGATA, 2015). Most landscape developments that are relevant to sustainability transitions, such as climate change, are putting pressure in several different ST-systems at the same time (SUTHERLAND; PETER; ZAGATA, 2015; ROSENBLOOM, 2020).

Sutherland, Peter, and Zagata (2015) also suggested that niches are located within more than one ST-system rather than on the fringe of a single ST-system. Besides, they argued that niches anchor in multiple ST-regimes, interacting with different ST-regimes at the same time. This multiple anchoring would increase niche stability and resilience because it would be able to keep developing in one ST-system even if it failed in other ST-system.

Papachristos and Adamides (2016) proposed using the *retroductive inference mode* (see Figure 2.6) in complement to qualitative research to address multi-systems interactions in the MLP. It would allow "to deduce the effects of non-linear generative mechanisms operating simultaneously and when there are feedback loops and delays among then" (PAPACHRISTOS; ADAMIDES, 2016, p. 5). The methodology they proposed has three steps: (i) identifying and characterizing the transition phenomenon; (ii) conjecturing generative mechanisms; (iii) modeling the systems' structure and simulating some hypotheses.

Figure 2.6 – The retroductive inference mode



Source: Papachristos and Adamides (2016)

Geels (2018b) proposed a different way to extend the MLP, making it suitable to analyze multi-system transitions. He called it the *whole system reconfiguration approach*, which is a ‘zoom-out’ approach in contrast to the usual ‘zoom-in’ of the MLP. The first consideration in this approach is considering multiple landscape events. The MLP usually focuses on landscape developments that positively influence ST-transitions. In the *whole system reconfiguration approach,* developments that put pressure in the ST-regimes to “move in the wrong direction” should also be considered (GEELS, 2018b).

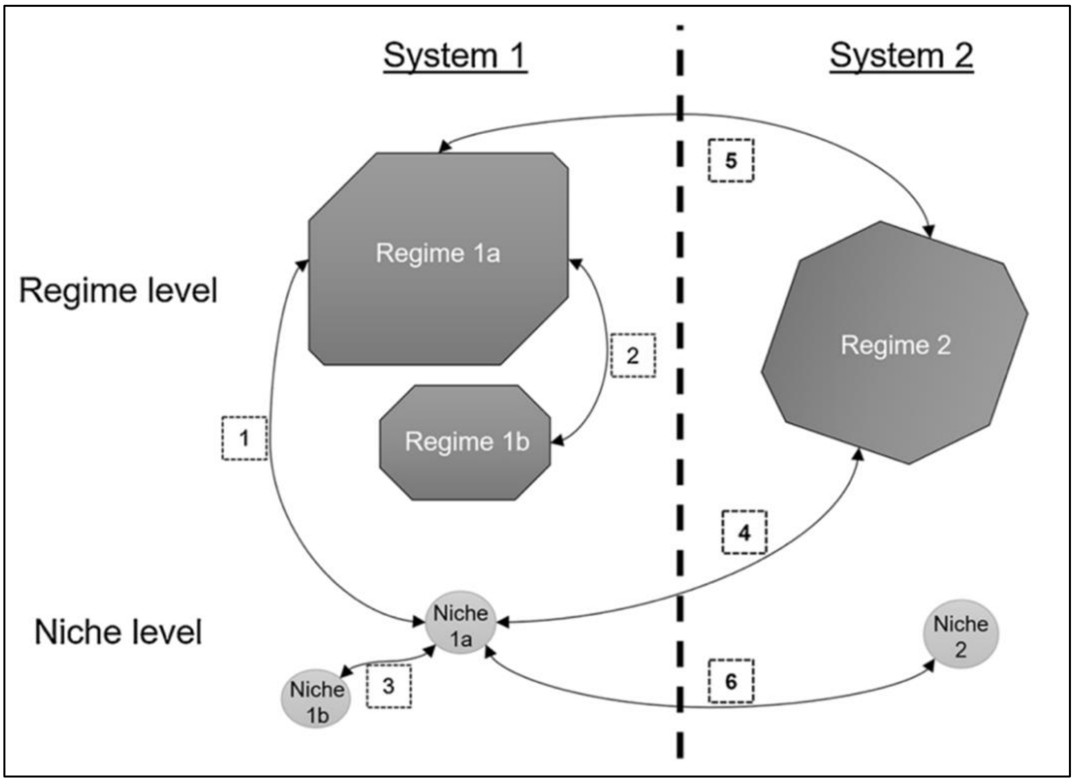
The second consideration is changing the focus from singular disruptive innovations to system reconfiguration. Therefore, this approach considers both radical innovation and incremental change. Multiple interacting change mechanisms can lead to gradual system reconfiguration through improvement, replacement, or modification of the system’s elements (GEELS, 2018b). Multi-regime interaction is essential in this process. Geels (2018b) used Raven and Verbong’s (2007) typology to analyze these interactions, although he did not consider *spillover*.

One last consideration in *the whole system reconfiguration approach* is that system configuration involves multiple niche innovations. Geels (2018b) considered four types of mechanisms through which these novelties may affect the ST-system. First, they may replace existing components of the ST-regimes. Second, they can be adopted by the ST-regimes in a symbiotic way, resulting in hybrid configurations. Third, they can improve the ST-regimes or create new linkages between different ST-regimes. Finally, niche innovations in parallel ST-systems can impact the ST-regimes (GEELS, 2018b).

Geels (2018b) argued that the *whole system reconfiguration approach* helps scholars distinguish between the process of change (gradual or radical) and the outcome of change (large or small). One drawback of this approach is losing some granularity, i.e., it becomes more challenging to analyze ST-transitions’ details. Therefore, he recommended using this approach together with the “conventional” MLP, zooming in and out, to address ST-transitions from different but complementary perspectives (GEELS, 2018b).

Building on Geels (2018b) and Papachristos, Sofianos, and Adamines (2013), Rosenbloom (2020) sketched (see Figure 2.7) the design of an approach that conceptualizes multi-systems interactions. He argued that these interactions are *diverse* (ST-systems share several different connections), *layered* (interactions happen across different levels and at multiple geographic scales), and *evolving* (system boundaries shift over time).

Figure 2.7 – Multi-system perspective approach



Interactions within system: 1 - Niche-Regime; 2 - Regime-Regime; 3 - Niche-Niche
Interactions across systems: 4 - Niche-Regime; 5 - Regime-Regime; 6 - Niche-Niche

Source: Rosenbloom (2020)

Rosenbloom (2020) also stressed that three elements are essential in the *multi-system perspective* approach: (i) analyze *functional and structural* couplings between systems (KONRAD; TRUFFER; VOSS, 2008); (ii) assess how *sites of interaction* could bring systems together, and accelerate ST-transitions (ROSENBLOOM, 2019); (iii) explore the *transition systems interaction patterns* (RAVEN; VERBONG, 2007; PAPACHRISTOS; SOFIANOS; ADAMIDES, 2013).

Lin and Sovacool (2020) assessed multi-system interactions using an extended version of the heuristic developed by Sandén and Hillman (2011) to analyze multi-mode interaction among technologies. They considered six modes of interaction:

(i) Competition: technology A and B inhibits each other.

(ii) Symbiosis: technology A and B benefit each other.

(iii) Neutralism: technology A and B do not affect each other.

(iv) Parasitism: technology A is benefited, and B is inhibited.

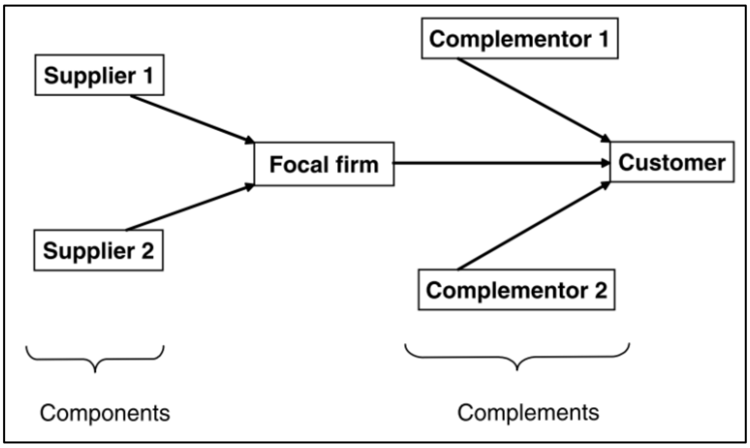
(v) Commensalism: technology A is benefited, and B is not affected.

(vi) Amensalism: technology A is inhibited, and B is not affected.

Lin and Sovacool (2020) indicated that these modes of interactions can be combined with the level of interaction between actors to characterize multi-system interactions. For example, the interaction between BEVs and PHEVs can be classified as intra-niche competition because they are niche technologies competing in the same ST-system, i.e., urban mobility. On the other hand, the relationship between BEVs and vehicle-to-grid (V2G) is characterized as inter-niche symbiosis because they are niche technologies from different ST-systems that benefit each other. In this case, the increase of BEVs in the urban mobility ST-system improve V2G applications viability in the electricity ST-system and the advancing of V2G technology in the electricity ST-system have a positive impact on the appeal of BEVs in the urban mobility ST-system.

Finally, it is useful to use some concepts from innovation ecosystem literature[21] when analyzing multi-system sustainability transitions. Adner and Kappor (2010) distinguished three types of firms in a innovation ecosystem, depending on their position in the innovation value chain (see Figure 2.8). First, there is the focal firm, i.e., the firm driving the innovation and producing the core technology (e.g., computers). Before the focal firm in the value chain, there are the suppliers, which provide components (e.g., processors) to the focal firm. After the focal firm, there are the complementors, which provide complements (e.g., software) to the users of the technology provided by the focal firm (ADNER; KAPOOR, 2010).

Figure 2.8 – Innovation value chain



Source: Adner and Kappor (2010)

[21] Innovation ecosystem literature studies "the collaborative arrangements through which firms combine their individual offerings into coherent, customer-facing solutions" (ADNER, 2006, p. 2). It has the same evolutionary economics roots of the MLP and builds on Moore's (1993) business ecosystem concept. However, there is no consensus about the definition and the operationalization of innovation ecosystems (OH et al., 2016).

Technological challenges in components improve the performance advantage of the technology leaders (first movers) by increasing the barrier to entry (ADNER; KAPOOR, 2010). Thus, component improvements can reduce technology leaders' interest in continuing to invest in the innovation. On the other hand, technological challenges in complements (complementors) decrease the performance advantage of technology leaders because it reduces the value offer of the main innovation (ADNER; KAPOOR, 2010). In this case, improvements in complements may increase technology leaders' investments in the innovation.

Besides, suppliers and complementors can be in a different level of the ST-system than the focal firm. For example, niche innovators can be supplied by ST-regime actors. Moreover, suppliers and complementors can be in a different ST-systems than the focal firm. Therefore, multi-system interaction can have different impacts on the niche, and consequently in the sustainability transition, depending on the position of the actors in the innovation value chain and ST-system.

2.1.3 Sustainability transitions in developing countries[22]

Sustainability transition studies have considerably overlooked spatial scales and dimensions (MONSTADT, 2009; SMITH; VOSS; GRIN, 2010; COENEN; BENNEWORTH; TRUFFER, 2012; HANSEN; COENEN, 2015; MURPHY, 2015). The relatively recent literature on 'geography of transitions' has addressed some of the issues related to the social-spatial dynamics of transitions, better-conceptualizing scales, spaces, and places in transition studies (KÖHLER et al., 2019; BINZ et al., 2020). 'Geography of transitions' captures the distribution of different transitions across space and the interconnections and interactions between the place where the transition is embedded and unfold and other places (BRIDGE et al., 2013; HANSEN; COENEN, 2015).

This attention to 'geography of transitions' was probably motivated by the increased use of sustainability transitions frameworks in developing countries (HANSEN; COENEN, 2015). These countries can be significantly different from the

[22] Studies in the sustainability transitions field (and many other research disciplines and fields) often label a diverse and heterogeneous group of countries as *developing countries*. This is done based on some social, cultural, political, and, specially, economic characteristics shared by these countries (HANSEN et al., 2018) and follow similar categorizations done by international organizations, such as the UN and the World Trade Organization. However, the notion of *developing countries* is contested both theoretically and politically (ESCOBAR, 1995). Some transition scholars prefer the term *Global South* rather than *developing countries.* For example, the Sustainability Transitions Research Network (STRN) uses the term *Global South* in one of its thematic groups (Transitions in the Global South). *Global South* is viewed as a more empowering and balanced term (KLOSS, 2017). Nonetheless, *developing countries* will be used in the thesis because it still is more common than *Global South* in sustainability transitions studies.

European countries where these frameworks were initially developed. Not coincidently, one of the most relevant and topical issues on the 'geography of transition' research agenda is transitions in developing countries (HANSEN et al., 2018; VAN WELIE et al., 2018; WIECZOREK, 2018; KÖHLER et al., 2019).

Building on Wieczorek (2018) and Köhler *et al*. (2019), it is possible to divide the most relevant issues when studying sustainability transitions in developing countries into three major themes:

(i) *Multi-scalarity, transnational linkages, and sustainability experiments*: most sustainability transitions studies assume, often implicitly, that transitions unfold in pre-conceived boundaries, ignoring multi-scalar characteristics of regimes, niches, experiments, and actors (WIECZOREK, 2018; BINZ et al., 2020). However, transnational linkages significantly impact innovation and transition in developing countries (BERKHOUT et al., 2010; FUENFSCHILLING; BINZ, 2018; HANSEN et al., 2018). Besides, many transition studies assume, based on catch-up and convergence theories, that technologies usually originate in developed countries and then are absorbed by developing countries (BERKHOUT; WIECZOREK; RAVEN, 2011; BINZ et al., 2012; WIECZOREK, 2018; KÖHLER et al., 2019). Some transition scholars are challenging these assumptions, indicating the up-scaling of sustainability experiments as the way to 'shift innovation' from developed to developing countries (JOLLY; RAVEN; ROMIJN, 2012).

(ii) *Uniformity, stability, and path-dependence*: ST-regimes in developing countries have more internal tensions, are less uniform and more unstable than in developed countries. Therefore, the ST-regime concept needs to be reviewed to encompass different levels of uniformity and stability. Transitions in these countries are more dynamic because both niches and regimes are more fluid. (BERKHOUT; WIECZOREK; RAVEN, 2011; RAMOS-MEJÍA; FRANCO-GARCIA; JAUREGUI-BECKER, 2018; VAN WELIE et al., 2018; WIECZOREK, 2018; KÖHLER et al., 2019).

(iii) *Normative orientation*: sustainability understanding varies across societies, reflecting on distinct sustainable development agendas among countries. Priorities in sustainability transitions can be significantly different in

> developed and developing countries (SMITH; VOSS; GRIN, 2010; WIECZOREK, 2018; KÖHLER et al., 2019). These differences significantly impact the objectives and the governance of sustainability transitions (RAVEN et al., 2017). Successful transition pathways towards sustainability in developed countries may be challenging to replicate in developing countries because of these differences (HANSEN; NYGAARD, 2013; ROMERO-LANKAO; GNATZ, 2013).

Sustainability experiments, *transnational linkages*, *uniformity and stability of ST-regimes* and *normative orientation* are relevant concepts for the thesis research and are further discussed in the next sections.

2.1.3.1 Sustainability experiments and transnational linkages

Many transition scholars, based on catch-up and convergence theories, assume that technology is originated in developed countries and then diffused to the rest of the world (BERKHOUT; WIECZOREK; RAVEN, 2011; BINZ et al., 2012; WIECZOREK, 2018; KÖHLER et al., 2019). Nordensvard, Zhou, and Zhang argued that even large emerging economies, such as China, India, Brazil, and South Africa, should not be seen as technology pioneers or core innovators. They defined these countries as semi-peripheral, i.e., countries with more capacity to absorb knowledge from core innovators than peripheral countries. Semi-peripheral countries have stronger transnational linkages with international organizations and developed countries than peripheral countries and, therefore, receive more resources from them (NORDENSVARD; ZHOU; ZHANG, 2018). Semi-peripheral countries can develop new technology. However, they are not at the innovation frontier and tend to focus on a few technologies. (SENGERS; RAVEN, 2015; NORDENSVARD; ZHOU; ZHANG, 2018).

In contrast, Quitzow (2015) affirmed that this linear concept of innovation and diffusion 'from North to South' is not valid in the increasingly integrated global economic system. He argued that follower countries have active roles in shaping technology trajectories. Developing countries can create new technologies and have sustainability transitions their way, avoiding to repeat the development trajectory of developed countries (BERKHOUT; ANGEL; WIECZOREK, 2009; BERKHOUT; WIECZOREK; RAVEN, 2011). Jolly, Raven, and Romijn (2012) referred to a 'shift in innovation' from developed to developing countries. Sustainability experiments, which are seen as a new source of innovation in developing countries, would be the base of this shift (WIECZOREK, 2018).

Berkhout et al. (2010, p. 262) defined sustainability experiments as “planned initiatives that embody a highly novel socio-technical configuration likely to lead to substantial (environmental) sustainability gains.” Sustainability experiments are the initial efforts to develop a novel way to solve a problem, requiring the formation of new networks of actors and unique combinations of knowledge and capabilities (BERKHOUT; WIECZOREK; RAVEN, 2011).

These experiments can be conducted in developing countries and developed countries through the interaction between the ST-regime and transnational actors (BERKHOUT et al., 2010). Wieczorek, Raven, and Berkhout (2015) defined transnational linkages as the cross-border structures and interactions that allow the flow of technology, capital, knowledge, people, institutions, and other resources between different localities, such as cities, regions, or countries. Therefore, countries that are not at the technological frontier can develop novel technologies by ‘anchoring’ global resources, such as global knowledge networks and international markets (BERKHOUT et al., 2010; BINZ; ANADON, 2018). The circulation of technologies between countries is at the core of sustainability experiments in developing countries (WIECZOREK; RAVEN; BERKHOUT, 2015).

This relevance of transnational linkages in sustainability experiments does not mean that developing countries are only receiving and using knowledge, technology, and other resources from developed countries. These experiments also allow developing countries to be ‘knowledge producers’, providing new knowledge and technologies to the global knowledge networks (BERKHOUT; WIECZOREK; RAVEN, 2011; SENGERS; RAVEN, 2014; QUITZOW, 2015). However, this knowledge transfer from the local to the global level does not happen spontaneously (SENGERS; RAVEN, 2015). Transnational linkages are necessary because they provide pipelines[23] that allow the exchange of tacit and codified knowledge generated in local experiments with actors outside the local cluster (SENGERS; RAVEN, 2015; WIECZOREK; RAVEN; BERKHOUT, 2015).

Hence, the transnational linkages are used in developing countries to anchor the resources necessary to enable sustainability experiments and to diffuse the results of these

[23]Pipelines are defined as communications channels built to allow extra-local knowledge flow (BATHELT; MALMBERG; MASKELL, 2004).

experiments. Therefore, sustainability experiments have multi-scalar configurations and are significantly impacted by multi-scalar dynamics (KUOKKANEN; YAZAR, 2018; BAUER; FUENFSCHILLING, 2019).

These multi-scalar configurations are embedded in multiple spatial scales, including the local dynamics where the experiments are implemented (HODSON; GEELS; MCMEEKIN, 2017). Place-specific institutional arrangements, such as public participation, local government autonomy, and legal framework, shape how experiments unfold (KUOKKANEN; YAZAR, 2018; RAVEN et al., 2019). Sustainability experiments in developing countries are usually set up with relevant participation of the local (city or region) government (WIECZOREK; RAVEN; BERKHOUT, 2015). Cities provide a favorable context for experimentation because they have both ST-regimes and niches characteristics, ideal for novel experiments (SPÄTH; ROHRACHER, 2012; JENSEN; FRATINI; CASHMORE, 2016; KUOKKANEN; YAZAR, 2018). Successful experiments in cities can give new technologies more credibility and legitimacy (SPÄTH; ROHRACHER, 2012).

A successful sustainability experiment can also lead to the gradual formation of transnational networks and stimulate the circulation of knowledge that will eventually constitute a new niche (FONTES; SOUSA; FERREIRA, 2016). Sengers and Raven (2015) showed that the success of the Bus Rapid Transit (BRT) in Bogotá and Curitiba influenced the development of this niche technology worldwide, especially in Latin America and Asia. However, innovation in developing countries is often restricted to single sustainability experiments (HANSEN et al., 2018), short-term and isolated from other experiments (e.g., small-scale wind turbine experiments in Kenya; Kamp and Vanheule, 2015). In many cases, the lack of a sequence of sustainability experiments does not enable nurturing a niche, hindering their upscaling and compromising future experiments (HANSEN et al., 2018).

As detailed in Section 2.1.1.2, successful successive sustainability experiments help stabilize the niche. Combining SNM with innovation ecosystems theory, Walrave et al. (2018) argued that having a sequence of experiments with feedback (the current experiment is informed by the previous one) increase the niche external viability. This increase is the result of the alignment between the development trajectory emerging in the niche and the value proposition of the innovation ecosystems that form the niche (WALRAVE et al., 2018).

The transitions literature has not addressed many issues regarding the upscaling of sustainability experiments. First, it is not clear how sustainability experiments should be designed to lead to sustainability transitions (WIECZOREK, 2018; KÖHLER et al., 2019). Second, research needs to clarify which instruments can promote experiments and accelerate sustainability transitions in developing countries (WIECZOREK, 2018; KÖHLER et al., 2019). Third, research could further explore how sustainability experiments worldwide connect and influence each other, especially the connections between developing countries (SENGERS; RAVEN, 2015; WIECZOREK, 2018).

2.1.3.2 Uniformity and stability of ST-regimes

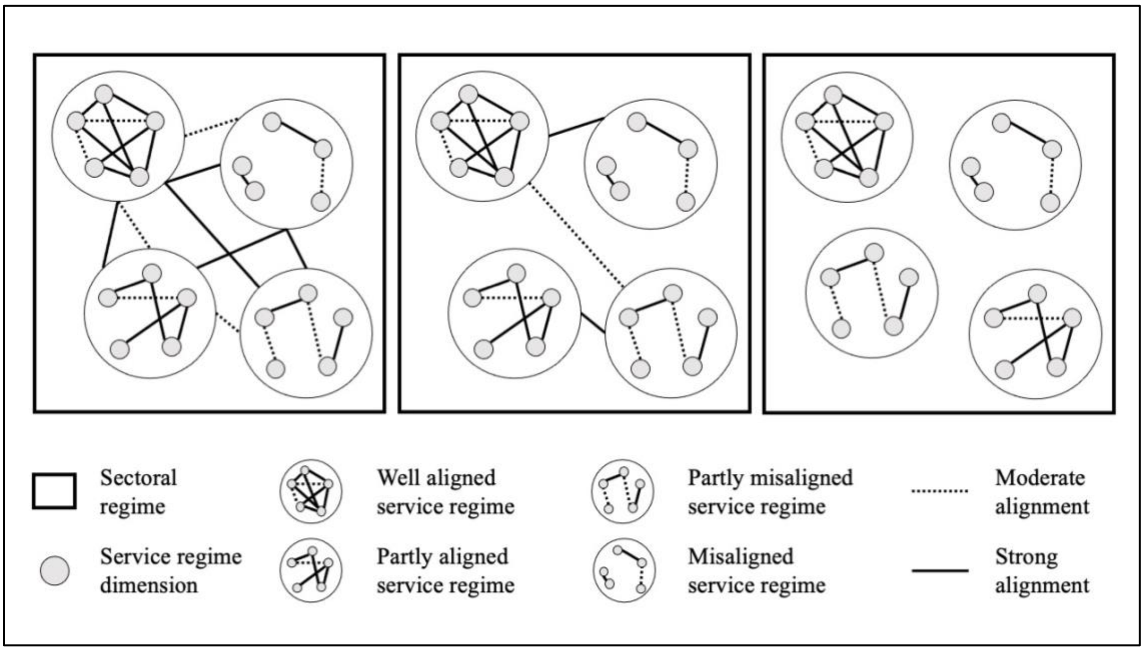
The transitions literature predominately conceptualizes ST-regimes as uniform, homogeneous, and coherent structures, although acknowledging that there are some inconsistencies, irregularities, and conflicts inside them (GEELS, 2011; SPÄTH; ROHRACHER, 2012). Though a ST-regime's uniformity may be valid in developed countries, ST-regimes in developing countries show a much higher level of heterogeneity, inconsistencies, and hybridization (VAN WELIE et al., 2018; WIECZOREK, 2018).

Developing countries often present a mixture of well and ill-functioning institutions, which are contested and personalized, privileging some groups over others. These aspects make the ST-regimes institutionally heterogeneous (RAMOS-MEJÍA; FRANCO-GARCIA; JAUREGUI-BECKER, 2018). For example, many cities in developing countries have highly complex and heterogeneous ST-regimes to fulfill essential services. The resources are unevenly distributed, with the wealthiest neighborhoods having access to modern infrastructures and technologies, while the poorest ones rely on informal and inefficient alternatives (FURLONG, 2014; SENGERS; RAVEN, 2014; VAN WELIE et al., 2018).

Van Welie *et al.* (2018) conceptualized heterogeneous ST-regimes distinguishing between two levels: *service regime* and *sectoral regime*. *Service regime* is a similar concept to the ST- regime used in transitions literature. It refers to the technologies, rules, routines, and institutional aspects related to providing a service, for example, the private car ST-regime. The *sectoral regime* refers to broader economic and societal factors associated with fulfilling a societal function, such as transport. In transitions studies, this level is often loosely referred to as the sector or domain in which the ST-regime is embedded (VAN WELIE et al., 2018). Some authors call it the ST-system (GEELS, 2004).

There is a hierarchy between these two regimes, with one or more *service regimes* composing the *sectoral regime*. Each *service regime* of a *sectoral regime* has its own rules, culture, user practices, infrastructure, and institutional arrangements, and they all interact at the sectoral level (VAN WELIE et al., 2018). *Sectoral regimes* are characterized by alignments and misalignments between their *service regimes* (see Figure 2.9). Well-aligned *sectoral regimes* have *service regimes* that complement each other, providing users with different combinations of services to fulfill their needs. On the contrary, misaligned *sectoral regimes* are inefficient, miss the necessary structures to connect their *service regimes*, and offer options that are insufficient to meet the needs of many users (VAN WELIE et al., 2018).

Figure 2.9 – Sectoral and service regimes



Well aligned sectoral regime (left); partly aligned sectoral regime (center); misaligned (or fragmented) sectoral regime (right)
Source: Developed by the author based on Van Welie *et al.* (2018) and Schippl and Truffer (2020).

Service regimes are stable and robust when five socio-technical dimensions align (SCHIPPL; TRUFFER, 2020): (i) technologies and infrastructures; (ii) organizational mode; (iii) user requirements; (iv) planning practices and public financing; and (v) societal meaning. The *service regime* becomes weaker if there are misalignments between two or more of these dimensions. When a *service regime* is weak, a new *service regime* may emerge without necessarily substituting the older. Besides, the *service regime* can vary from region to region. For example, the *service regimes* available in one neighborhood may be different from those present in other parts of the city (VAN WELIE et al., 2018).

Van Welie *et al.* (2018) aimed to overcome binary niche-regime conceptualization in transition theories, especially the MLP, which assumes that any ST-transition will eventually lead to a single and universal technology (FURLONG, 2014), independently of the pathway, as discussed in section 2.1.1.4.6. They proposed a gradient of *service regimes* with different strength and local embeddedness levels instead of a single dominant regime. In this framework, the dominant regime is just one of many possible configurations of a *sectoral regime*.

This framework is useful in developing countries, where assuming universality as the goal of a ST-transition may be problematic. Promoting the coexistence of different technologies can be a more effective way of facilitating service extension than seeking a universal solution, even if this solution is the most efficient technical option (FURLONG, 2014). For example, using off-grid solar PV technology has been more effective for electrifying rural areas in Uganda than extending the electricity grid. However, the latter alternative is more technically efficient (BHAMIDIPATI; ELMER HANSEN; HASELIP, 2019).

Ghosh and Schot (2019) defended that the view of ST-transitions as changes of ST-regime based on regime destabilization and niche innovation is a bias from developed countries. They argued that the role of incumbents may be more important than niche innovations for ST-regime changes in developing countries. According to Ghosh and Schot (2019), ST-regimes change can be of three types: *optimization*, *transformation*, and *transition*. They distinguished five dimensions of ST-regimes: (i) science and technology, (ii) policy and governance, (iii) market and users, (iv) industry structure and strategy, and (v) sociocultural dimension. They also consider the three types of ST-regime's rules proposed by Geels (2004): regulative, cognitive and normative.

Therefore, regime *optimization* would occur when landscape pressures cause changes in regulative and cognitive rules of one or two dimensions of the ST-regime. *Transformation* would be the result of changes of regulative and cognitive rules in three or four dimensions due to landscape events. Finally, regime *transition* would happen when landscape pressures cause change in all rules of all dimensions (GHOSH; SCHOT, 2019). According to Ghosh and Schot (2019), this framework is a method to systematic analyze pathways of regime change and is not based on the niche-regime-landscape interaction, like the methods proposed by Geels and Schot (2007) and Geels *et al.* (2016). Therefore, this framework would be more suited to analyze transitions in developing countries (GHOSH; SCHOT, 2019).

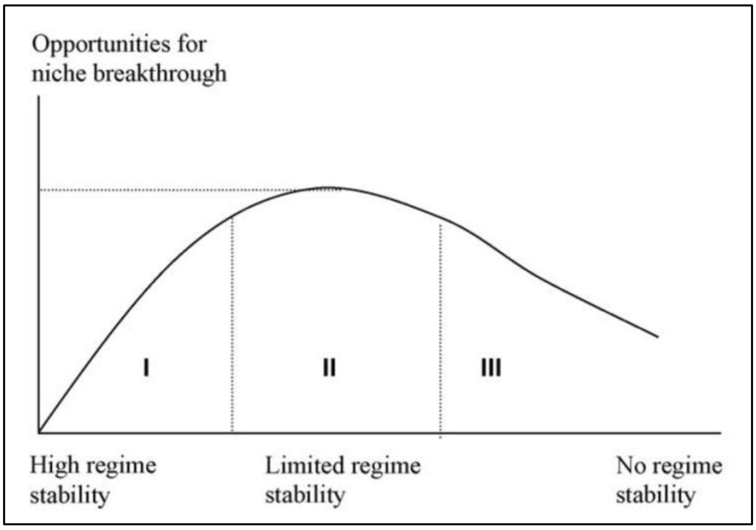
Besides being heterogeneous, ST-regimes in developing countries are also less stable than usually assumed in transitions literature (RAMOS-MEJÍA; FRANCO-GARCIA; JAUREGUI-BECKER, 2018; WIECZOREK, 2018). These countries face issues that are less common in developed countries. Some examples are political and economic instability, high levels of poverty and inequality, underdeveloped markets, weak government administrations, less enforceable rules and regulations, contested institutional and governance capacities, prominence of informal institutions, and low levels of transparency (ALTENBURG, 2009; BERKHOUT; WIECZOREK; RAVEN, 2011; SIXT; KLERKX; GRIFFIN, 2018; TRANSPARENCY INTERNATIONAL, 2020). All these issues contribute to ST-regimes being relatively fluid, instead of stable, in developing countries (BERKHOUT; WIECZOREK; RAVEN, 2011; HANSEN et al., 2018).

According to transitions' theory, unstable regimes facilitate the unfolding of ST-transitions. Incumbents are less committed to unstable ST-regimes and more likely to support, or at least not fight, ST-transitions, as detailed in section 2.1.1.4.5. Besides, ST-regimes in developing countries are less likely to be locked-in because they often have not yet invested much in infrastructure (energy, water, transportation) (FUENFSCHILLING; BINZ, 2018; WIECZOREK, 2018). Therefore, radical changes should be easier to implement in these ST-regimes than in the stable and path-dependent ST-regimes of developed countries (BOSCHMA et al., 2017). However, many studies show that this is not always the case (FURLONG, 2014; HANSEN et al., 2018).

Although some ST-regime destabilization is necessary to enable ST-transitions, after a certain point, more instability reduces the opportunities for change (VERBONG et al., 2010; HANSEN et al., 2018), as can be seen in Figure 2.10. Instability in ST-regimes can become barriers to change. Highly unstable environments can limit investments in new technologies, compromising niche development (BERKHOUT et al., 2010; FURLONG, 2014). Besides, informal settings developed by people trying to cope with formal ST-regimes' systemic inefficiency to meet their needs often become strong and resilient ST-regimes in developing countries (HANSEN et al., 2018; RAMOS-MEJÍA; FRANCO-GARCIA; JAUREGUI-BECKER, 2018; VAN WELIE et al., 2018). Biomass gasification in India (VERBONG et al., 2010), motorcycle taxi in Bangkok

(SENGERS; RAVEN, 2014), sanitation in Nairobi (VAN WELIE et al., 2018), and urban planning in Der es Salaam (HERSLUND et al., 2018) are some examples of how instability and informality can hinder transitions.

Figure 2.10 – Breakthrough opportunities for niches in relation to regime stability



Source: Verbong et al. (2010)

Therefore, one issue that transition literature has not addressed is defining the necessary level of regime instability to allow ST-transitions to unfold and the point that this instability begins to hinder ST-transitions. A related question is how different ST-regime stability levels affect niche development (HANSEN et al., 2018). Besides, is ST-regime destabilization necessary for a transition to unfold if the ST-regime is already unstable (VAN WELIE et al., 2018; KÖHLER et al., 2019)? Another relevant issue is what types of governance strategies can destabilize the existing ST-regime without compromising niche development and sustainability transitions as a whole (WIECZOREK, 2018). Finally, does the same strategy apply to formal and informal ST-regimes?

A new conceptualization of ST-regimes that encompass various grades of uniformity and stability is needed, as most of the current conceptual frameworks do not apply to many developing countries (KÖHLER et al., 2019). The conceptual framework proposed by van Welie *et al.* (2018) is an exciting proposal and can be further validated and improved with more empirical data, especially from transitions in developing countries. Some relevant issues in this context are how heterogeneous ST-regimes influence path-dependence and opportunities for transitions and the possible transitions pathways that can result in these cases (VAN WELIE et al., 2018; WIECZOREK, 2018; KÖHLER et al., 2019).

2.1.3.3 Normative orientation

Having sustainability as the normative orientation of ST-transitions can be challenging because sustainability is an ambiguous and contested concept, despite the extensive literature on this subject (KEMP; MARTENS, 2007; WALKER; SHOVE, 2007; KUHLMAN; FARRINGTON, 2010; RAVEN et al., 2017). Nonetheless, transitions literature has paid little attention to how different understandings of sustainability impact ST-transitions (RAVEN et al., 2017; WIECZOREK, 2018; CUPPEN et al., 2019; KÖHLER et al., 2019). Besides, the disagreements and contradictions around what sustainability is and how to achieve it can be amplified by the significant social challenges faced by developing countries (ALTENBURG, 2009; RAMOS-MEJÍA; FRANCO-GARCIA; JAUREGUI-BECKER, 2018; WIECZOREK, 2018).

Sustainability is not a neutral attribute of sustainability transitions. It is the outcome of multiple negotiations and contestations between several actors in different arenas (WALKER; SHOVE, 2007; RAVEN et al., 2017). The understanding of sustainability varies according to what actors, networks, niches, ST-regimes, and ST-systems are interacting (GARUD; GEHMAN, 2012; ROMERO-LANKAO; GNATZ, 2013). Actors have different visions of sustainability based on their interests, expectations, and interpretations. These visions are subject to negotiations between the actors and shape values and principles that promote or block transition pathways (HODSON; GEELS; MCMEEKIN, 2017; RAMOS-MEJÍA; FRANCO-GARCIA; JAUREGUI-BECKER, 2018).

The multiple visions of sustainability and the priorities of sustainability transitions significantly impact the objectives and the governance of these transitions (RAVEN et al., 2017). These visions can compete with each other to define these priorities, co-exist in a parallel and non-conflictual way, or be complementary, reinforcing each other (HODSON; GEELS; MCMEEKIN, 2017). Although this diversity of visions makes the governance of sustainability complex, contested, and controversial, it also improves the capacity to deal with uncertainties and future shocks (STIRLING, 2011; RAVEN et al., 2017). A successful sustainability transition will depend on the different actors achieving a shared vision of the best pathway towards sustainability (ESSLETZBICHLER, 2012).

However, for a transition to be genuinely sustainable, its vision of sustainability and the values and principle associated with it must consider environmental issues as well as aspects of social justice and social inclusion (HANSEN et al., 2018). Otherwise, the transition pathway may lead to significant ecological outcomes, such as reducing GHG emissions, but poor social outcomes, such as increasing poverty or inequality, and vice-versa (SWILLING; MUSANGO; WAKEFORD, 2016; RAMOS-MEJÍA; FRANCO-GARCIA; JAUREGUI-BECKER, 2018).

In developing countries, elites may coopt sustainability transitions due to a lack of transparent processes, power imbalances, clientelist relations, and corruption (HANSEN et al., 2018; NEWELL, 2019). These issues make these elites harder to unsettle than incumbents in developed countries. Visions of sustainability from many actors may be ignored, leading to 'unjust transitions' managed by elites not to disturb the existing distributions of economic and political power (RAMOS-MEJÍA; FRANCO-GARCIA; JAUREGUI-BECKER, 2018; NEWELL, 2019). Swilling, Musango, and Wakeford (2016), for example, showed that the ruling elite in South Africa is controlling the transition to renewable energy to maintain the rent-seeking provided by the coal and nuclear ST-regimes. Other studies have identified similar issues in Kenya (NEWELL; PHILLIPS, 2016) and Nigeria (OSUNMUYIWA; BIERMANN; KALFAGIANNI, 2018).

Therefore, place-specific views of sustainability significantly influence how and if sustainability transitions unfold (HANSEN; COENEN, 2015; KÖHLER et al., 2019). Transferring successful policies and governance frameworks from one place to another is not straightforward (HANSEN; NYGAARD, 2013; ROMERO-LANKAO; GNATZ, 2013). Issues such as undemocratic systems and high inequality levels in many developing countries make this transferring even more challenging and almost impossible in some cases (HANSEN et al., 2018; WIECZOREK, 2018).

Research on sustainability transitions need to be more reflexive about the place-specific context in which these transitions are addressed since the understating of sustainability is very much context-dependent (RAVEN et al., 2017; WIECZOREK, 2018; KÖHLER et al., 2019). Researchers should be careful when applying sustainability transitions conceptual frameworks in developing countries because they were developed in a European context, with a significantly different understanding of *sustainability* (HANSEN et al., 2018). Besides, although many studies have shown that place-specificity matters for sustainability transitions, it is still necessary to understand better how place-specificity influences transition processes (HANSEN; COENEN, 2015).

2.2 Sustainable urban mobility

The importance of mobility to achieve sustainable development was first acknowledged in the 1992 Earth Summit in Rio de Janeiro. The concept of sustainable mobility[24] was first presented in the 1992 EC Green Paper on the Impact of the Transport on the Environment (HOLDEN et al., 2020). The Green Paper stated that sustainable mobility "should enable transport to fulfill its economic and social role while containing its harmful effect on the environment" (COMMISSION OF THE EUROPEAN COMMUNITIES, 1992, p. 5). The Green Paper acknowledged both the environmental (e.g., air and water pollution, and land-use change) and the social (e.g., accidents, congestion) impacts of mobility. It also gave attention to urban mobility, affirming that transport is one of the leading causes of urban degradation.

In 2004, the World Business Council for Sustainable Development (WBCSD) initiated the Mobility 2030 Project to make mobility more affordable and safer and reduce its environmental impact (WBCSD, 2004). The project's working group included some of the world's leading automobile manufacturers (Volkswagen, Toyota, Renault-Nissan, General Motors, and Ford) and some energy sector companies (e.g., British Petroleum and Shell). They defined sustainable mobility as "the ability to meet society's need to move freely, gain access, communicate, trade and establish relationships without sacrificing other essential human or ecological values, today or in the future" (WBCSD, 2015, p. 11).

In 2019, the Sustainable Mobility for All (SuM4All), a platform that reunites several organizations and companies, including the World Bank and the UN, defined sustainable mobility in terms of four global policy goals: universal access, efficiency,

[24] The term sustainable mobility is preferred in Europe, while sustainable transport is preferred in North America (BLACK, 2010). These two terms refer to the same ideas and policy implications (HOLDEN; GILPIN; BANISTER, 2019). However, Berger et al. (2014) argued that mobility captures both potential transport, i.e., "the capacity of an individual to overcome physical distance" (SAGER, 2006, p. 466), and revealed transport, i.e., the travel that actually takes place. According to Berger et al. (2014), both potential transport and revealed transport should be considered when assessing sustainability of mobility systems. Therefore, it would be better to use sustainable mobility than sustainable transport. Moreover, Berger et al. (2014) affirmed that mobility systems encompass not only the technical aspects of the transport system (e.g., modes of transportation, infrastructure), but also the organizational models, the regulatory frameworks, the user habits, etc. This definition of mobility system is very close to that of a socio-technical system. Therefore, sustainable mobility and mobility system will be used in this text rather than sustainable transport and transport system.

safety, and green mobility (SUM4ALL, 2019). Their focus was on increasing rural mobility, making mobility gender-neutral, improving transport logistics, reducing road accidents, and decreasing air and noise pollution from transport.

Although the sustainable mobility concept can be applied to urban mobility, some researchers, organizations, and governments use the more specific concept of sustainable urban mobility. For example, the Brazilian government defined sustainable urban mobility as the outcome of a set of transport and circulation policies aiming to provide broad and democratic access to urban space by prioritizing collective and non-motorized transportation in an effective, socially inclusive, and ecologically sustainable way (MINISTÉRIO DAS CIDADES, 2004).

Rodrigues da Silva et al. (2015, p. 147) also referred to sustainable urban mobility in their research, defining it as “the satisfaction of the basic needs of the individuals and a freedom of movements for the society as a whole, including the free choice of transportation modes, in a safe manner and without jeopardizing the human health and the ecosystems.” This broad definition could also be applied to sustainable mobility, as is the case with other definitions of sustainable urban mobility in the literature. Moreover, many authors use sustainable mobility instead of sustainable urban mobility when addressing mobility in the urban space (e.g., Hildermeir and Villareal, 2014; Hoffmann, Weyer, and Longen, 2017). Other authors use sustainable mobility and sustainable urban mobility interchangeably (e.g., Hodson, Geels, and McMeekin, 2017; Canitez, 2019).

Although many studies in the sustainability transitions literature address sustainable mobility, just a few of them define this concept. Besides, many of the definitions are vague, stating, for example, that sustainable mobility is the mobility which is in accordance with the principles of sustainable development (HØYER, 2000; NÆSS et al., 2011) or that sustainable mobility is a response to the current unsustainable organization of the mobility systems (HODSON; GEELS; MCMEEKIN, 2017).

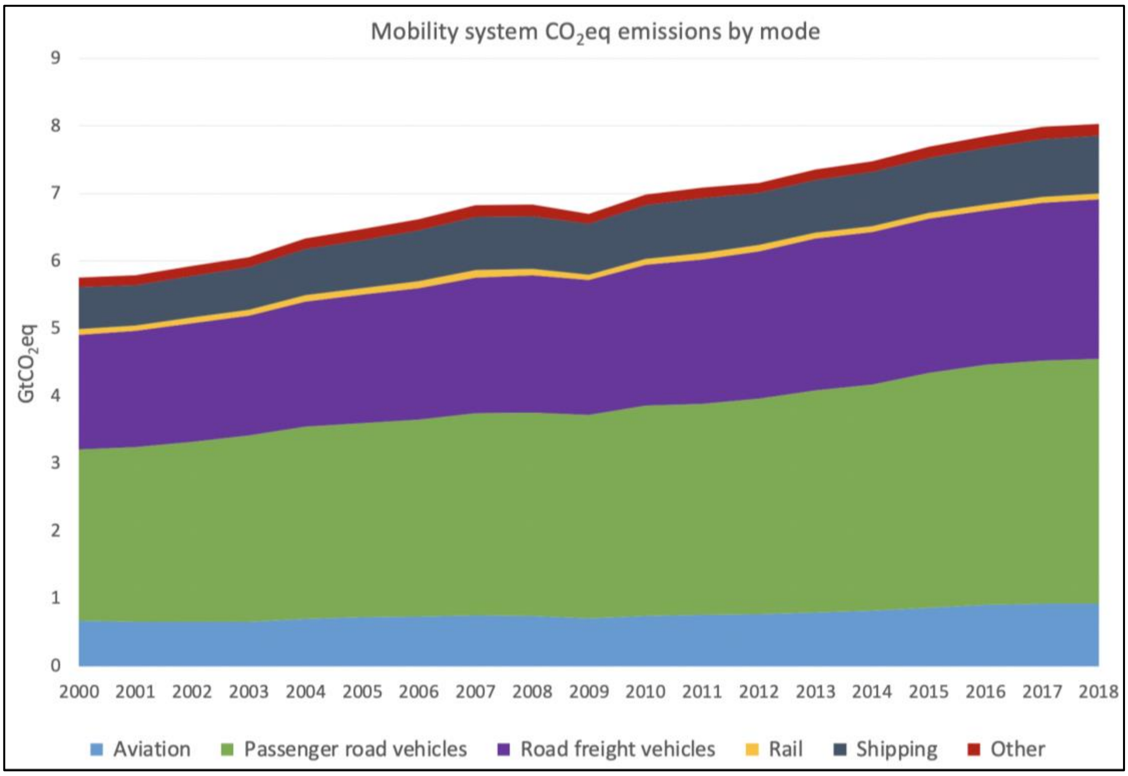
There is no political or scientific consensus on a definition of sustainable mobility (BERGER et al., 2014; HOLDEN et al., 2020). It is a contested concept, subject to a diversity of meanings and interpretations depending on the disciplinary or political context. Besides, sustainable mobility definitions have changed over time to consider more modes of transportations and other impacts from the mobility system on society and the environment (FRÄNDBERG; VILHELMSON, 2010; BERGER et al., 2014). Holden, Gilpin, and Banister (2019) distinguished four generations of sustainable mobility studies from 1992 to 2018, each with a broader understating of sustainable mobility than the previous one. This broadening of the sustainable mobility concept has considerably increased the complexity of researches on this topic (BERGER et al., 2014).

Therefore, Black (2010) argued that it is easier to agree on what makes the current mobility system unsustainable than to reach a consensus on what sustainable mobility means. In other words, it is easier to define what sustainable mobility is not than what it is. Besides, Holden et al. (2020) argued that mobility's negative impacts on society and the environment have already been widely recognized. These impacts are (BLACK, 2010; BERGER et al., 2014; HOLDEN et al., 2020):

(i) *Depletion of non-renewable resources*. The mobility system is a significant consumer of non-renewable materials and fuels. It accounted for approximately 29.1% of the world's total final energy consumption in 2018, from which more than 96% were from fossil fuels (IEA, 2019b). This system is also responsible for around 17% of the world's consumption of steel (WORLD STEEL ASSOCIATION, 2020) and 26% of aluminum (EUROPEAN ALUMINIUM, 2019).

(ii) *GHG emissions*. Mobility modes are considerably contributing to climate change. They were responsible for the discharge of 8.2 $GtCO_2eq$ in 2018 (IEA, 2019a), corresponding to 14.7% of the global GHG emissions (OLIVIER; PETERS, 2020). GHG emissions from the mobility system have been steadily increasing for the past two decades, as shown in Figure 2.11. This figure also shows that emission from passenger road vehicles have increased more than any other mode of transportation.

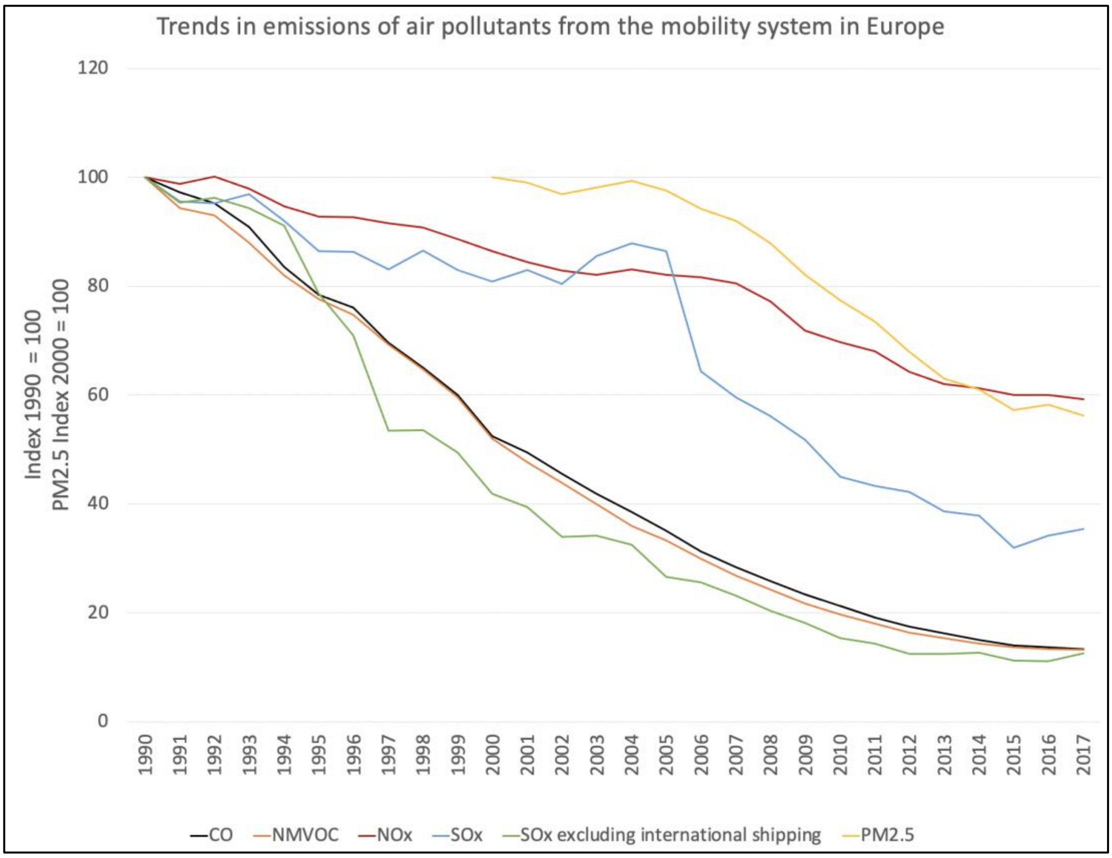
Figure 2.11 – Mobility system CO2eq emissions by mode



Source: IEA (2019b)

(iii) *Local air pollution*. Although the emission of air pollutants from the urban mobility system has considerably reduced in the last 30 years (see Figure 2.12), these vehicles are still great contributors to local and regional air pollution. They were responsible for 21.0% of carbon monoxide (CO), 9.3% of non-methane volatile organic compounds (NMVOC), 55.4% of nitrogen oxides (NOx), 19.8% of particulate matter with a diameter of 2.5 µm or less ($PM_{2.5}$), and 12.1% of sulfur oxides (SOx) emitted in Europe in 2017 (EUROPEAN ENVIRONMENT AGENCY, 2019). More importantly, air pollutants emitted by the mobility system globally led to approximately 385.000 premature deaths in 2015 (ANENBERG et al., 2019).

Figure 2.12 – Trends in emissions of air pollutants from the mobility system in Europe



Source: European Environment Agency (2019)

(iv) *Local noise pollution*. According to the World Health Organization (WHO, 2011), exposure to road traffic, rail, and aircraft noise can cause cardiovascular diseases and sleep disturbances, impair children's cognitive ability, and disturb physical, mental, and social wellbeing. In Europe, for example, more than 210 million people are exposed to road noise levels above the threshold recommended by WHO (BOER; SCHROTEN, 2007).

(v) *Crash fatalities and injuries*. More than 1.35 million people die, and nearly 50 million are injured in traffic-related accidents every year. It is the leading cause of death for children and young adults aged between 5 and 29 years and the 8th leading cause of death for people of all ages. Although the rate of road traffic deaths (18 per 100,000 people per year) has remained stable in the last 15 years, the expansion of road transportation in this period, mainly in developing countries, means that the absolute number of deaths has increased considerably. 93% of global crash fatalities occur in developing countries (WHO, 2018). Nonetheless, many policymakers try to avoid including crash fatalities and injuries in the sustainable mobility debate (BLACK, 2010).

(vi) *Transport infrastructure impacts*. The development of transport infrastructures, especially roads and railways, is associated with many direct and indirect environmental impacts. It has many effects on soil (e.g., soil compaction) (OECD, 2006) and causes habitat fragmentation, which can have negative impacts on biodiversity (EUROPEAN ENVIRONMENT AGENCY, 2004). One of the main spillover effects of road construction is its negative impact on forest cover (ASHER; GARG; NOVOSAD, 2018). For example, spatial spillover from roads is directly related to deforestation in the Amazon Forest (PFAFF et al., 2007).

(vii) *Unequal access*. Access to mobility services is uneven and can increase economic inequality and social exclusion (HOLDEN; GILPIN; BANISTER, 2019). Disadvantage groups (low-income earners, women, and minorities) bear higher levels of commuting burdens (ZHAO; LI, 2016) and face more mobility obstacles, which can enlarge inequalities by hampering the access to jobs and education (HERNANDEZ, 2018). Moreover, the mobility system reinforces discrimination and promotes spatial segregation, especially in developing countries (INWOOD; ALDERMAN; WILLIAMS, 2015; ARELLANA et al., 2020).

(viii) *Congestion*. Although it is often not regarded as a significant obstacle to sustainable mobility (BLACK, 2010), congestion has many different impacts and can intensify some of the mobility impacts previously described. During congestions, vehicles are used in a stop-and-go driving pattern, resulting in increased emissions of GHG and other air pollutants (BARTH; BORIBOONSOMSIN, 2008; LEVY; BUONOCORE; STACKELBERG, 2010) and higher fuel consumption (BLACK, 2010), when compared to a steady-state velocity driving pattern. Congestion also has significant negative impacts on the economy, such as lowering productivity and slowing employment growth (SWEET, 2011, 2014). Finally, congestion can have substantial effects on commuters' wellbeing (e.g., increase the stress level and reduce individual satisfaction), especially for those facing long commutes (HIGGINS; SWEET; KANAROGLOU, 2018), who are mostly poor people.

These issues show that the mobility system is unsustainable and in a trend of increasing its unsustainable patterns. However, these patterns are difficult to change because they are systemic and complex (BERGER et al., 2014). Besides, cities themselves are complex, making addressing urban mobility challenging (ZIPORI; COHEN, 2015; LAH, 2019b).

Each of the problems previously described needs to be addressed in different scales (BLACK, 2010; LAH, 2019b). GHG emissions and the depletion of non-renewable resources are global problems, but many of its solutions are local. On the other hand, air pollution and congestion are local and regional issues, but national and even international policies may be needed to address them. Therefore, there needs to be a coordination between actors at different levels to tackle the unsustainable patterns of urban mobility (BLACK, 2010; VAGNONI; MORADI, 2018).

The urban mobility ST-system has another characteristic that makes it harder to change than other ST-ystems: its physical parts have long lifetimes (HOLDEN; GILPIN; BANISTER, 2019). Cars, buses, and trains can be used for decades if they receive proper maintenance. The infrastructures, such as bridges, roads, and harbors, can last even longer. Moreover, changing cities' layouts (e.g., widening streets and expanding metro lines) usually is complicated, time-consuming, and expansive (GLAESER, 2011). Therefore, urban mobility ST-systems' sustainability transition is a long-term process (HOLDEN; GILPIN; BANISTER, 2019).

Geels (2018b) indicated that the urban mobility ST-system consists of several ST-regimes, such as auto-mobility, railway, bus, and non-motorized transport. These ST-regimes are impacted differently by the same landscape pressures and are also affected by different landscape events (GEELS, 2018b; GOYAL; HOWLETT, 2018). The transition to sustainable urban mobility involves interactions between these ST-regimes and interactions of these ST-regimes with several niches in the urban mobility ST-system and even other ST-systems, such as electricity and fossil fuels (GEELS, 2018b).

There is no 'one size fits all' solution or a 'silver bullet' policy to address urban mobility issues (BERGER et al., 2014; DIJK; GIVONI; DIEDERIKS, 2018) because mobility needs vary according to several factors, such as user preferences, social norms, local characteristics (e.g., topology, climate, urban density), and existing infrastructure (BERGER et al., 2014; JAVAID; CREUTZIG; BAMBERG, 2020; KALLENBACH, 2020). These factors influence the sustainable urban mobility policies that can be implemented and their results (DIJK; GIVONI; DIEDERIKS, 2018; BARDAL; GJERTSEN; REINAR, 2020).

For example, Kallenbach (2020) identified that the main focus of discussions about sustainable urban mobility in Germany is reducing air pollution through technological solutions and improving road safety. There is little consideration for alternatives such as reducing travel demand or increasing public and non-motorized modes of transportation. However, Coelho and Abreu (2019) found considerably different patterns in Brazil, where the sustainable urban mobility discourse is focused on improving public transport and increasing non-motorized and shared modes of transportation.

Another example of how social and cultural aspects influence urban mobility is the trend detected by Spickermann, Grienitz, and von der Gratch (2014) and Hopkins (2017). According to these authors, the 'generation Y,' i.e., people born between 1980 and 2000, is less attracted to automobility and willing to use other transportation modes due to environmental concerns, financial constraints, and new social practices (e.g., sharing practices). This generation, and probably the ones that will follow, demands mobility solutions customized to their individual needs. Therefore, private car ownership should be substituted by mobility as a service (SPICKERMANN; GRIENITZ; VON DER GRACHT, 2014). However, this trend of reducing automobility is stronger in Western Europe than in other parts of the world (TEOH; ANCIAES; JONES, 2020), especially in developing countries, where the car is still considered a symbol of prosperity and status (CANITEZ, 2019).

There are many alternatives and proposals to achieve sustainable urban mobility. Many authors have tried to identify and categorize the main solutions to urban mobility unstainable patterns. Nykvist and Whitmarsh (2008) and Xenias and Whitmarsh (2013) identified three main approaches to foster sustainable mobility: (i) improving efficiency and reducing the impact of vehicles through technology; (ii) increasing the use of more sustainable modes of travel, i.e., substituting the car by public transport and non-motorized transport; and (iii) reducing the travel demand by improving urban planning, encouraging lifestyle changes and increasing the use of communications technologies (e.g., teleworking and e-commerce).

Black (2010) divided the possible solutions to urban mobility unsustainable patterns in five categories:

(i) *Pricing solutions* refers to assessing the full costs of transportation and charging users for it through taxes and tolls (e.g., carbon taxes).

(ii) *Planning solutions* are strategies to manage and reduce travel demand and enhance sustainable practices (e.g., carpooling and parking restraint).

(iii) *Policy solutions* are local, national, or international policies (e.g., regulations aimed at making fossil fuel vehicles more efficient and tax breaks for electric cars).

(iv) *Education solutions* aim to instruct users about the negative impacts of automobility and the benefits of non-motorized transport.

(v) *Technology solutions* focus on substituting the existing technologies with more sustainable alternatives (e.g., electric vehicles and biofuels).

Geels (2012) identified the most promising 'green' niche developments in the urban mobility system:

(i) *Inter-modal travel*, i.e., the use of more than one mode of transportation in the same journey.

(ii) *Cultural and socio-spatial innovations*, such as sustainable urban planning (e.g., compact cities and smart growth) and vehicle sharing schemes.

(iii) *Demand management*, i.e., initiatives aimed at changing user behavior, such as travel awareness campaigns.

(iv) *Modernizing public transport*, including solutions as BRT and buses with clean propulsion systems.

(v) *Information and Communication Technologies* to facilitate traffic management and to enable teleworking and teleshopping.

(vi) *Green propulsion technologies*, including electric vehicles and fuel cell vehicles.

Marletto (2014) distinguished three transition pathways that may emerge from the urban mobility system's current status. The first pathway is 'AUTO-city,' which would result in a system based on private and shared electric cars. The second pathway is 'ECO-city,' and its outcome would be a low-carbon urban mobility system based on integrating public transport with shared electric cars and bicycles. The last pathway proposed by Marletto (2014) is 'ELECTRI-city,' which would be a transition with heavy influence from the electricity ST-system and based on shared electric cars and bicycles integrated to an electricity system based on smart grid and distributed generation.

Moradi and Vagnoni (2018) conducted a literature review and interviews with experts from the urban mobility ST-system to identify the most promising niche innovations to achieve sustainable urban mobility. The result was: (i) integrated transport modes, (ii) sustainable urban planning (e.g., compact city), (iii) green propulsion technologies (e.g., electric vehicles, biofuels, hydrogen fuel cell vehicles), (iv) sharing schemes (car and bikes), (v) demand management, (vi) public transport innovation (e.g., BRT), and (vii) information and communication technologies (e.g., intelligent transport systems and teleworking).

Holden et al. (2020) focused on three elements that need to be addressed to achieve sustainable urban mobility: the strategy (*what needs to be done?*), the leading agent (*who takes the lead?*), and the narratives to achieve sustainable urban mobility (*how can it be done?*). They identified three strategies (improving efficiency, shifting the transportation mode, reducing travel demand) and three leading agents (experts, users, and firms). Combining the strategies and the agents leads to nine different narratives on how to achieve sustainable urban mobility (see Table 2.2).

Table 2.2 – Sustainable mobility narratives

Strategy	Agents		
	Experts	Users	Firms
Efficiency	Green government	Green purchaser	Clean vehicles
Alteration	Public transport provider	Responsible traveler	Shared mobility
Reduction	Compact city	Essential life	Travelling electrons[25]

Source: Adapted from Holden et al. (2020, p. 3).

Holden et al. (2020) also combined the main aspects of these narratives to create three 'Grand Narratives' that, according to them, would allow meeting sustainable urban mobility in the next 10 to 20 years. Each 'Grand Narrative' builds on a different strategy, combining the actions of the various agents and allowing the coordination of varying levels of decision making. Therefore, the *low mobility societies* grand narrative is a combination of compact city, essential life, and travel electrons. *Public transport 2.0* is composed of public transport provider, responsible traveler, and shared mobility.

[25] Travelling electrons refer to the use of communication and information technologies to avoid travels. Therefore, it would be possible "to let electrons travel instead of people" (HOLDEN et al., 2020, p. 5).

Electromobility is the combination of green government, green purchaser, and clean vehicles.

None of the authors cited before indicated autonomous vehicles as one of the main options to achieve sustainable urban mobility, probably because this technology is still not as advanced as the others. Nonetheless, this technological solution attracts considerable attention from researchers, automakers, the media, and the public (SOVACOOL; AXSEN, 2018). Incumbents from the automobility ST-regime understand that autonomous vehicles will play a significant role in future urban mobility. It is the fastest growing technology in the automotive industry, with a high degree of innovation (LANG; MOHNEN, 2019). Most automakers are investing in fully automated vehicles, and many current vehicle models already offer drivers some level of automation (MARLETTO, 2019). Besides, many 'outsiders' of the urban mobility ST-system are also investing in developing fully autonomous cars, such as Google. For all these reasons, autonomous vehicles are an alternative that should not be ignored.

Therefore, building on the studies presented, it is possible to assume that the main alternatives to the sustainable urban mobility transition are (NYKVIST; WHITMARSH, 2008; BLACK, 2010; GEELS, 2012; XENIAS; WHITMARSH, 2013; MARLETTO, 2014, 2019; MORADI; VAGNONI, 2018; HOLDEN et al., 2020): (i) biofuels, (ii) shared vehicles; (iii) integrated public transport; (iv) compact cities; (v) information and communication technologies (ICT); (vi) automated vehicles; and (vii) electric vehicles.

Finally, it is important to call attention to two points. First, many of these alternatives to achieve sustainable urban mobility can be unsustainable if not used properly. They can reduce congestion, GHG emissions, and air and noise pollution but, at the same time, exacerbate socio-spatial inequalities and urban segregation (SÁ et al., 2019). Sustainable mobility projects may be driven by vested interests, which may cause unexpected and socially undesirable outcomes (BERGER et al., 2014). For example, autonomous vehicles can encourage longer commutes, inducing increased fossil fuel consumption and urban sprawl, if not coupled with other technologies and specific policies (SOVACOOL; AXSEN, 2018; MARLETTO, 2019).

Second, transport modes' diversity is critical to attain long-term sustainable urban mobility (BLACK, 2010). As already stated, there is no single solution to the urban mobility ST-system unsustainable patterns. It is not a matter of selecting the best alternative, instead it is necessary to make the best use of all the available options, taking advantage of the synergies between them (HOLDEN; GILPIN; BANISTER, 2019).

Besides, promoting multiple gradual and joint changes can have a more significant impact on urban mobility than investing in a single disruptive technology (GEELS, 2018b). Therefore, policy solutions should promote diverse niche innovations, encompassing technologies, services, and institutions (NYKVIST; WHITMARSH, 2008).

2.2.1 Electric cars

Although the hype around EVs increased in the 2010s, this is not a new technology. It is an invention of the 19th century. There is no agreement about who created the first EV, as many inventors in Europe and the USA were working on it simultaneously. Some authors credit this invention to the Hungarian engineer Ányos Jedlik, who developed a small-scale model car powered by an electric motor in 1828 (CHAN, 2013). Other authors affirm that the credit should be given to Scottish inventor Robert Anderson, who developed the first prototype electric-powered carriage between 1832 and 1839 (SPERLING, 1995, 2018; IEA, 2013). The development of EVs accelerated after the invention and improvement of the rechargeable battery by Frenchmen Gaston Planté and Camille Faure between 1859 and 1881 (SPERLING, 1995; CHAN, 2013). In the last two decades of the 19th century, many different EV models were presented in the UK, the USA, France, and Germany (CHAN, 2013).

The first commercial application of EVs was as a fleet of taxis in New York City in 1897. At this point, many EV manufacturers emerged in the USA and Europe, such as Baker Electric and Columbia Electric (CHAN, 2013; IEA, 2013). By 1900, EVs had 38% of the automobile market share, while steam automobiles and ICEV had 40% and 22%, respectively (BLACK, 2010). However, with the Ford Model T introduction in 1908, which cost half the EV's price, the EVs and steam automobiles started to decline (SPERLING, 1995). Besides, battery technology was not evolving as fast as gasoline vehicles technology, and gasoline was cheaper than electricity. Therefore, by the second half of the 1910s, ICEV cost much less, had a longer range and better performance, and were cheaper to ride than an EV (SPERLING, 1995, 2018; CHAN, 2013). In 1915, EVs had only 2% of the automobile market share, and they had disappeared entirely from the market by 1935 (SPERLING, 1995, 2018; IEA, 2013).

EVs only received some attention again in the 1960s due to concerns about air pollution in the USA and the desire to reduce the dependence on oil imports in Japan (SPERLING, 1995; BLACK, 2010). However, car manufactures in both countries only developed prototypes and sold a few units to niche markets. EVs were never mass-produced (BLACK, 2010). The Oil crisis in the 1970s also gave EVs some momentum (CHAN, 2013), and GM even announced the plan to produce EVs commercially. Yet, as the oil prices decreased in the 1980s, this plan was abandoned (BLACK, 2010). Nonetheless, EVs were used in some specific applications worldwide during the 20th century, such as the electric milk delivery trucks in the UK (BLACK, 2010).

However, it was only in 1990, when the California Air Resources Board (CARB) required that 2% of the new car sales of all major automakers[26] in California be zero-emission vehicles (ZEVs) by 1998 and 10% by 2003, that EVs were taken serious again (TILLEMANN, 2015; SPERLING, 2018). This decision motivated a series of investments in EVs, not only in the USA but also in some European and Asian countries (BLACK, 2010; TILLEMANN, 2015; SKJØLSVOLD; RYGHAUG, 2020). However, just around 2,000 EVs were sold in California by 2003. This poor result was the combination of lack of effort from the car manufactures, pressures from the fossil fuels sector, and George W. Bush's election[27] in 2000 (TILLEMANN, 2015; SPERLING, 2018). Nonetheless, Sperling (2018) argued that the main reason for EVs' failure at the beginning of the 21st century was the same problem as 100 years before: poor battery performance.

Many companies and scientists, including renowned figures such as Thomas Edison, invested a lot of time and money trying to advance batteries since the 1890s. However, the first significant improvement came only in the 1990s, with the nickel-metal-hydride battery development (SPERLING, 2018). But it was only with the development of the lithium-ion battery in the 2000s that EVs had, for the first time, a power source with high energy density, good durability, and reasonable cost (TILLEMANN, 2015; SPERLING, 2018). Further improvements and mass production have considerably decreased batteries' costs, especially in the second half of the 2010s (SPERLING, 2018). The expectation is that prices will continue to fall well beyond 2030 (IEA, 2020).

In the 19th and early 20th centuries, EVs were all battery electric vehicles (BEV). Nonetheless, EVs now encompass a few different technologies besides BEVs: plug-in hybrid electric vehicles (PHEV), hybrid electric vehicles (HEV), and fuel cell electric vehicles (FCEV) (IEA, 2020). BEVs use an electric powertrain and are only powered by

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[26] CARB considered 'major automakers' those selling more than 35,000 cars a year in California (SPERLING, 1995).

[27] Bush's administration discontinued most of the initiatives of the previous administration to encourage the development of EVs (TILLEMANN, 2015).

batteries. Thus, their range depends on the battery capacity (UN-NOOR et al., 2017). These vehicles are recharged by plugging them into an electric charger and have zero pipeline GHG and air pollutant emissions (OFFER et al., 2010; GATON, 2018).

HEVs were the first EVs introduced to the market in the 1990s (GATON, 2018). They combine an internal combustion engine with an electric powertrain and a battery. The internal combustion engine is used at higher speeds, while the electric powertrain and battery are used at lower speeds (UN-NOOR et al., 2017). If the HEV needs more power than what the internal combustion engine is providing, the battery can be used to supply it (BAYINDIR; GÖZÜKÜÇÜK; TEKE, 2011). HEVs are only refueled by fossil fuels and cannot be plugged into an electric charger (GATON, 2018). The battery is recharged by the internal combustion engine when the power requested by the car's transmission is lower than the internal combustion engine output (BAYINDIR; GÖZÜKÜÇÜK; TEKE, 2011). PHEVs are HEVs that use electric propulsion as the primary drive force (UN-NOOR et al., 2017). They have a larger battery and a smaller internal combustion engine than HEVs (GATON, 2018). The internal combustion engine is used to increase the vehicle's range, recharging the battery when its charge is low (UN-NOOR et al., 2017; GATON, 2018). PHEVs battery can also be recharged by plugging the vehicle in an electric charger (GATON, 2018).

Fuel cell electric vehicles have some similarities with battery electric vehicles: they have no internal combustion engine, do not emit any pipeline air pollutant, and use an electric powertrain (OFFER et al., 2010). However, instead of a battery, FCEVs are powered by fuel cells, which usually use hydrogen as the fuel. Chemical reactions in the fuel cell produce the electricity used to feed the powertrain (UN-NOOR et al., 2017; GATON, 2018). These cars are refueled in hydrogen filling stations, and this process takes almost the same time as refueling an ICEV (UN-NOOR et al., 2017). Recent trends in the EV market indicate that plug-in vehicles (BEVs and PHEVs) have become the mainstream EV technology[28] (UN-NOOR et al., 2017; IEA, 2020). These trends also point out that BEVs might become the dominant EV technology in the near term, although FCEVs might challenge them in the long term (IEA, 2020).

In the 1890s and 1900s, EVs were appreciated because they were cleaner, quieter, and easier to drive than ICEVs (CHAN, 2013). Modern EVs maintain all of these qualities and have massively improved since the 1990s (SPERLING, 2018). For the first time since

[28] For this reason, the thesis will focus on plug-in vehicles, BEVs and PHEVs, and, therefore, the term EV is used to refer to BEVs and PHEVs, unless otherwise stated.

the beginning of the 20th century, EVs can compete with ICEVs in terms of performance and price (TILLEMANN, 2015; SPERLING, 2018).

Nonetheless, an EV is still more expensive to buy than an ICEV. However, when the total cost of ownership is considered, including fuel expenses and purchase costs, EVs are already competitive with ICEVs in many countries (IEA, 2020). Although this competitiveness is due to EV subsidies, it should be emphasized that ICEVs also largely benefit from subsidies (SPERLING, 2018). According to the International Monetary Fund, petroleum subsidies totaled U$ 2.1 trillion in 2017 (COADY et al., 2019). Moreover, EVs offer a series of other benefits compared to ICEVs, which can address many of the unstainable patterns of urban mobility described in Section 2.2.

The main advantage of EVs over ICEVs is that they have considerably lower GHG emissions over their life cycle[29]. According to the IEA (2019c), PHEVs and BEVs life cycle GHG emissions are, on average, approximately 25 tCO_2eq. HEVs and FCEVs have slightly higher life cycle GHG emissions, 27.5 tCO_2eq, while ICEVs emissions are around 35 tCO_2eq (IEA, 2019c). Nonetheless, EVs, especially BEVs, have higher GHG emissions in the production phase than ICEVs due to the emissions associated with the extraction of the rare elements used in manufacturing the battery packs (EUROPEAN ENVIRONMENT AGENCY, 2018; IEA, 2019c). GHG emissions in the use phase of EVs are much lower than ICEVs. Therefore, the breakeven point when EVs start having lower life cycle GHG emissions than ICEVs begins when the vehicle mileage reaches between 10,000 miles and 60,000 miles (IEA, 2019c). This variation is related to the power system (BEV, PHEV, FECV, or HEV), battery chemistry, and electricity mix of the country where the EV will be used (IEA, 2019c).

The electricity generation mix has a considerable impact on the GHG emissions savings of EVs. Pero, Delogu, and Pierini (2018) estimated the life cycle GHG emissions of BEVs and ICEVs considering three different electricity mixes: the Norwegian, the Polish, and the average EU. They indicated that a BEV's life cycle GHG emissions are 10.2 tCO_2eq in Norway, 26.2 tCO_2eq in the EU, and 50.2 tCO_2eq in Poland, while they estimated 47.5 tCO_2eq life cycle GHG emissions for an ICEV (PERO; DELOGU; PIERINI, 2018). Therefore, in Poland, where 78% of electricity generation comes from coal (IEA, 2019b), BEVs life cycle GHG emissions are higher than those of ICEVs.

[29] Full life cycle from resource extraction ('cradle') to the use phase and disposal phase ('grave'), including all EV components, such as the battery and powertrain.

However, Burchart-Korol et al. (2018) estimated that EVs life cycle GHG emissions in Poland are 3% lower than those of ICEVs.

In China, where the electricity mix is slightly less based on coal (66%) than Poland and renewables have higher participation in the mix (26%) (IEA, 2019b), BEVs and PHEVs life cycle GHG emissions are, respectively, 17 to 25% and 2 to 7% lower than those of ICEVs (YANG et al., 2021; ZENG et al., 2021). Spain's electricity mix has a high participation of renewable (37%) and nuclear (20%) sources, and only 14% of coal and 21% of natural gas (IEA, 2019b). BEVs and HEVs in Spain have life cycle GHG emissions of 48% and 15% lower than those of ICEVs (PUIG-SAMPER NARANJO et al., 2021). In Brazil, where more than 80% of electricity comes from renewable sources (EPE, 2020a), BEVs and PHEVs life cycle GHG emissions are, respectively, 48% and 17% lower than ICEVs[30] (DE SOUZA et al., 2018).

EVs can considerably contribute to reduce local air pollution (IEA, 2019c). The main objective of many policies to promote EVs is improving urban air quality. The CARB's 'ZEV rule' of 1990 aimed to reduce California's air pollution, especially in Los Angeles, and not to reduce GHG emissions (TILLEMANN, 2015; SPERLING, 2018). Reducing air pollution is also the leading purpose of China's public policies to stimulate EV sales (SPERLING, 2018). BEVs have a significant advantage over ICEVs and other EVs in reducing local air pollution because they have zero tailpipe emissions.

Most EVs emit less air pollutants during use than ICEVs (EUROPEAN ENVIRONMENT AGENCY, 2018; IEA, 2019c). However, even BEVs emit air pollutants during their use due to road, tire, and brake wear (EUROPEAN ENVIRONMENT AGENCY, 2018). Besides, there are emissions of many air pollutants over the life cycle of an EV. These emissions mainly happen during the production phase and to generate the electricity that will charge the EV (MITROPOULOS; PREVEDOUROS, 2015).

The emissions of air pollutants NO_x, SO_2, PM_{10}, and $PM_{2,5}$ over the life cycle of an EV can be 1.1 to 2.5 times higher than that of an ICEV (MITROPOULOS; PREVEDOUROS, 2015; RANGARAJU et al., 2015; WU; ZHANG, 2017; SHI et al., 2019; YANG et al., 2021). These emissions mainly occur in the production phase,

[30] In Brazil, the use of E27 gasoline, a mixture with 73% gasoline and 27% hydrous ethanol considerably reduces the GHG emissions of ICEVs in comparison to other countries (DE SOUZA et al., 2018). This is why the reduction in GHG emissions by BEVs in Brazil are not greater than in Spain, despite Brazil's less carbon-intensive electricity mix.

especially during the manufacturing of the battery pack. This component's production accounts for 17% to 42% of NO_x, 29% to 68% of $PM_{2,5}$ and 34% to 55% of SO_2 emissions over the life-cycle of an EV (YANG et al., 2021).

The electricity mix also has a significant impact on NO_x, SO_2, and PM_{10} emissions. Increasing the use of renewable or nuclear sources in the electricity mix can make the EVs emissions of these pollutants lower than those of ICEVs (WU; ZHANG, 2017; SHI et al., 2019; YANG et al., 2021). For example, the EVs life cycle emissions of NO_x are lower than those of ICEVs in Brazil, Belgium, and France. Besides, the NOx, SO_2, and PM_{10} emissions by EVs are significantly lower in these countries than in nations with more carbon-intensive electricity mix, such as China, India, and the USA (RANGARAJU et al., 2015; WU; ZHANG, 2017).

Nonetheless, EVs emit much less NMVOC, NO_x, PM_{10}, and $PM_{2,5}$ during their use than ICEVs (WU; ZHANG, 2017; SHI et al., 2019; YANG et al., 2021). Therefore, shifting from ICEVs to EVs can considerably improve urban areas air quality if EV's factories and electric power plants, especially coal-fired and gas-fired plants, are located far from these areas. In this case, there is a shift of the pollution sources from urban (the cars) to non-urban areas (the factories and power plants) and, possibly, an increase in the dispersion of these sources (JOCHEM; DOLL; FICHTNER, 2016; EUROPEAN ENVIRONMENT AGENCY, 2018). Besides, since EVs emit less air pollutants than ICEVs during use, the greater the car's mileage, the greater the advantage of EVs over ICEVs (SYRÉ; HEINING; GÖHLICH, 2020).

Soret, Guevara, and Baldasano (2014) estimated that substituting 40% of Madrid and Barcelona's car fleets to EVs would reduce local NO_x pollution in these cities by 17% and 11%, respectively. This change would also mitigate PM_{10} and $PM_{2,5}$ pollution in the cities. Hooftman et al. (2016) indicated that ICEVs' contribution to morbidity and health damages associated with local air pollution in Belgium is two to ten times higher than that of EVs.

EVs are quieter than ICEVs at speeds below 30 km/h because the electric motor does not make mechanical noise like an internal combustion engine (CAMPELLO-VICENTE et al., 2017). For speeds over 30 km/h, the rolling noise caused by the attrition between the tire and the road starts to surpass the engine noise. This rolling noise is the same for EVs and ICEVs (EUROPEAN ENVIRONMENT AGENCY, 2018). Above 50 km/h, the difference between the noise of an EV and an ICEV is imperceptible to the human ear (CAMPELLO-VICENTE et al., 2017). Therefore, EVs' impact on noise reduction is more evident in urban areas, where speeds are usually slower than in peri-urban and rural areas and highways. Campello-Vicente et al. (2017) estimated that substituting ICEVs with EVs can reduce in 10% the people exposed to road noise above 65 dB[31].

Although the quieter ride of EVs helps reduce noise pollution, it might also increase crash fatalities and injuries. Karaaslan et al. (2018) used computer models to simulate EVs' impact on traffic safety and concluded that these vehicles increase the likelihood of an accident involving pedestrians by 25% compared to ICEVs. The risks are exceptionally high in noisy environments and low light conditions. However, equipping EVs with warning sounds can improve pedestrians' detectability to a level even higher than ICEVs without turning them into annoying noise sources (POVEDA-MARTÍNEZ et al., 2017; STEINBACH; ALTINSOY, 2019).

The demand for various non-renewable resources is considerably higher for the manufacture of EVs than ICEVs. UBS (2017) estimated that producing an EV demands 70% more aluminum and 80% more copper than manufacturing an ICEV. Besides, rare elements, such as nickel, cobalt, lithium, and rare earths, are used in EVs and not in ICEVs (UBS, 2017). According to Hawkins et al. (2013), the production of an EV requires two times more aluminum and 4.5 times more copper than an ICEV. On the other hand, UBS (2017) and Hawkins et al. (2013) indicated that EV manufacturing requires approximately 70% less iron and 7% less steel than ICEVs.

Most life cycle assessments (LCA) also indicate that EVs have a more significant impact on resource depletion than ICEVs (DOLGANOVA et al., 2020). Pero, Delogu, and Pierini (2018) indicated that the resource depletion impact of an EV is 32% higher than an ICEV in Europe due to the EV's powertrain dependence on rare elements. Bouter et al. (2020) estimated that BEVs and PHEVs in France have, respectively, 152% and 57% more impact on the depletion of mineral resources than ICEVs (BOUTER et al., 2020). Helmers, Dietz, and Weiss (2020) estimated that the effect on mineral resource depletion of an EV produced and used in the EU is three times higher than an ICEV, mainly due to the elements required to manufacture the battery pack. Considering cars produced and used in China, Zeng et al. (2021) estimated that BEVs and PHEVs have, respectively, 126% and 82% higher impacts on metal depletion than ICEVs.

[31] This level of noise exposure increase the risk of cardiovascular diseases, sleep disturbances, and mental illness (BOER; SCHROTEN, 2007).

However, it must be emphasized that the results of these LCAs do not consider the depletion of fossil fuels as part of the depletion of mineral (or metal) resources. Most LCAs show that the impact of ICEVs on fossil fuel depletion is approximately 40% higher than that of EVs (DOLGANOVA et al., 2020; HELMERS; DIETZ; WEISS, 2020; ZENG et al., 2021). Therefore, when fossil fuel depletion are considered together with mineral resource depletion in the same category of analysis, most LCAs indicate that EVs have an equal or lower impact on resource depletion than ICEVs (CHOMA; UGAYA, 2017; DE SOUZA et al., 2018; DOLGANOVA et al., 2020). Besides, improvements in EVs' recycling process, especially of the battery packs, can reduce these vehicles' impact on resource depletion (HARPER et al., 2019). Nonetheless, the reuse and recycling of the batteries is a complex process that still requires better industrial recycling techniques, viable reuse applications, and regulations to ensure that all recyclable materials are recovered (SKEETE et al., 2020).

Substituting ICEVs with EVs would not reduce traffic congestions. Nonetheless, there are some indirect positive impacts of EVs in these situations. First, the concentrated emissions of air pollutants and GHG during a traffic congestion would be reduced (JOCHEM; DOLL; FICHTNER, 2016). For example, some Chinese cities limit the circulation of ICEVs during peak hour traffic to reduce the emissions of air pollutants, but EVs are not subjected to this restriction (WANG; PAN; ZHENG, 2017). Second, the noise pollution from traffic congestions would also be significantly diminished. Cars usually travel at speeds below 50 km/h during congestions. The noise pollution from vehicles in this situation is mostly engine noise, which is much lower in EVs than in ICEVs (VERHEIJEN; JABBEN, 2010). These two positive impacts would significantly improve people's quality of life, especially in highly congested cities such as São Paulo, Los Angeles, and Istanbul.

EVs and ICEVs share the same transport infrastructures, such as roads, highways, bridges, and tunnels. Therefore, the impacts of the construction and maintenance of these infrastructures will be the same for both types of vehicles. Nevertheless, the transition from ICEVs to EVs requires the implementation of a charging infrastructure for the EVs. Although this infrastructure may have lower environmental impacts than the fueling infrastructure for ICEVs, the latter is already installed. This infrastructure's impacts on the environment will not be reversed with its phase out. Therefore, when replacing an ICEV with an EV, there is an additional and non-neglectable environmental cost associated with the need to implement the charging infrastructure (KABUS et al., 2020).

Regarding unequal access to mobility, without the appropriate policies, the transition to EVs can exacerbate the existing inequalities between those who can afford a car and those who cannot (SPERLING, 2018; SOVACOOL et al., 2019b). ICEVs are already too expensive for many people (SPERLING, 2018), especially in developing countries. EVs' higher initial cost makes them more unaffordable than ICEVs (SOVACOOL et al., 2019b), even though EVs total cost of ownership is equal to or lower than that of ICEVs (IEA, 2020). Moreover, some policies used to lower the initial cost of EVs, such as tax rebates, benefit high-income citizens who pay high taxes but are less useful for middle and low-income citizens (TALANTSEV, 2017; ORTAR; RYGHAUG, 2019).

Besides, policies to promote EVs can disproportionally benefit high-income citizens and lead to an unjust distribution of the burdens and costs of EVs among society. For example, increasing taxes on ICEVs and fossil fuels to finance subsidies for EVs, such as tolls exemptions, charging discounts, and insurance reductions, unfairly transfer part of the cost of EVs to the taxpayers who do not have an EV (MULLEN; MARSDEN, 2016; TALANTSEV, 2017; SOVACOOL et al., 2019a). Moreover, financing EVs subsidies may also reduce the public resources available to invest in mobility alternatives more accessible to low-income citizens, such as public transport (HENDERSON, 2020).

The transition to EVs may also exacerbate inequalities between urban and non-urban households. People living in rural areas often do not have access to a reliable electricity network and may need vehicles with a longer range than what current EVs offer. This situation usually can make EVs not suitable for rural households (ORTAR; RYGHAUG, 2019; SOVACOOL et al., 2019a). Besides, charging infrastructure is concentrated in core urban areas, making it less accessible to rural and peri-urban households (HENDERSON, 2020).

Contrary to these assumptions, Rubens, Noel, and Sovacool (2018) and Chen et al. (2020) indicated that the living area (urban, peri-urban or rural) has no significant impact on consumer's decision to buy an EV in Nordic countries[32]. Moreover, Newman et al. (2014) suggested that EVs can be more suitable to non-urban than urban households. The formers have space to charge the EV at home. Their daily commuter distance is compatible with EVs range, and they drive more mileage per year than urban households,

[32] Denmark, Finland, Iceland, Norway and Sweden.

which makes the relationship between operational and purchasing costs better (NEWMAN et al., 2014).

Finally, the shift of the air pollution emissions from the urban areas (cars) to non-urban areas (factories and power plants) can also be considered an unfair consequence of substituting ICEVs by EVs (AHN; KIM; KWON, 2018). The air pollution is transferred from urban to non-urban areas, disproportionately impacting these areas. Besides, the residents are often unaware of this situation (AHN; KIM; KWON, 2018).

However, the transition to EVs can positively impact the unequal access to mobility if policymakers adopt a more reflexive governance focused on promoting mobility justice (MULLEN; MARSDEN, 2016). They must avoid regressive EV subsidies, support the development of lower-cost EVs, design inclusive policies that give larger subsidies to low-income citizens, couple the transition to EVs with a parallel shift to renewable energy, and guarantee the installation of charging stations in low-income neighborhoods and non-urban areas (SPERLING, 2018; SOVACOOL et al., 2019b).

EVs have advantages not only over ICEVs, but also over other urban mobility alternatives. Regarding GHG emissions, EVs are competitive with public transport alternatives, such as buses and trains (SPERLING, 2018; HELMERS; DIETZ; WEISS, 2020). According to the UK Department for Business, Energy & Industrial Strategy (BEIS), the GHG emission factor of buses and trains is approximately 104 gCO_2eq/passenger.km and 41 gCO_2eq/passenger.km, respectively (BEIS, 2020). Considering the EU average occupancy rate of 1.57 for private cars (CASTELLANI et al., 2017), EVs' GHG emission factor is approximately 38 gCO_2eq/passenger.km for BEVs and 73 gCO_2eq/passenger.km for PHEVs and HEVs (BEIS, 2020). ICEVs emission factor is 115 gCO_2eq/passenger.km considering the same occupancy rate (BEIS, 2020). Nonetheless, the emission factor is reduced if two passengers or more are transported in the car (see Table 2.3).

Table 2.3 – GHG emission factor (gCO_2eq/passenger.km) for different occupancy rates and vehicle power systems

Vehicle type	Vehicle occupancy rate (passenger/vehicle)				
	1	1.57	2	3	4
	GHG emission factor (gCO_2eq/passenger.km)				
BEV	60	38	30	20	15
PHEV	115	73	58	38	29

HEV	115	73	57	38	29
ICEV (gasoline)	181	115	90	60	45

Source: developed by the author based on BEIS (2020)

The GHG emission factor of BEVs is lower than that of buses even when BEVs transport only one person. BEVs' emission factor is also lower than a train factor if they are transporting at least two people. PHEVs and HEVs, have lower GHG emission factors than conventional public transport if transporting three or more passengers. BEVs GHG emission factor advantage over public transport is even more significant in countries with low occupancy rates for public transportation, such as the USA (SPERLING, 2018; DAVIS; BOUNDY, 2021). BEVs' edge over public transport should also be more significant in countries with similar vehicle occupancy rates but less carbon-intensive electricity mix than the UK, such as Brazil[33]. Moreover, Cuéllar, Buitrago-Tello, and Belalcazar-Ceron (2016) estimated that BEVs in Bogotá emit less NO_x and $PM_{2,5}$ during their use than the buses used in the city public transport system, including the diesel-powered BRT. The only exception is the electric BRT.

However, cars using biofuels, such as ethanol, have considerably lower GHG emissions over their life cycle than EVs. According to de Souza et al. (2018), cars fueled by ethanol in Brazil have life cycle GHG emissions 55% and 148% lower than those of BEVS and PHEVs, respectively. Hoque et al. (2019) estimated that the life cycle GHG emissions of cars fueled by E65 fuel (65% ethanol and 35% gasoline) are 17% and 46% lower than those of BEVs and PHEVs in Australia. However, biofuels vehicles have considerably higher impacts than EVs regarding water use, land use, eutrophication potential, acidification potential, and photochemical oxidation potential (DE SOUZA et al., 2018; HOQUE et al., 2019).

Other alternatives to improve urban mobility, such as shared mobility and automated vehicles (AV), also do not have a better impact in reducing GHG emissions than EVs if these solutions are based on ICEVs. For example, Table 2.3 shows that an ICEV carrying four passengers has a GHG emission factor higher than that of an EV (if Europe's private car average occupancy rate is considered). Nonetheless, shared mobility can significantly reduce the number of vehicles necessary to meet the demand for mobility, reducing congestion and GHG emissions associated with car production (SPERLING, 2018).

[33] The occupancy rate for private cars in Brazil is 1.5 (ANTP, 2020a).

There are different levels of vehicle automation. The Society of Automotive Engineers defined six levels of driving automation[34], varying from level 0 (no automation) to 5 (full automation). Levels 1 and 2 require a driver and only have supporting features. Level 3 does not require a driver all the time, but the driver must be ready to drive if needed. Level 4 is fully automated under limited conditions, but a driver will be required if these conditions are not met. Level 5 is a fully autonomous vehicle, which does not require a driver in any situation. Each of these automation levels has different impacts on the unsustainable patterns of urban mobility, but most studies on AVs usually consider fully autonomous (level 5) vehicles. Besides the level of automation, autonomous cars can also be connected to other vehicles through communications systems. These are called connected and automated vehicles (CAV).

Many studies indicate that AVs powered by fossil fuels have higher life cycle GHG and air pollutant emissions than EVs with no automation (e.g., Greenblatt and Saxena, 2015; Wang et al., 2018; Patella et al., 2019; and Stogios et al., 2019). Moreover, fully automating ICEVs can increase the emissions of this type of car by 2.5% to 42%, depending on factors such as the driving behavior of the automated system and the average distance the car travel without passengers (WANG et al., 2018; STOGIOS et al., 2019; SALEH; HATZOPOULOU, 2020). These same factors can also make fully automated BEVs have higher GHG and air pollutants emissions than conventional BEVs (SALEH; HATZOPOULOU, 2020). Nonetheless, in optimal conditions, electric AVs could reduce GHG emissions by 60% compared to ICEVs with no automation (STOGIOS et al., 2019).

CAVs based on internal combustion engines also have higher life cycle GHG and air pollutant emissions than EVs with no automation. According to Gawron et al. (2018), a connected and automated ICEV would emit at least 56% more GHG than a conventional BEV. Besides, an internal combustion engine CAV emissions would be 2.3 times higher than those of an electric CAV (KEMP et al., 2020). The emissions of NO_2 would also be considerably lower if an urban mobility system with 100% electric CAVs is adopted (TU et al., 2019). However, as is the case with AVs, substituting ICEVs with electric CAVs can also increase GHG and air pollutants emissions depending on the operational conditions adopted (BROWN; DODDER, 2019).

[34] See https://www.sae.org/news/2019/01/sae-updates-j3016-automated-driving-graphic for more information on the Society of Automotive Engineers levels of driving automation.

Although AVs and CAVs may harm the reduction of GHG and air pollutants emissions, most studies predict positive impacts in other unsustainable patterns of urban mobility. AVs can significantly reduce congestions, consequently increasing the average speed by 51% and reducing the average travel time by 31% (PATELLA et al., 2019). AVs and CAVs can also considerably reduce crash fatalities and injuries. However, the main benefits may only be achieved when the whole vehicle fleet, including cars, buses, trucks, and others, is fully automated (SPERLING, 2018).

Most studies about AVs and CAVs indicate that the potential of these technologies to make urban mobility more sustainable is maximized if combined with EVs (GAWRON et al., 2018; WANG et al., 2018; PATELLA et al., 2019; STOGIOS et al., 2019; SALEH; HATZOPOULOU, 2020). EVs catalyze the environmental results of the other main alternatives to achieve sustainable urban mobility. Without electric powertrains, automated and shared vehicles are not much better than current ICEVs in reducing GHG emissions and local air and noise pollution. Public transport would also benefit from electrification. For example, electric BRT emissions of GHG, NO_2 and $PM_{2,5}$ are almost 90% lower than those of diesel BRT in Colombia (CUÉLLAR; BUITRAGO-TELLO; BELALCAZAR-CERON, 2016). EVs could also be a great option to be used in combination with compact city designs and communication and information technologies. These two alternatives aim to reduce mobility needs, leading to fewer and shorter trips, which would be a good fit for EV and reduce range anxiety.

Many authors (e.g., Sperling, 2018; Axsen and Sovacool, 2019; and Whittle et al., 2019) defend that a genuinely sustainable urban mobility system can only be achieved by a combination of EVs, CAVs and shared vehicles. Shared autonomous electric vehicles can reduce GHG emissions and the depletion of non-renewable resources, decrease local air and noise pollution, minimize crash fatalities and injuries, diminish the demand for transport infrastructure and reduce congestion (SPERLING, 2018; AXSEN; SOVACOOL, 2019). If properly governed, the combination of these three technologies can also reduce urban mobility costs to values lower than any other transportation mode, including public transport, and make urban mobility more accessible to all people (SPERLING, 2018). Further social and environmental benefits could be achieved if shared autonomous electric vehicles were combined with reduced mobility needs through communication and information technologies or compact city designs (WHITTLE et al., 2019).

Therefore, EVs will most certainly have a role in the transition to sustainable urban mobility, as the primary 'tool' of this transition or as a complementary one. EVs can be the technology that will make the private car ST-regime less harmful to the environment, especially considering climate change, or be part of a more profound change in the entire urban mobility ST-system (KANGER et al., 2019). Either way, a transition from ICEVs to EVs will cause many functional and symbolic changes to both automobility and urban mobility, which will impact each consumer and society as a whole (SOVACOOL; AXSEN, 2018). It is just the magnitude and the reach of these changes that will increase if EVs are combined with other alternatives to achieve sustainable urban mobility.

In summary, EVs are more sustainable than ICEVs, and most alternatives to make urban mobility sustainable, when the focus is on reducing GHG emissions. EVs also emit less pollutants, such as NMVOC, NO_x, PM_{10}, and $PM_{2,5}$, during their use phase than ICEVs. Besides, EVs are considerably quieter than ICEVs, which can positively impact noise pollution, notably in large cities. However, EVs do not have such a positive impact in other unsustainable patterns of urban mobility. As detailed in this section, the impact of EVs on the depletion of non-renewable resources other than fossil fuels is greater than ICEVs. EVs could also increase crash fatalities and injuries and exacerbate the existing inequalities between those who can afford a car and those who cannot. Besides, transitioning from ICEVs to EVs would not reduce congestion or the impacts of the transport infrastructure in the environment. Nonetheless, EVs can have a positive impact in almost all unsustainable patterns of urban mobility if combined with other alternatives to make urban mobility more sustainable, such as automated vehicles and communication and information technologies. Moreover, these other alternatives have greater synergy with EVs than ICEVs.

3. RESEARCH DESIGN

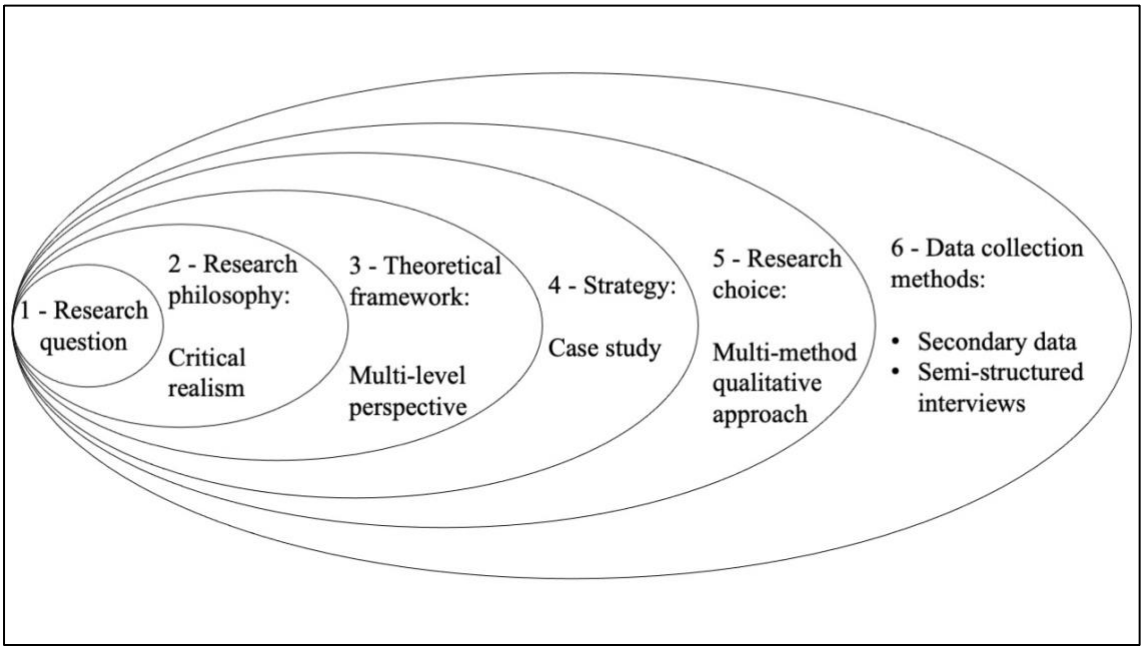
The thesis's research design follows the different layers of the 'transition research onion' developed by Zolfagharian et al. (2019). The 'research onion' is a framework that allows depicting the issues considered when choosing the methods used to address a research question (SAUNDERS; LEWIS; THORNHILL, 2019). Zolfagharian et al. (2019) adapted this framework to contemplate the different methodologies used in transitions studies.

The research question that guides the research form the first layer of the research onion. This question defines what the research will try to discover, explain or answer and sets the research boundaries (SAUNDERS; LEWIS; THORNHILL, 2019). The following layer is the research philosophy, which refers to the epistemological and ontological assumptions that guide method selection and decision-making during the research (LEE; SAUNDERS, 2017; SAUNDERS; LEWIS; THORNHILL, 2019). The third layer is the theoretical framework used in the study. In 'the transition research onion,' a theoretical framework is "any theoretical construct, conceptual framework, analytical tool, heuristic device, analytical framework, concept, or model that guides transition research" (ZOLFAGHARIAN et al., 2019, p. 4). The four main theoretical frameworks of the sustainability transitions field were detailed in Section 2.1.1.

The fourth layer comprises the research strategy, i.e., the researcher's plan to answer his or her research question. It can be considered the methodological link between the research philosophy and the theoretical frameworks on one side and the research methods on the other side (SAUNDERS; LEWIS; THORNHILL, 2019). The research choice forms the fifth layer of the research onion. It refers to the methodological option of using qualitative, quantitative, or mixed methods (SAUNDERS; LEWIS; THORNHILL, 2019). Finally, the last layer refers to the methods and techniques used to gather the data and collect the evidence necessary to answer the research question. The choice of methods used in the research is guided by the choices made in the previous layers of the research design.

The research design of the thesis is shown in Figure 3.1. The choices made for each of these layers will be detailed and explained in the following sections.

Figure 3.1 – Research design of the thesis



Source: Developed by the author

3.1 Research philosophy

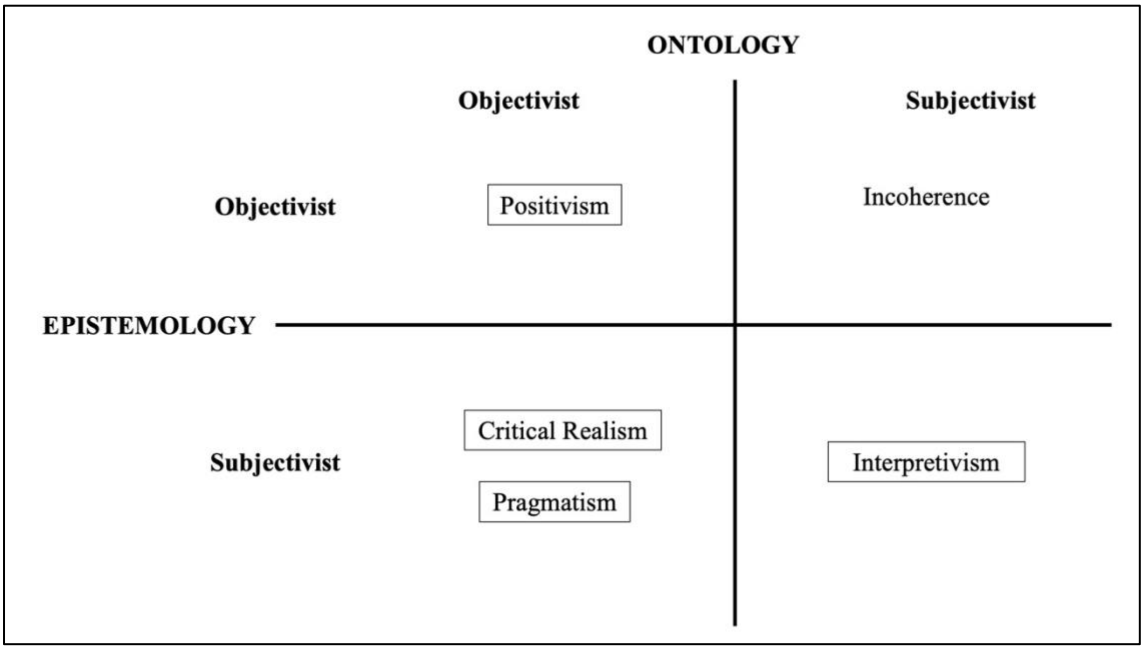
According to the 'transition research onion,' after defining the research question (see Chapter 0), the following step is choosing a research philosophy to guide the study. Having a clear research philosophy is essential to design coherent research and achieve credible results (DANERMARK et al., 2002; SAUNDERS; LEWIS; THORNHILL, 2019). Most studies in transitions' literature do not make their ontological and epistemological assumptions clear, although these assumptions can usually be inferred from the research (ZOLFAGHARIAN et al., 2019). Zolfagharian et al. (2019) indicated that the main research philosophies in transitions' studies are positivism, critical realism, interpretivism, and pragmatism. The ontology and epistemology adopted in the thesis are closer to pragmatism[35] and, mostly, critical realism[36] philosophies, i.e., a pragmatic-critical realist position, as explained next.

[35] *Pragmatism* originated in the late nineteenth century in the works of Charles Peirce, William James and John Dewey, who established *American Pragmatism* as an alternative to Western rationalism (SAUNDERS; LEWIS; THORNHILL, 2019). This philosophy of science understands that "concepts are only relevant in as much as they are relevant for action" (KELEMEN; RUMENS, 2008, p. 40).

[36] *Critical realism* is a philosophy of science pioneered by Roy Bhaskar that combines '*ontological realism*' with '*epistemological relativism*'(JOHNSON; DUBERLEY, 2000; SAYER, 2000). The term '*critical realism*' is actually the elision of Bhaskar's general philosophy of science '*transcendental realism*', which refers to the general ontology he developed from his analysis of scientific practices, and Bhaskar's special philosophy of the human sciences '*critical naturalism*', which refers to his attempt of reorienting the human sciences from *positivist* goals of prediction to *realist* ones of explanation (COLLIER, 1994; BHASKAR, 2011).

The primary ontological assumption adopted in the thesis is that reality, including social phenomena, exists and operates independent of human knowledge of it. This objectivist ontology is compatible with positivism, critical realism, and pragmatism, but not with interpretivism (see Figure 3.2), which assumes a subjectivist ontology, i.e., understands that reality is the result of human cognitive process (JOHNSON; DUBERLEY, 2000; SAUNDERS; LEWIS; THORNHILL, 2019).

Figure 3.2 – Epistemology and ontology of the main research philosophies in transition studies



Source: Developed by the author based on Johnson and Duberley (2000) and Saunders, Lewis and Thornhill (2019)

Regarding epistemology, the main assumption is that human knowledge is socially produced, transient and fallible, which may be called '*epistemological relativism*' (BHASKAR, 2008). This subjective epistemology is in line with interpretivism, critical realism, and pragmatism, but not with positivism's objectivist epistemology (see Figure 3.2), which presupposes theory-neutral empirical observations as the only foundation for knowledge and science as a way of predicting and controlling social and natural events (JOHNSON; DUBERLEY, 2000).

Therefore, the thesis's central ontological and epistemological assumptions are incompatible with positivism and interpretivism but are coherent with a pragmatic-critical realist position. This position is further detailed in the next paragraphs, making explicit the ontological and epistemological positions of pragmatism and critical realism on which it is based.

A fundamental ontology of critical realism is that objects (or entities; e.g., people, organizations, institutions, attitudes, traditions) have causal powers and liabilities (causal properties) that, when triggered, may generate events (SAYER, 1992). These events are what researchers investigate to uncover the structure of the objects studied and to identify and understand their causal powers and liabilities. According to critical realism, structures[37] are internally related elements that generate and constrain objects' causal powers (COLLIER, 1994; SAYER, 2000). Besides, structures are nested within other structures (SORRELL, 2018). Understanding an object's structures and causal properties allows researchers to explain the events (SAYER, 2000; SORRELL, 2018). "Science, then, is the systematic attempt to express in thought the structures and ways of acting of things that exist and act independently of thought" (BHASKAR, 2008, p. 242).

Another essential critical realist ontology is centered on *emergence*. Critical realism assumes that, although more complex structures are composed of less complex structures, these more complex structures have emergent powers, i.e., causal properties irreducible to the less complex structures. In other words, an object or entity may have properties that their components do not have (COLLIER, 1994; SAYER, 2000). A widely used example is that water's constituents do not possess its ability to extinguish fire since both oxygen and hydrogen are highly inflammable. Therefore, a component is not a pure function of the whole and, concomitantly, the whole is not a pure function of its parts (COLLIER, 1994). In this ontology, reality is stratified, with each of its levels having its own emergent powers (SAYER, 2000). This assumption has an epistemological consequence: critical realism refuses any type of reductionism, including atomism[38] and holism[39] (COLLIER, 1994; DANERMARK et al., 2002).

For critical realists, the stratified reality is divided into three overlapping domains: the *real*, the *actual*, and the *empirical* (SAYER, 1992; COLLIER, 1994; BHASKAR, 2008). The *real* is everything that exists, regardless of humans knowledge of it, comprising structures and causal properties of objects (SAYER, 2000). This level

[37] The concept of '*structure*' is different from '*social structure*' (DANERMARK et al., 2002). The critical realist concept of '*social structure*' is detailed in Section 3.2.

[38] Atomism "claims that a reality is only understood when it is resolved into its smallest components" (COLLIER, 1994, p. 117).

[39] Holism claims that "the part is only, and is entirely, explicable in terms of the whole of which its part" (COLLIER, 1994, p. 117).

encompasses the mechanisms of nature, i.e., how things act (BHASKAR, 2008). The *actual* refers to the events resulting from these mechanisms' action if and when they are activated (COLLIER, 1994; SAYER, 2000). The *empirical* only encompasses what can be experienced or observed (SAYER, 2000). The *empirical* is a subset of the *actual*, which, in its turn, is a subset of the *real* (BHASKAR, 2011).

Critical realism distinguishes two types of relations between entities: *contingent* and *necessary*. A *contingent* relation is one that is neither necessary nor impossible. A *necessary* relation is one in which the existence of one part presupposes the other (SAYER, 2000). For example, there is a *necessary* relationship between a teacher and a student since there can be no teacher without a student. On the other hand, the relationship between two students is *contingent*. Nonetheless, the *contingent* relationship may have significant effects. For example, the students may help each other. Besides, *necessary* relations can be asymmetric. In this case, one part is *necessary* for the other but not the contrary (SAYER, 2000). For example, money is *necessary* for the banking system to exist, but money can exist without banks.

This distinction is required to explain the critical realism view of causality. Instead of looking at relations between discrete events (*cause and effect*), critical realists focus on objects' nature and mechanisms. These mechanisms are *necessary* to the object's nature. As a result, if the nature of an object changes, the mechanisms also change (SAYER, 1992; DANERMARK et al., 2002). Moreover, some mechanisms may exist unexercised, which means that a mechanism and its effects are *contingent*. Depending on the conditions, the same mechanism can generate distinct outcomes or may not even be triggered, and different mechanisms can generate the same effect (SAYER, 1992; DANERMARK et al., 2002). Any event is *necessarily* related to the nature of the objects involved but is *contingent* on the conditions in which these objects' mechanisms were activated (SAYER, 1992). As a result, the nature of the objects involved in an event enables what can happen but does not pre-determine what will happen (SAYER, 2000).

One important implication of this assumption is that mechanisms are often unclear from empirical observations. Experiences and observations do not exhaust what could happen because some mechanisms may exist untriggered (SAYER, 1992). In other words, the *empirical* do not exhaust the *real* (BHASKAR, 2011). Therefore, it is impossible to pre-determine future events based only on empirical observations (SAYER, 2000; BHASKAR, 2011). A prediction based solely on the observations of regular successions of events reduces the understanding of causality to the *empirical* level, ignoring the mechanisms that genuinely caused these events at the *real* level (SORRELL, 2018). This assumption means that critical realism rejects positivism's epistemological determinism (JOHNSON; DUBERLEY, 2000).

Concerning the '*epistemological relativism*' adopted by critical realism, it is important to emphasize two points. First, critical realists share with interpretivists the assumption that all knowledge is socially produced but argue that this assumption does not exclude causal explanation. Critical realists assume a more comprehensive conceptualization of causation (SAYER, 2000; DANERMARK et al., 2002; BHASKAR, 2008). Second, critical realists reject *judgmental relativism*[40], i.e., the assumption that all beliefs are equally valid and that there is no reason to prefer one kind of knowledge over another (COLLIER, 1994).

All the ontological and epistemological assumptions detailed so far are mainly related to critical realism. Pragmatism will be considered in the thesis to deal with an epistemological conundrum of critical realism (JOHNSON; DUBERLEY, 2000). Given that critical realism adopts an '*epistemological relativism*' and rejects theory-neutral observational language, how would it be possible to evaluate epistemic constructions developed to explain observed events? Which socially constructed criteria of logic would be used in this evaluation (JOHNSON; DUBERLEY, 2000)?

A solution to this conundrum is proposed by Sayer (1992) using pragmatist ideas. He argued that the realist "admission that all knowledge is fallible does not mean all knowledge is equally fallible" (SAYER, 1992, p. 67). Therefore, theories should be evaluated concerning their *practical adequacy* to the world. In other words, theories need to be 'usable in practice' (SAYER, 2000). A theory will be more 'usable' than another if it better enables us to achieve our goals, ends, and expectations (JOHNSON; DUBERLEY, 2000). Nonetheless, evaluating the 'usability' of theory is in itself a fallible process (JOHNSON; DUBERLEY, 2000).

Acknowledging that a theory has *practical adequacy* does not mean that all its constituent parts are correct or practically adequate (SAYER, 2000). According to Sayer (1992), "it is the structured, differentiated and uneven nature of the world that gives rise to these cognitive possibilities of unevenly developed yet practically adequate knowledge" (SAYER, 1992, p. 78). Thus, it is possible to have distinct and

[40] Collier (1994) criticized this assumption of critical realists, specially Bhaskar (2008), arguing that this restricted form of relativism undermines the characteristic position of relativists because it does not help the 'value-to-facts' argumentation as it was supposed to do.

incommensurable theories that have equal *practical adequacy*. It is also possible to have inconsistent theories with *practical adequacy* and internally consistent and coherent theories that do not have it (SAYER, 2000).

Finally, it should be emphasized that adopting a pragmatic-critical realist position does not mean accepting pragmatic ontologies that are different from critical realist ones. For example, Rorty's (1982) pragmatic assumption that science does not need a philosophy or any particular ontology. As detailed, the philosophical position adopted in the thesis is much closer to critical realism than pragmatism. The pragmatic epistemology is only considered to address a conundrum in critical realism.

3.2 Theoretical framework

The multi-level perspective (MLP) draws upon concepts from many different social theories, notably evolutionary economics (e.g., ST-regimes and niches), sociology of innovation (e.g., technology as social-constructs), and neo-institutional theory (e.g., ST-regimes as semi-coherent set of rules) (GEELS; BERKHOUT; VAN VUUREN, 2016). Therefore, it should not be expected that this theoretical framework's ontological and epistemological assumptions would fully integrate with any philosophical perspective (GEELS, 2010). Nonetheless, McDowall and Geels (2017, p. 46) argued that the MLP "works from a critical realist approach." Indeed, many ontological and epistemological affinities exist between critical realism and the MLP, despite some points of tension (SORRELL, 2018).

Concerning ontology, both critical realism and the MLP understand reality as independent of human knowledge of it and layered (MCDOWALL; GEELS, 2017) in contrast to 'flat ontologies' (SAYER, 2000). Besides, they share the belief that structure governs events' courses (SVENSSON; NIKOLERIS, 2018). However, there are two ontological tensions between critical realism and the MLP. The first issue has been detailed in Section 2.1.1.4.7 and concerns the ambiguous distinction between ST-systems and ST-regimes. As already discussed, from a critical realist perspective, it would be better to drop the ST-regime concept and focus only on the ST-system (SORRELL, 2018).

The second ontological issue refers to the MLP conception of social structure as internal rules dependent on agential recognition based on Gidden's structuration theory (SVENSSON; NIKOLERIS, 2018). This conceptualization is incompatible with critical realism view of social structure as external relations between social entities

(SVENSSON; NIKOLERIS, 2018), encompassing many entities with emergent powers, such as “physical artefacts, material interests, economic incentives and political power” (SORRELL, 2018, p. 47).

Nonetheless, the MLP assimilation and combination of ontologies from different social theories (KÖHLER, 2012) means that it does not rely solely on the structuration theory view of social structure (SORRELL, 2018). For example, ST-systems’ conceptualization encompasses entities external to agents, such as artifacts (GEELS, 2004). Besides, the criticism of the social structure conceptualization in the MLP has already been addressed by some authors. For example, Geels and Schot (2010) and Geels (2020) proposed the use of Archer’s (1982, 1995) morphogenetic approach to better address social structure and agency in the MLP. This social realist explanatory framework conceptualizes agency-structure interactions based on *analytical dualism*[41] instead of structuration theory’s *duality of structure*[42].

Concerning epistemology, both critical realism and the MLP rejects the core assumptions of positivism. The MLP aims to explain ST-transitions by identifying causal mechanisms and patterns in these transitions (MCDOWALL; GEELS, 2017). This aim is coherent with critical realism epistemological views that: (i) the objective of social research is to explain how and why particular phenomena occur (SORRELL, 2018); (ii) this explanation depends on the identification of causal mechanisms and how they work (SAYER, 2000). Besides, the pragmatic-critical realist epistemology assumption that knowledge should be evaluated concerning how successfully it guides action towards the realization of particular objectives (JOHNSON; DUBERLEY, 2000) is aligned with the goal-oriented (towards sustainability) epistemological character of transitions theoretical frameworks (GEELS, 2011).

The central epistemological tension between critical realism and the MLP is that researchers using this framework have the tendency not to emphasize causal explanation to the same extent as critical realists, what makes the MLP more ‘loose’ (SORRELL, 2018). Geels (2011) argued that this ‘looseness’ (or flexibility) of the MLP makes it more adaptable and, therefore, more suitable to analyze the complex dynamics of transitions.

[41] “Analytical dualism is a method for examining the interplay between these strata [structure and agency]; it is analytical precisely because the two are interdependent but it is dualistic because each stratum is held to have its own emergent properties” (ARCHER, 1995, p. 133–134).

[42] According to structuration theory, duality of structure is the proposition that “rules and resources drawn upon in the production and reproduction of social action are at the same time the means of system reproduction” (GIDDENS, 1984, p. 19).

However, this flexibility leads to an issue (from a critical realist point of view). It makes the comparison between the MLP and competing theories more difficult (SORRELL, 2018).

According to Sorrel (2018), another epistemological difference between the MLP and critical realism is their mode of scientific inference. The MLP mainly uses abduction, while critical realism emphasizes that causal mechanisms can only be identified through retroduction (DANERMARK et al., 2002; SORRELL, 2018). However, Ritz (2020) argued that abduction and retroduction are complementary parts in the process of theoretically explaining empirically observed phenomena. Danermark et al. (2002) argued that the differences between abduction and retroduction in concrete research are not clear. Besides, there are methods to combine the MLP with retroduction in the transitions' literature (e.g., Papachristos and Adamides, 2016. See Section 2.1.2).

Despite these ontological and epistemological mismatches between critical realism and the MLP, this theoretical framework is flexible enough to allow any necessary adjustment to make it more compatible with critical realism (SORRELL, 2018). Besides, most of these mismatches have already been addressed in the transitions' literature. Therefore, the MLP is a suitable theoretical framework to be used under critical realism.

Other reasons make the MLP a suitable theoretical framework for the thesis, apart from being compatible with a pragmatic-critical realist position. The MLP is the most used theoretical framework in transitions studies (SOVACOOL; HESS, 2017; ZOLFAGHARIAN et al., 2019) and one of the central frameworks in STRN (GEELS, 2020). This framework allows simplifying, ordering, and analyzing complex transitions, considering technological, political, economic, socio-cultural, and environmental aspects, as detailed in Section 2.1.1.4. Thus, it is a useful tool to analyze and interpret sustainability transitions.

Besides, social research is typically guided by *middle-range theories*, such as the MLP, and not *grand theories*, because the formers offer researchers more indications on how to collect empirical evidence (BRYMAN, 2012). The high levels of abstraction of *grand theories* make it more challenging to implement them in social research. The *middle range theories* act as intermediates between the *grand theories* and the patterns of social behavior, organization, and change observed in empirical research (MERTON, 1968).

Although the MLP has been most used to evaluate past transitions through historical case studies, several researchers have used this framework to analyze different aspects of ongoing and future transitions (e.g., Verbong and Geels, 2007; Hörisch, 2018; Lin, Wells and Sovacool, 2018; and Andersen and Markard, 2020). Therefore, the MLP is a suitable framework to address the sustainability transition to electric cars in Brazil, which is a transition in its early stages.

Nonetheless, there are some aspects of the MLP that need further theoretical development. One is how multi-system interactions impact sustainability transitions (see Section 2.1.2). Another issue is how to adjust the MLP to use it in developing countries since this theoretical framework was developed and used more in developed countries (see Section 2.1.3). The research question which will be addressed in the thesis relates to both aspects. Therefore, there is an opportunity to develop and improve the MLP.

3.3 Strategy

The case study is a research strategy to investigate "contemporary phenomenon (the 'case') in depth and within its real-world context, especially when the boundaries between phenomenon and context may not be clearly evident" (YIN, 2018, p. 46). This strategy is useful when the case is interesting *per se* and not as a representative of a broader population (BRYMAN, 2012; LEE; SAUNDERS, 2017). The term 'case' usually refers to a location, e.g., a country or an institution, where the research will be conducted (BRYMAN, 2012). The case study strategy usually relies on multiple research methods and diverse data sources, and its design is generally guided by theoretical propositions previously developed (LEE; SAUNDERS, 2017; YIN, 2018).

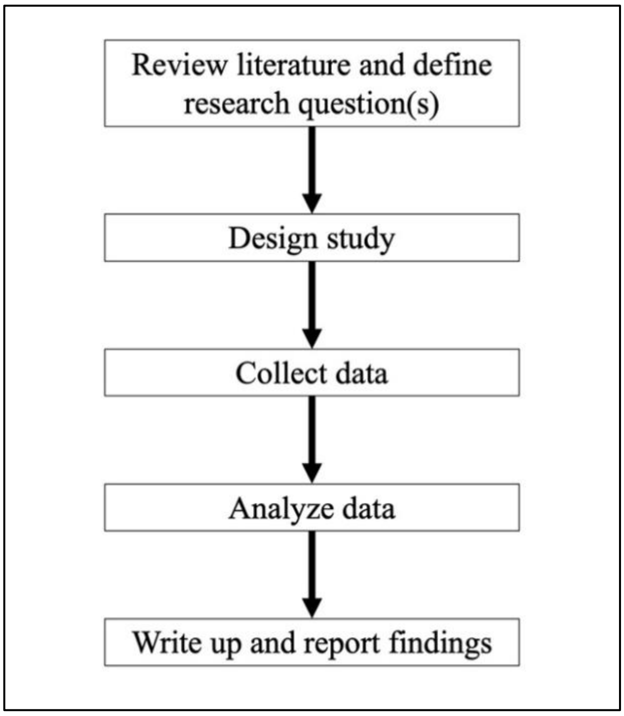
This strategy can encompass and excel in accommodating most ontological and epistemological positions (YIN, 2018). Lee and Saunders (2017) indicated that case studies are suitable to be used in research that adopts philosophies with a realist ontology and an interpretivist epistemology, such as critical realism. Danermark et al. (2002) affirmed that the case study is a very well-suited strategy to obtain knowledge about the mechanisms that explain phenomena. According to them, carefully selected case studies are a significant component of social science based on critical realism (DANERMARK et al., 2002). Besides, Easton (2010) argued that critical realism provides a philosophical justification and a logical framework for case studies.

Case study is the most used research strategy in transitions studies (KÖHLER et al., 2019; ZOLFAGHARIAN et al., 2019) and has been used in combination with the MLP since the initial development of this framework (e.g., Geels, 2002, 2005). Geels and Schot (2010) argued that the MLP requires a research strategy that is rich in context and can track complex events over time because transitions are complex non-linear processes that unfold over time. They advocated that the case study strategy meets these needs since it allows detailed process tracing, investigating patterns, and testing rival theories (GEELS; SCHOT, 2010).

Therefore, the case study is an appropriate strategy to be used under a critical realist philosophy and the MLP theoretical framework. Besides, case studies are most suitable to answer 'how' and 'why' research questions, which usually require extensive investigation and in-depth and insightful explanations of complex phenomena (LEE; SAUNDERS, 2017; YIN, 2018), such as the thesis' research question (see Chapter 0).

According to Lee and Saunders (2017), the researcher needs to choose between the orthodox and the emergent approach when using the case study strategy. The orthodox approach progresses in a linear and structured way (see Figure 3.3), while the emergent approach is more flexible and iterative. The orthodox approach will be used in the thesis because its more straightforward process demands less time than the emergent approach, which requires many revisits and reformulations of each stage of the research. This difference is relevant in thesis research in which the time available to do the study is limited.

Figure 3.3 – Case study orthodox approach



Source: Developed by the author based on Lee and Saunders (2017)

The first step in designing a case study is selecting the case. The literature review and the research question provide the elements necessary to identify relevant cases and help set the boundaries of the case study (YIN, 2018).

The case selected for the thesis is the *Projeto Estratégico de Pesquisa e Desenvolvimento – P&D nº 22: "Desenvolvimento de Soluções em Mobilidade Elétrica Eficiente"* (Strategic Research and Development Project - R&D nº 22: "Development of Efficient Electric Mobility Solutions", SRDP-22) from ANEEL. SRDP-22 objective is to prepare the Brazilian electricity ST-system for the transition to EVs and to make this transition feasible in Brazil. In 2019, ANEEL invited companies from the electricity ST-system to submit R&D projects aligned with these objectives to be part of SRDP-22. The agency selected 30 projects which would receive a total funding of R$ 463.8 million (US$ 118.3 million[43]). These projects can be considered sustainability experiments, as they are planned initiatives that incorporate a highly innovative socio-technical technology, the electric car, which is likely to provide significant sustainability gains. Thus, they are referred to as sustainability experiments for the remainder of the thesis.

SRDP-22 was selected for the case study based on four of the rationales[44] suggested by Lee and Saunders (2017). The first rationale considered was *theory-based selection*, which involves selecting cases because of their recognizable importance for theory development (LEE; SAUNDERS, 2017). The logic for choosing SRDP-22 is that it provides an excellent opportunity to test some aspects of the MLP theoretical framework. It allows studying a ST-transition involving multi-systems interactions, which is an aspect that is still underdeveloped in the MLP (HASSINK; GRIN; HULSINK, 2018; KÖHLER et al., 2019; ROSENBLOOM, 2019, 2020). Second, this ST-transition is happening in a developing country, which is a case little explored in the MLP (HANSEN et al., 2018; VAN WELIE et al., 2018; WIECZOREK, 2018; KÖHLER et al., 2019).

The second rationale considered was *confirming or disconfirming case selection*. It involves selecting a case that presents an opportunity to either extend or set new boundaries to an existing theory (LEE; SAUNDERS, 2017). This rationale is close to *theory-based selection.* As already detailed, the case study selected allow testing the applicability of the MLP to explain transitions in developing countries since this theoretical framework was developed and more used in developed countries.

[43] Considering the currency rate between Real and Dollar at the time.
[44] Not all the rationales are mutually exclusive (LEE; SAUNDERS, 2017).

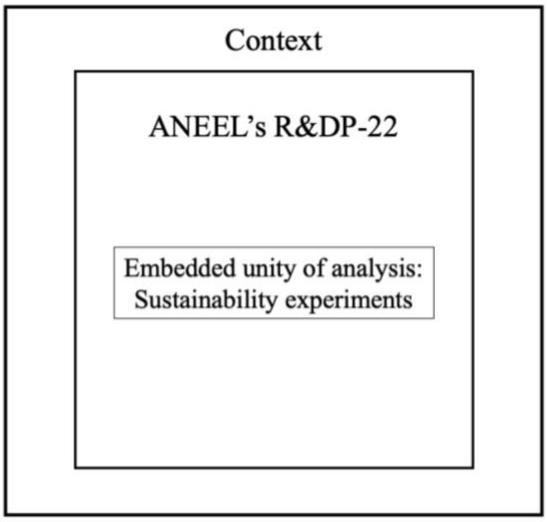
The third rationale used in the case study selection was *intensity selection*. This rationale refers to selecting a case because it exhibits several qualities of the phenomenon being studied (LEE; SAUNDERS, 2017). SRDP-22 is the best example of the electricity ST-system influencing the transition to electric cars in Brazil. Besides, several actors from the electricity and the urban mobility ST-systems are participating of SRDP-22, which guarantees a broad representation of the ways these two ST-systems are interacting regarding the transition to the electric car.

Finally, the fourth rationale was *opportunistic selection*, which refers to unforeseen or singular opportunities to access a case related to the problem addressed by the research (LEE; SAUNDERS, 2017). In this case, the opportunity is that I have worked for several years in the Brazilian electricity ST-system. This previous experience gives me access to many actors who would not otherwise be interested in speaking to researchers. These actors include officials from ANEEL and representatives of some of the companies who are developing the sustainability experiments that are part of SRDP-22.

After selecting the case, the next step in designing the case study is choosing between a single-case or a multiple-case design and deciding the unity of analysis, holistic or embedded (LEE; SAUNDERS, 2017; YIN, 2018). Holistic case studies have a single unity of analysis, and the case study is considered as one whole unit. Embedded case studies have two or more units of analysis, enhancing the insights, especially in single-case designs (LEE; SAUNDERS, 2017; YIN, 2018).

Given the characteristics of the case, an embedded single-case design was selected. The focus of the case study is SRDP-22. The sustainability experiments that are part of SRDP-22 are the embedded unit of analysis (see Figure 3.4). Each experiment is considered both individually and as a part of the SRDP-22. Differences and similarities between the experiments allow a better understanding of the case study.

Figure 3.4 – Case study design



Source: Developed by the author

3.4 Research choice

Qualitative and quantitative methods can be used in the case study strategy, although this strategy is often described as a more viable choice when using a qualitative research approach (LEE; SAUNDERS, 2017; YIN, 2018). Yin (2018) argued that it is more important to have multiple sources and multiple data collection methods than deciding between using qualitative or quantitative methods when using the case study strategy. These various sources of evidence allow triangulation, which strengthens the construct validity of the case study (YIN, 2018). Therefore, case studies should be used with multi-method research approaches. The choice between qualitative, quantitative, or mixed methods will depend on the research question (LEE; SAUNDERS, 2017).

Sayer (1992) argued that critical realist research needs some qualitative evidence and analysis. Using only quantitative methods does not allow the kind of retroductive inference necessary in critical realist research (SAYER, 1992, 2000). Besides, Sayer (1992) also pointed to the need for a 'triangulation process' during the research to highlight inconsistencies, mis-specifications, and omissions. Therefore, multi-method qualitative and multi-method mixed research approaches would be appropriate considering critical realism.

Concerning sustainability transitions, Zolfagharian et al. (2019) showed that most studies in this field use qualitative methods. Moreover, qualitative case studies are among the primary research choices in transitions studies (ZOLFAGHARIAN et al., 2019). Geels (2002) argued that one of the MLP strengths is its capacity to allow the researcher to process and analyze complex qualitative data. Moreover, McDowall and Geels (2017) pointed out that most of the dimensions that need to be analyzed in transitions studies, such as cultural meanings and conflicts, are very difficult to parametrize and quantify. These dimensions are better analyzed through qualitative processes. Thus, the MLP is more suited to be used in combination with qualitative rather than quantitative methods.

Therefore, a multi-method qualitative approach will be used in the thesis. It will combine different qualitative data collection methods to allow the necessary triangulation of the data. These methods are detailed in the next section.

3.5 Data collection methods

Two different data collection methods are used: secondary data and semi-structured interviews, which are described and detailed in the following sections.

3.5.1 Secondary Data

According to Yin (2018), our 'record-keeping society' means that secondary data collection is relevant to almost all case studies. Besides, the internet has made this type of data more accessible (YIN, 2018). Using secondary data is also an effective way to gather evidence for the research. This method usually requires less time and financial resources than other methods, such as surveys and interviews (BRYMAN, 2012). Secondary data is also unobtrusive and can be used as contextual data for case studies (SAUNDERS; LEWIS; THORNHILL, 2019).

However, in a case study, secondary data should be used to corroborate (or contradict) the primary data obtained by other methods, rather than being the primary source of evidence. In this case, contradictory data suggest the need for further investigation (YIN, 2018). It is essential to have multiple secondary data sources, as it is unlikely that all the necessary data will be obtained from a single source. There are several secondary data sources, such as documents (from government institutions, private companies, international organizations, among others), archival records, official statistics, and mass media outputs (BRYMAN, 2012; YIN, 2018; SAUNDERS; LEWIS; THORNHILL, 2019). Scott (1990) recommends evaluating every secondary data source using four criteria: *authenticity*, *credibility*, *representativeness*, and *meaning* (or comprehensibility). Any secondary source should only be considered in the research if it meets these criteria (SCOTT, 1990).

Therefore, secondary data was collected to contextualize the case study. The focus was to identify the main sustainability experiments in the Brazilian electric car niche involving actors from the electricity and the urban mobility ST-systems between 1990 and 2018, i.e., before the SRDP-22 started. Five data sources were used: (i) Google News, (ii) *Folha de São Paulo*; (iii) O *Estado de São Paulo*; (iv) *O Globo*; (v) *Canal Energia*. Google News was selected because it offers a compilation of news from several news outlets. *Folha de São Paulo*, *O Estado de São Paulo* and *O Globo* were chosen because they are the three main newspapers in Brazil (YAHYA, 2021). Finally, *Canal Energia* was also used because it is the main website for news related to the electricity ST-system.

The search terms used were '*carro elétrico*', '*veículo elétrico*', '*setor elétrico*', '*setor de energia*', and '*mobilidade elétrica*'. Different combinations of these terms were used for each of the data sources according to the way their respective search tool operates. In most cases, it was necessary to do more than one search. The combinations used are presented in Table 3.1.

Table 3.1 – Combinations of search terms used for each data source

Data source	Combinations of search terms
Google News	"carro elétrico" OR "veículo elétrico" AND "setor elétrico" OR "setor de energia" "carros elétricos" OR "veículos elétricos" AND "setor elétrico" OR "setor de energia" "mobilidade elétrica" AND "setor elétrico" OR "setor de energia"
Folha de São Paulo	"carro elétrico" OR "veículo elétrico" "carros elétricos" OR "veículos elétricos" "mobilidade elétrica"
O Estado de São Paulo	"carro elétrico" OR "veículo elétrico" "carros elétricos" OR "veículos elétricos" "mobilidade elétrica"
O Globo	"carro elétrico" OR "veículo elétrico" AND "setor elétrico" OR "setor de energia"
	"carros elétricos" OR "veículos elétricos" AND "setor elétrico" OR "setor de energia"

Data source	Combinations of search terms
	"mobilidade elétrica" AND "setor elétrico" OR "setor de energia"
Canal Energia	"carro elétrico" OR "veículo elétrico" OR "carros elétricos" OR "veículos elétricos" OR "mobilidade elétrica"

Source: Developed by the author

The screening and selection process consisted of reading the headlines and subheadings of the news returned by the research tool and selecting those that described sustainability experiments in the electric car niche involving actors from the electricity and the urban mobility ST-systems. The news selected were then read in its entirety to check if they really referred to sustainability experiments in the electric car niche. The ones that did not mention any sustainability experiment or did not involve actors from both ST-systems were discarded.

Then, the news selected were cross validated with information from the websites of the companies involved. Information that was not available on the companies' websites were also discarded. Finally, the results of the search in the five data sources were combined and compared to eliminate duplicates. The result was a compilation of the main[45] sustainability experiments in the electric car niche involving actors from the electricity and the urban mobility ST-systems between 1990 and 2018.

Secondary data regarding the case itself was also collected. All documents available in the ANEEL database related to SRDP-22 were collected and analyzed. ANEEL database was accessed through the agency's *Consulta Processual* website[46], which allows users to access ANEEL's documents and administrative processes and monitor their progress. 61 documents related to SRDP-22 were retrieved from this database. Besides, some information that was not available in the ANEEL database, for example, the status of each experiment in 2022, was requested through the Access to Information Law.

These documents made it possible to identify other institutions that assisted ANEEL in the conception of SRDP-22, such as the *Centro de Gestão e Estudos Estratégicos* (CGGE, Management and Strategic Studies Center) and the German

[45] This is not a compilation of all experiments in the electric car niche involving actors from the electricity and the urban mobility ST-systems between 1990 and 2018 because some experiments may not have been reported in the news. However, it is considered that the main experiments are those that have been reported.

[46] https://www.gov.br/aneel/pt-br/canais_atendimento/processo-eletronico/consulta-processual

development agency Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). Thus, the websites of these institutions were also searched for documents related to SRDP-22. Other sources of secondary data used were the websites, reports and press releases from all companies, public bodies, research institutes, and universities that are participating the sustainability experiments that are part of SRDP-22.

3.5.2 Semi-structured interviews

Interviews are the most important source of evidence in most case studies and are especially helpful in developing explanations to social phenomena (YIN, 2018). There are many types of research interviews depending on the level of standardization and the number of participants (SAUNDERS; LEWIS; THORNHILL, 2019). Yin (2018) recommended using *in-depth* (or unstructured) interviews in case studies. These are exploratory and emergent interviews in which no kind of guide or structure is used. The researcher allows the interviewee to talk freely about the phenomenon being studied, and the direction of the interview is usually defined by the interviewee and not the researcher (SAUNDERS; LEWIS; THORNHILL, 2019).

Lee and Saunders (2017) proposed *semi-structured* interviews as a great method to be used in case studies. *Semi-structured* interviews, like *in-depth* interviews, are not standardized. However, *semi-structured* interviews have some pre-determined themes or key questions that must be addressed during the interview (SAUNDERS; LEWIS; THORNHILL, 2019). These themes are derived from existing theory or previous exploratory research. Nonetheless, new themes can emerge during a *semi-structured* interview and then be aggregated to the interview guide and be used in the next interviews. Although *semi-structured* interviews are an open process and can follow many directions, it is usually the researcher, not the participant, who directs the interview (SAUNDERS; LEWIS; THORNHILL, 2019).

The option to use *semi-structured* interviews instead of *in-depth* interviews in the thesis research is based on two rationales. First, having some structure ensures that the themes relevant to the study are covered during the interviews and not just the themes that the interviewees consider important. Second, *in-depth* interviews can be very long, often demanding more than two hours (YIN, 2018), which is more time than most participants in the research are willing to provide. Besides, it becomes much more difficult to predict how long the interviews will last. In contrast, *semi-structured* interviews allow covering the important themes more quickly and better predicting the time necessary for the interviews, which is a relevant information to the participants.

17 actors were selected for the interviews through purposive sampling. The goal of this sampling is to judge and select the samples, in this case the people, that yield the most relevant information to answer the research question (YIN, 2015; SAUNDERS; LEWIS; THORNHILL, 2019). Therefore, the participants in the research are deliberately selected based some criteria (BRYMAN, 2012). This kind of sample selection is common in qualitative research, especially in case studies (BRYMAN, 2012; SAUNDERS; LEWIS; THORNHILL, 2019).

The first criteria used to select the actors for the interviews was that they must have participated directly of SRDP-22. The second criteria were the relevance of the actor in SRDP-22. Given that it would not be feasible to interview all actors involved in the program, those that were considered more influential were selected for the interviews. The influence of each actor was evaluated based on some criteria. All actors involved in the conceptualization of SRDP-22 were considered very influential.

Therefore, the first actors invited for interviews were representatives of ANEEL's *Superintendência de Pesquisa e Desenvolvimento e Eficiência Energética* (SPE, Superintendence of Research and Development and Energy Efficiency). SPE is the ANEEL's department that was responsible for the conception and implementation of SRDP-22. SPE was also in charge of selecting the sustainability experiments that are part of SRDP-22. Besides, SPE is now responsible for monitoring and controlling the progress of the project. Actors representing other institutions involved in the conception of the program were also invited for interviews, such as the *Centro de Gestão e Estudos Estratégicos* (Center for Strategic Studies and Management - CGEE).

Besides, actors involved in the sustainability experiments that are part of SRDP-22 were invited for interviews. In this case, the relevance of each actor was assessed based on the number of experiments they are participating in SRDP-22, the number of other actors they are connected to through the experiments and the total estimated cost of these experiments. The actors network maps presented and discussed in Section 5.1 helped to identify the influential actors in SRDP-22.

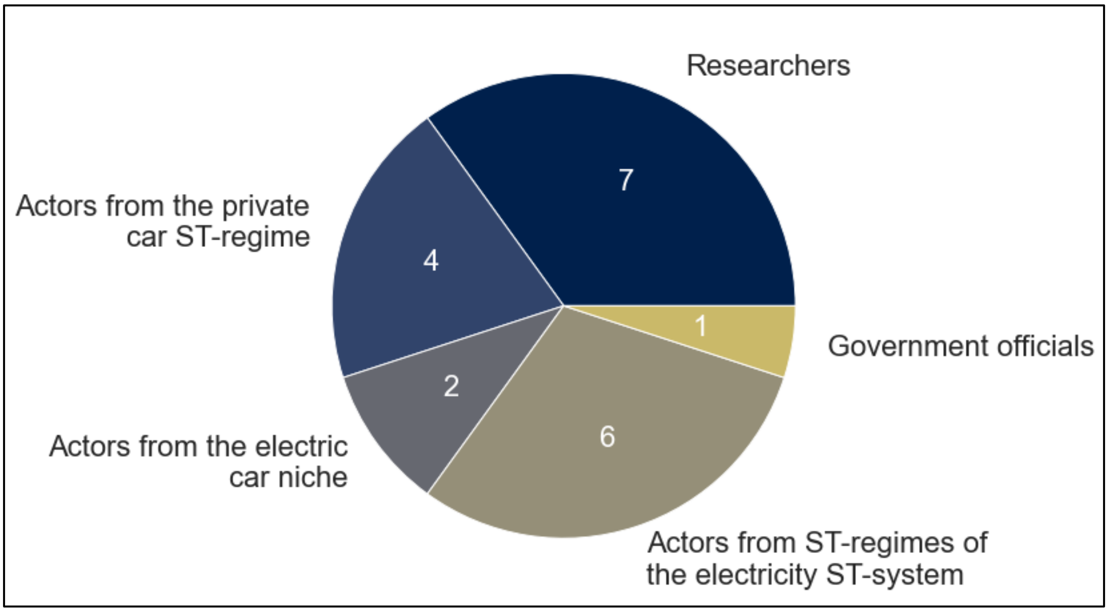
Another 22 actors were chosen through snowball sampling. In this case, the first participants of the research were asked to indicate other people who have significant knowledge of the case and can contribute to the research (BRYMAN, 2012; LEE; SAUNDERS, 2017). People who were spontaneously cited during the interviews as knowledgeable of the case were also selected for interviews. In fact, the ones spontaneously cited should be preferred to the ones indicated (YIN, 2015). These people were selected based on the same criteria used in the purposive sampling. Only those who met those criteria were selected for interviews.

All the 39 actors selected were invited for interviews by e-mail. However, only 20 of them agreed to participate in the research. In addition, one of them did not agree to participate in an interview but agreed to submit the answers to the interview questions in writing.

The interviews were conducted between April and July 2022. All interviews were remote due to the COVID-19 pandemic. They were carried out over the internet using tools such as Google Meet and Microsoft Teams. None of these interviews were recorded and only notes were taken. When necessary, participants were contacted again after the interview to clarify eventual conflicts between their responses and other data.

The 20 actors who participated in the interviews can be divided in 5 classes: government officials, actors from the private car ST-regime, actors from ST-regimes of the electricity ST-system, actors from the electric car niche, and researchers from universities and research centers. Figure 3.5 shows how many actors interviewed were from each of these classes.

Figure 3.5 – Niche or regime of the actors participating in SRDP-22



Source: Developed by the author

3.5.2.1 Main themes of the semi-structured interviews

The following questions were used to guide the semi-structured interviews with the institutions involved in the conception of SRDP-22.

(i) What is the main objective of SRDP-22?
(ii) How is SRDP-22 progressing? What are the most relevant results so far?
(iii) How can the results of SRDP-22 facilitate the transition to electric cars in Brazil?
(iv) What are the main challenges to the transition to electric cars in Brazil?
(v) How can the electricity ST-system facilitate the transition to electric cars in Brazil?
(vi) Has the COVID-19 pandemic disrupted the experiments? If yes, what are the main impacts and how were they mitigated?

The following questions were used to guide the semi-structured interviews with the actors involved in the sustainability experiments.

(i) How was the experiment(s) in which your company/research center/university participates in SRDP-22 conceived? Has your company/research center/university proposed the experiment(s) to partners or has it been approached by these partners to integrate their experiment(s)?
(ii) What is the role of your company/research center/university in the experiment(s)?
(iii) Do foreign institutions (e.g., companies, research centers, universities) participate in the experiment(s)? If yes, what is their role and how are they interacting with the other participants of the experiment(s)?
(iv) In the experiment(s), is there an exchange of knowledge and/or technology between the participants?
(v) What are the main technological advances that might be obtained in the experiment(s) in which your company/research center/university is participating?
(vi) How will SRDP-22 influence the electric vehicle market in Brazil?
(vii) Would your company/research center/university be investing in electric mobility regardless of SRDP-22?
(viii) There would be so many companies from the electricity ST-system investing in electric mobility experiments if it weren't for SRDP-22?

(ix) Has the COVID-19 pandemic disrupted the experiments? If yes, what are the main impacts and how were they mitigated?

3.6 Analytical framework

Following the thesis objectives, the first analytical stage of the thesis is the characterization of the ST-systems, ST-regimes and niches involved in the phenomenon that is being studied. The characterization of the ST-systems and ST-regimes are particularly complex because the boundaries of these analytical levels are not always clear, as discussed in Section 2.1.1.4.7. The definition of ST-system, ST-regime, and niche proposed by Geels (2004) and detailed in Section 2.1.1.4 are adopted. However, to make it easier to operationalize the MLP, the framework proposed by van Welie *et al.* (2018) is used in the characterization (see Section 2.1.3.2).

First, it is considered that ST-regimes can be identified as the technologies, rules, routines, and institutional aspects related to providing a service associated with a societal need. The ST-system is the combination of all the different ST-regimes that provides services that can fulfill a societal need. Second, the characterization also considers the internal alignment of the ST-regimes and the alignments between the ST-regimes that compose a ST-system. The more well-aligned is a ST-regime, the more stable it is. Similarly, the more well-aligned are the ST-regimes of a ST-system, the more stable is the whole system (see Section 2.1.3.2).

The next analytical stage of the thesis the characterization of the sustainability experiments that are part of SRDP-22. Building on the transitions' theories, detailed in the Chapter 2, the sustainability experiments are characterized based on eight categories: (i) actors involved, (ii) start and end date, (iii) level of interaction, (iv) mode of interaction, (v) value-chain level of interaction, (vi) resources exchanged in the experiment, (vii) impact of transnational linkages on the experiment, and (viii) impact of the experiment on the sustainability transition. This characterization is based on secondary data, but it was supplemented with primary data from the interviews.

Regarding the level of interaction, there are six possibilities, considering the typology proposed by Rosenbloom (2020) (see Section 2.1.2): (i) intrasystem niche-regime; (ii) intrasystem regime-regime; (iii) intrasystem niche-niche; (iv) intersystem niche-regime; (v) intersystem regime-regime; (vi) intersystem niche-niche. Although all the experiments of the case study involve some kind of intersystem interaction between the electricity and urban mobility ST-systems, there may be more than one interaction in the same experiment. Therefore, intrasystem interactions can be present in these experiments.

The typology proposed by Sandén and Hillman (2011) (see Section 2.1.2) is used to characterize the modes of interactions between the ST-regimes and niches involved in the sustainability experiments. Therefore, there are six possible classifications for the modes of interaction: (i) competition, (ii) symbiosis, (iii), neutralism, (iv) parasitism, (v) commensalism, and (vi) amensalism.

The value-chain level of interaction characterization is based on innovation ecosystems literature (see Section 2.1.2). The type of technology impacted by the sustainability experiment result in different impacts in the sustainability transition. Therefore, the experiments are classified accordingly to the technology that is their focus. There are three classifications: (i) focus on the main technology, i.e., the electric car, (ii) focus on component technologies, such as batteries or electrical powertrains, and (iii) focus on complementary technologies, such as charging stations or vehicle-to-grid applications.

Sustainability experiments involve exchanges of resources between the actors that are participating (see Section 2.1.3.1). There are five types of resources that can be exchanged: (i) capital, (ii) knowledge, (iii) technology, (iv) people, and (v) rules and institutions. More than one type of resource can be exchanged in an experiment.

Transnational linkages can have a significant impact on sustainability experiments (see Section 2.1.3.1). Therefore, the sustainability experiments are also characterized in terms of the role of transnational linkages in it: (i) transnational linkages are present and influence the experiment, (ii) transnational linkages are present but do not influence the experiment, and (iii) transnational linkages are not present.

According to transitions literature, the sustainability experiments can have two impacts on the sustainability transitions. They may contribute to the consolidation of the technological niche or help to destabilize the existing ST-regime. Building on Strategic Niche Management (see Section 2.1.1.2), there are three ways in which a sustainability experiment can contribute to the niche consolidation: (i) articulating expectations and visions, (ii) building new networks of actors, and (iii) creating learning process at multiple dimensions (technical, market and user preferences, cultural, infrastructure, industry and production, regulations and policies, and societal and environmental).

Regarding ST-regime destabilization (see Section 2.1.1.4.5), sustainability experiments can: (i) increase economic and socio-political pressure on the ST-regime, (ii) disrupt existing incumbent networks and coalitions, (iii) change public perception of the ST-regime, (iv) lead to change in ST-regimes rules, and (v) set and keep the problems associated with the ST-regime (e.g., pollution and climate change) in the political agenda.

Thus, the impact of the sustainability experiments on the sustainability transition to electric cars in Brazil are classified according to these eight categories. An experiment may cause more than one of these impacts. Table 3.2 shows a summary of all the categories used to characterize the sustainability experiments.

Table 3.2 – categories used to characterize the sustainability experiments

Category	Classifications
Actors involved	-
Start and end date	-
Level of interaction	Intrasystem niche-regime Intrasystem regime-regime Intrasystem niche-niche Intersystem niche-regime Intersystem regime-regime Intersystem niche-niche
Mode of interaction	Competition Symbiosis Neutralism Parasitism Commensalism Amensalism
Value-chain level of interaction	Focus on the main technology Focus on component technologies Focus on complementary technologies
Resources exchanged in the experiment	Capital Knowledge Technology

Category	Classifications
	People Rules and institutions
Impact of transnational linkages on the experiment	Transnational linkages are present and influence the experiment Transnational linkages are present but do not influence de experiment Transnational linkages are not present
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions Niche consolidation - build new networks of actors Niche consolidation - create learning process at multiple dimensions Regime destabilization - increase economic and socio-political pressure on the ST-regime Regime destabilization - disrupt existing incumbent networks and coalitions Regime destabilization - change public perception of the ST-regime Regime destabilization - lead to change in ST-regimes rules Regime destabilization - set and keep the problems associated with the ST-regime in the political agenda

Source: Developed by the author

After the characterization of each experiment, the data gathered was compiled and combined with the data collected during the interviews to allow a broader view of SRDP-22 and the identification of the main impacts the experiments have on the sustainability transition to electric cars in Brazil. This compilation is presented in Chapter 5.

The final analytical stage is to assess how sustainability experiments in the electric car niche that involve actors from the electricity and the urban mobility ST-systems influence the sustainability transition to the electric car in Brazil. The results presented in Chapter 5 are analyzed and discussed in Chapter 6. These results are also used to assess current conceptualizations and theories on multi-system sustainability transitions in developing countries, presented in Chapter 2.

Therefore, the primary and secondary data gathered in the case study are used to assess how significant is the influence of the electricity ST-system to the sustainability transition to electric cars in Brazil. The normative orientation impact in the transition to EVs in Brazil is also analyzed. This is relevant because there is no consensus of what sustainable urban mobility is, as discussed in Section 2.2. The normative orientation has a significant impact in sustainability transitions because sustainability is not a neutral attribute of these transitions, as detailed in Section 2.1.3.3. In addition, the role of incumbents in transitions in developing countries and how transnational linkages influence sustainability experiments are also discussed in Chapter 6. Finally, these assessments are used to highlight how the actors from the electricity ST-system can help accelerate the sustainability transition to the electric car in Brazil.

3.7 Research bias

Many strategies were used to manage, minimize and, when possible, eliminate bias from the research. However, any research has its own bias because it is impossible to eradicate all kinds of biases (YIN, 2015; LEE; SAUNDERS, 2017). The aim of this section is to describe the strategies used to deal with bias and to acknowledge and report the possible biases that still exist. This procedure is necessary to make the research reliable and replicable, even though, replication is often difficult to achieve in social sciences (BRYMAN, 2012; YIN, 2018).

An important step to reduce bias is reflecting on all the different ways the research question could be answered (LEE; SAUNDERS, 2017). The concepts and theories used in the thesis were selected after an extensive literature review, which considered many different theories. The theory chosen, the rationale for its selection, and the rival theories are all clearly described in Chapters 2 and 3.

Another important process to minimize and eliminate bias is having a clear and well-founded research design (YIN, 2018). The research strategy used in the thesis is based on relevant research philosophy (critical realism) and theory (MLP). In case studies, a systematic and careful designed research avoid the perception that the researcher “seeming to find what she or he had set out to find” (YIN, 2018, p. 328).

The selection of the case for the case study followed a handful of selection rationales, aiming to assure its relevance to the research problem of the thesis and to theory. The research relies on multiple sources of evidence, to overcome any bias associated with one of them. Besides, the research methods used for data collection are well-established and widely used in case studies. A case study research database was created, documenting all the relevant evidence used. This database will be accessible to any researcher[47], improving the case study reproducibility and reliability.

Some specific measures were taken to reduce bias during data collection, i.e., in the secondary data and the interviews. Secondary data are subject to various types of biases. First, there is purposive bias, i.e., when data is inaccurately registered deliberately (SAUNDERS; LEWIS; THORNHILL, 2019). For example, companies may omit minor accidents, managers can distort graphics to make them look better to the stakeholders, and governments often fail to include statistics that are not favorable to them in reports. Purposive bias can be difficult to detect. The best way to minimize it is to triangulate information from multiple sources, which should be independent of each other if possible (BRYMAN, 2012; SAUNDERS; LEWIS; THORNHILL, 2019).

Another possible source of bias in secondary data are changes in the way data are collected (SAUNDERS; LEWIS; THORNHILL, 2019). This can happen, for example, when a better method to measure something is developed. This type of change is usually disclosed, especially when the data is collected by governments. Thus, the researcher can take the changes into account. However, companies are not likely to register this kind of change (SAUNDERS; LEWIS; THORNHILL, 2019). In this case, the biases in the data can be difficult to detect. A possible solution to this problem is to talk with the data curator and ask if there was any change in the data collection methods.

Finally, secondary data can also have bias when the data collection method used was inadequate for that kind of data (SAUNDERS; LEWIS; THORNHILL, 2019). For example, flaws in the design (e.g., how to deal with missing data) and conduct (e.g., use of unsealed envelopes) of clinical trials can bias the results (YORDANOV et al., 2015). Therefore, the researcher must verify that the research methods used for data collection were adequate, before using it in his or her own research as secondary data (BRYMAN, 2012; SAUNDERS; LEWIS; THORNHILL, 2019).

Therefore, all information extracted from secondary data was, when possible, cross-checked with other sources of data to identify possible biases. Contradictory information from different sources of secondary data is clearly flagged in the thesis. In cases where

[47] The exception is interview notes, which will remain private to ensure the anonymity of interviwees.

the data collection method changed overtime, only the data collected with the same methods were used. All secondary data sources that used inadequate methods for data collection was disregarded.

Interviews can also be biased if not handled properly. One possible source of bias in the thesis' interviews was the sampling methods used for selecting the interviewees. Purposive and snowball sampling are relevant and accepted methods for qualitative research (YIN, 2015; SAUNDERS; LEWIS; THORNHILL, 2019). Nonetheless, as the interviewees were not randomly selected, there is a clear bias associated with this selection process, called participation bias (BRYMAN, 2012). This bias is introduced because the selected participants may differ significantly from the entire group of actors involved in the case being studied (HESTBECH et al., 2011; PIRASTU et al., 2021). Therefore, caution should be taken when making analysis, especially in terms of generalizing the results, because the samples are not statistically representative of the population (BRYMAN, 2012; YIN, 2015).

Another source of participation bias is non-response. Some actors think interviews are time-consuming, intrusive, and even useless. Thus, they refuse to take part in them. This may introduce a bias in the research because only those who are willing to participate in the research will be interviewed (BRYMAN, 2012; SAUNDERS; LEWIS; THORNHILL, 2019).

The best way to minimize the participation bias when using non-probability sampling is to have clear criteria to the selection process (BRYMAN, 2012; YIN, 2015). These criteria must be based on theory and able to distinguish the most informative participants to answerer the research question (SAUNDERS; LEWIS; THORNHILL, 2019). Besides, the criteria must not be changed after the selection process started (BRYMAN, 2012). All these conditions were met in the thesis sampling process, as described in Section 3.5.2.

Another possible source of bias in interviews is interviewer bias. The interviewer's comments, tone and non-verbal behavior, how the questions are posed, and even the order of the questions may impact the way the interviewees respond to these questions (SAUNDERS; LEWIS; THORNHILL, 2019). This kind of bias may also be introduced by the way the interviewer interprets the participants' answers.

Yin (2015) recommended the following procedures to minimize interviewer bias: (i) avoid long questions and commenting the interviewees answers[48], (ii) be non-directive, i.e., let the participant decide the sequence in which the topics are discussed, (iii) be careful with language and expressions used so as to remain neutral and not betray your own opinions and biases, (iv) maintain a good rapport with the interviewees, avoiding creating a situation that could upset them. Besides, Saunders, Lewis and Thornhill (2019) suggest that all questions should be open and formulated in a way to avoid simple yes or no answers. Leading or proposing questions must be avoided. All these procedures were followed during the interviews.

Bias in interviews can also be introduced by interviewees. It is called interviewee bias or response bias. Interviewees may be not willing to share their knowledge of the case if they do not trust in the interviewer or do not feel comfortable during the interview. Besides, an interview is an intrusive process, which often makes the interviewees unwilling to disclose certain information or discuss determined topics even if they agreed to participate in the interview (SAUNDERS; LEWIS; THORNHILL, 2019). Therefore, interviewees may provide only a partial, possibly inaccurate, view of the case to conform to a socially acceptable model of behavior (BRYMAN, 2012).

Saunders, Lewis and Thornhill (2019) suggested providing the interviewees with an information sheet and consent from prior to the interview. According to them, this process can significantly reduce the participants anxiety about the interview and help build trust. Nonetheless, the best way to deal with response bias is to triangulate the information gathered in one interview with other interviews and sources. In case of contradictory information, the interviewees should be contacted again and asked to clarify it (YIN, 2018; SAUNDERS; LEWIS; THORNHILL, 2019). All these procedures were followed during the research.

Finally, Yin (2018) suggested that having multiple researchers instead of a single researcher is a great way to minimize bias in a case study. Although most of the work in a PhD thesis is done by the PhD candidate, the present thesis should not be considered a single researcher case study. Several researchers, notably my supervisors, have reviewed this thesis research at different stages and proposed ways to eliminate or minimize existing biases.

[48] Commentaries should only be made if they are necessary to clarify something the interviewee have not understood.

Avoiding bias is just one of a set of actions the researcher needs to take to ensure that the research complies with the highest ethical standards (YIN, 2018). Other ethical considerations are discussed in the next section.

3.8 Ethical considerations

Ethical issues emerge during all the stages of social research (BRYMAN, 2012; SAUNDERS; LEWIS; THORNHILL, 2019). It is the researcher's responsibility to ensure the appropriateness of the research. Therefore, the researcher needs to assure the integrity of the study, avoid any harm to the participants, guarantee their privacy, provide them with full information about the research process and the implications of their involvement, and ensure the confidentiality of the data and the anonymity of the participants, unless authorized by them to disclose their identities and statements (BRYMAN, 2012; SAUNDERS; LEWIS; THORNHILL, 2019).

The *Comitê de Ética em Pesquisa em Ciências Humanas e Sociais* (CEP/CHS, Research Ethics Committee in Human and Social Sciences) of the University of Brasília defined that any research involving human beings and using qualitative methods of data collection or analysis must be submitted for approval. The research needs to be registered in the Brazilian government's database *Plataforma Brasil*, managed by the *Comitê de Ética em Pesquisa* (CEP, Research Ethics Committee). CEP then forwards the research to CEP/CHS for analysis. In addition, CEP/CHS requires that all participants in the research receive and sign an 'informed consent form.'

The thesis research project was registered in *Plataforma Brasil* on February 23rd, 2022, with CAAE[49] number 56162522.3.0000.5540. The project was approved by CEP/CHS on March 24th, 2022, The CEP/CHS report approving the research project is presented in Annex A. Besides, a partial report with information on the progress of the research was sent to CEP/CHS on September 20th, 2022. The final report will be sent when this Thesis is finished and approved. The informed consent form that was used in the research has been developed following the CEP/CHS guidelines and is presented in Appendix A.

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[49] *Certificado de Apresentação de Apreciação Ética* (Certificate of Presentation of Ethical Appreciation).

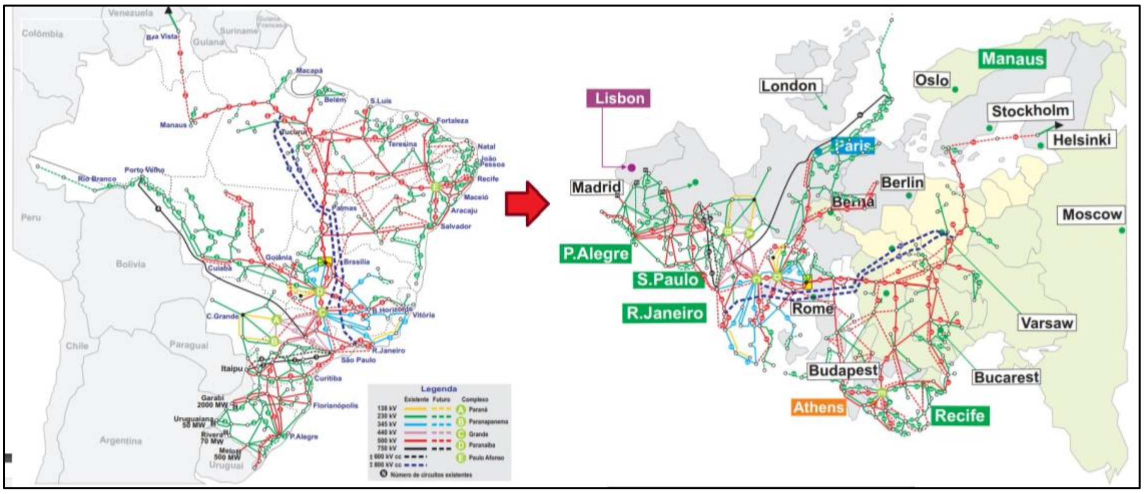
4. CASE STUDY - CONTEXTUALIZATION

In this section, the main ST-systems, ST-regimes, and niches related to the case study are detailed. First, the electricity ST-system and all the ST-regimes and niche that compose it are characterized. Then, the urban mobility ST-system is introduced, detailing how the private car ST-regime dominates it. This ST-regime and the electric car niche are discussed in more detail than the other ST-regimes and niche that compose the urban mobility ST-systems given their central role in the case study. Next, there is an analysis of the sustainability experiments with electric cars involving actors from the electricity ST-system prior to SRDP-22. Finally, the last section of this chapter presents how SRDP-22 was conceived, its main goals, and the sustainability experiments that are part of the program.

4.1 The Brazilian electricity system

Brazil is the eighth-largest electricity producer in the world (ENERDATA, 2020). The Brazilian electricity system produced 656.1 TWh of electricity in 2021, of which 74.4% were from renewable sources (EPE, 2022a). Brazil is also the second-largest producer of hydroelectricity and the seventh-largest producer of wind electricity (IEA, 2021). Besides, the Brazilian electrical grid has more than 145 thousand kilometers, one of the world’s largest (MME; EPE, 2019). It could cover almost all of Europe, as shown in Figure 4.1.

Figure 4.1 – The Brazilian electrical grid projected over Europe

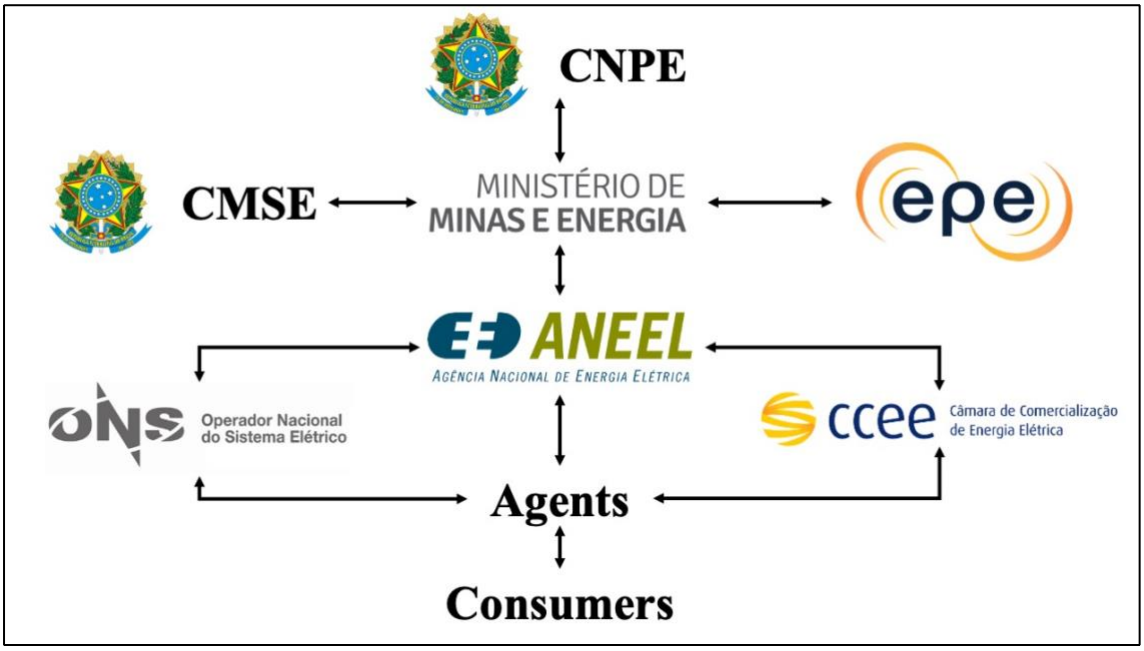


Source: ONS (2018)

This large and complex electricity system is coordinated and supervised by several government institutions (see Figure 4.2). The *Conselho Nacional de Política Energética*

(CNPE, National Energy Policy Council) is responsible for advising the Republic's Presidency on the formulation of directives to guide the rational use of the country's energy resources. The Ministry of Mines and Energy (MME) manages the electricity system by formulating, implementing, and supervising policies aimed at the country's energy development. The *Comitê de Monitoramento do Setor Elétrico* (CMSE, Electricity Sector Monitoring Committee) monitors and evaluates energy supply's continuity and security. The CNPE and the CMSE are both chaired by the MME. The *Empresa de Pesquisa Energética* (EPE, Energy Research Company) provides the MME with studies to support planning the electricity system's operation and expansion.

Figure 4.2 – The organization of the Brazilian electricity ST-system



Source: developed by the author

ANEEL regulates and supervises the electricity system, especially its agents' performance. The agency also has the attribution of defining the energy tariffs for 'captive consumers,' i.e., consumers that can only buy electricity from the local electricity distribution company, which has a concession from the government to operate in the area where these consumers are located. The *Operador Nacional do Sistema Elétrico* (ONS, National Electric System Operator) manages the Brazilian electricity system. This institution supervises and coordinates the production and transmission of electricity to optimize the system and guarantee electricity supply to all consumers. Finally, the *Câmera de Comercialização de Energia Elétrica* (CCEE, Electricity Trading Chamber) is responsible for the Brazilian electricity market, enabling operations of purchase and sale of electricity.

The agents of the Brazilian electricity system are companies, public or private, that generate, transmit, distribute, commercialize, or import and export electricity. The 'free consumers' and 'special consumers' are also considered agents. 'Free consumers' are consumers that buy electricity in the *ambiente de contratação livre* (ACL, 'free contracting environment')[50] instead of buying it from the local electricity distribution company. A 'special consumer' is a group of 'free consumers' who negotiates and purchases electricity together in the ACL. There were 1,665 generators[51], 456 traders, and 53 distributors in 2021 (CCEE, 2022).

There were approximately 26,100 'free consumers' (including 'special consumers') in 2021, and they consumed 190.6 TWh. These consumers were mainly from the industrial and commercial sectors (see Table 4.1) (EPE, 2020a, 2020b). Most consumers in 2021 were 'captive consumers,' totalizing almost 87 million consumers, from which the most part was from the residential sector. 'Captive consumers' consumed 306.9 TWh in 2019 (EPE, 2022a, 2022b).

Table 4.1 – Electricity consumers in Brazil

Sector	'Free consumers'		'Captive consumers'		Total consumption (TWh)
	Quantity	Consumption (TWh)	Quantity (thousand)	Consumption (TWh)	
Industrial	10,568	157.5	458	22.8	180.4
Commercial	14,591	24.9	5,776	61.9	86.8
Residential	0	0	75,321	149.8	149.8
Agricultural	308	2.8	4,420	30.0	32.8
Public	631	5.1	1,056	39.3	44.4
Own use	1	0.2	9.7	3.2	3.3
Total	26,117	190.6	86,979	306.9	497.5

Source: EPE (2022a, 2022b)

[50] The ACL is an energy market where the prices are not regulated by ANEEL and are the result of the negotiations between seller and buyer.

[51] Including independent producers (companies authorized to produce and sell electricity in the ACL), self-producers (companies who produce energy for their own exclusive use), and companies that won public auctions to generate and sell electricity in the *ambiente de contratação regulada* (ACR, 'regulated contracting environment'). The ACR is an energy market regulated by ANEEL where the government buys energy through public auctions.

Considering the MLP analytical levels, the Brazilian electricity ST-system can be divided into several ST-regimes and niches. First, it must be emphasized that the government institutions presented in Figure 4.2 are part of all these ST-regimes. Some of these institutions, such as the MME and ANEEL, have specific departments that will be part of a particular ST-regime. In other cases, like the CNPE and CCEE, the whole institution is part of various ST-regimes. Besides, the different types of consumers are also part of different ST-regimes, with some consumers, usually 'free consumers', sometimes part of more than one ST-regime.

The primary rationale for differentiating between ST-regimes in the electricity ST-system is to consider the 'roles' that actors can have in the electricity ST-system: generation, transmission, distribution, and trading of electricity. All these services must be provided for the societal need for electricity to be fulfilled. Therefore, there is a generation ST-regime, a transmission ST-regime, a distribution ST-regime, and a trader ST-regime. These ST-regimes have their own technologies, routines, institutions, and rules, even though they may share some of these aspects. It is the alignments between these ST-regimes that compose the electricity ST-system.

However, although there is only one main technology in the transmission[52], distribution, and trader ST-regimes, there are many different alternatives to generate electricity in the Brazilian electricity ST-system. Besides, routines, institutions, and rules can significantly vary based on the technology adopted. For example, hydroelectric companies have different interests and follow distinct rules than wind energy companies or thermoelectric companies. Besides, it is not expected that any of these technologies will dominate the electricity ST-system, leading to one single ST-regime.

Therefore, the following ST-regimes can be identified: large hydroelectric ST-regime, small hydroelectric ST-regime, wind ST-regime, solar ST-regime, nuclear ST-regime, thermoelectric ST-regime, and biomass ST-regime.

Large and small hydroelectric power plants are considered distinct ST-regimes because they have significantly different characteristics. Small hydroelectric plants (SHP) are often seen as an environmentally friendly solution to generate electricity[53]. In contrast,

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[52] There are two technologies to transmit electricity: high voltage direct current (HVDC) and high voltage alternate current (HVAC). However, most of the Brazilian electricity grid uses the HVCA technology. HVDC is only used in specific applications, in which large amounts of energy are transmitted through long distances (e.g., the interconnection between the Belo Monte hydroelectric plant and the state of São Paulo).

[53] Some people contest this view. See Leuzinger, Coutinho and Santana (2020) for an overview of the environmental impacts of small hydroelectric power plants.

large hydroelectric plants suffer a lot of pressure from environmental groups because of their large reservoirs' socio-environmental impacts. Besides, SHPs are subject to different legislation than large hydroelectric plants.

Natural gas, coal, and oil thermoelectric power plants are considered one single ST-regime because they have the same role in the Brazilian electricity ST-system and similar interests and characteristics. These plants are usually used when the reservoirs of the large hydroelectric power plants are at a critically low level or when a fast dispatch of energy[54] is necessary because of a sudden peak in demand or an emergency in the electrical grid (MME; EPE, 2019). Nonetheless, they are not used under normal operating conditions due to higher prices and greater GHG emission levels than the other energy sources in the Brazilian electricity system (TOLMASQUIM, 2016).

Until recently, solar energy would be considered a niche. However, given the exponential growth of this technology in recent years in Brazil (from 0.8 GWh in 2016 to 16.8 GWh in 2021), and the fact that it is already competing with other sources in the Brazilian electricity system, it is considered a ST-regime.

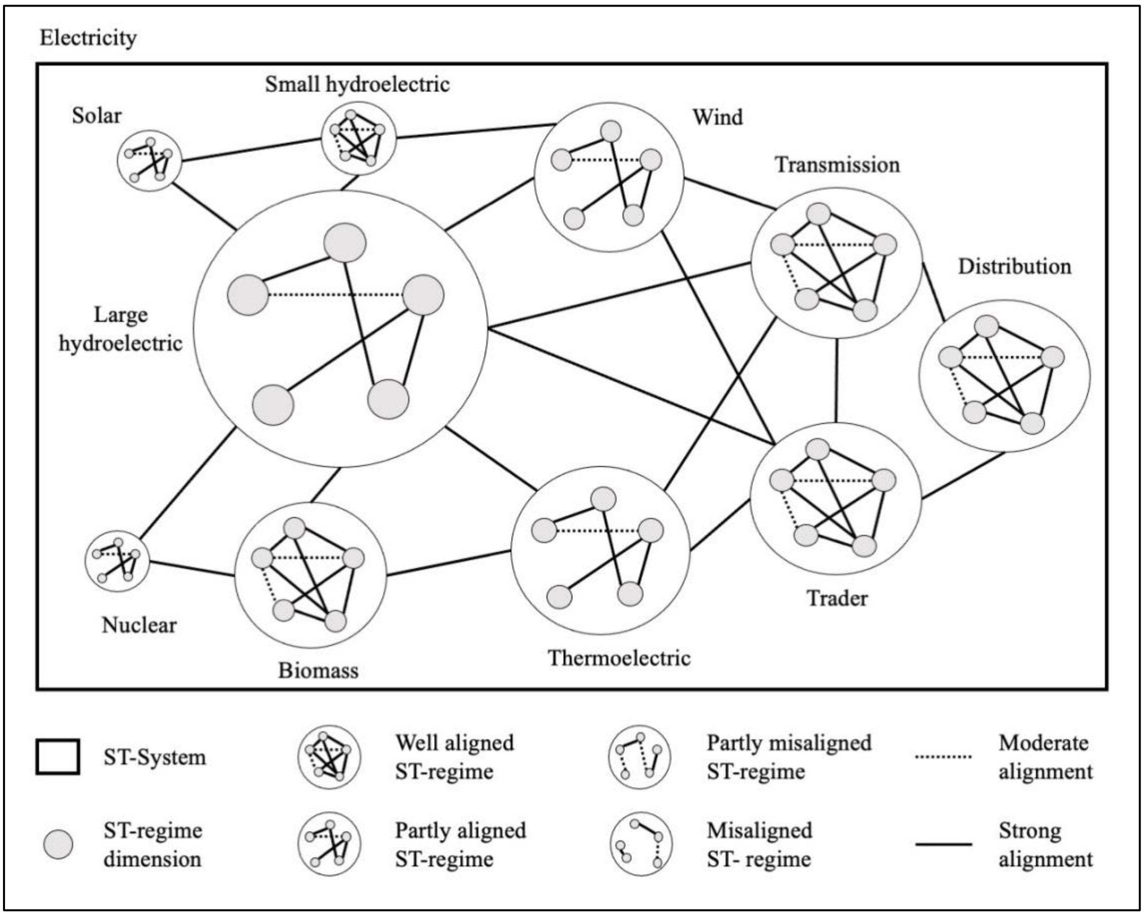
The electricity ST-system can be considered well aligned. Its ST-regimes have significant complementarity with one another. Although the large hydro ST-regimes dominate the electricity generation, this dominance has been decreasing over the last decade, and other renewable sources are becoming relevant. Solar and wind energy have great synergy with hydroelectricity because the latter can compensate for the formers' inherent intermittency. Besides, the electricity generation ST-regimes and transmission, distribution, and trader ST-regimes have a high level of integration, which ONS and ANEEL guarantee. Although there is competition between the electricity generation ST-regimes for the market share, this competition is limited because the electricity system expansion follows EPE's long-term planning, which softens market forces.

Besides, all the ST-regimes in the electricity ST-system can be considered well or partly well aligned. Solar and wind ST-regimes present some unreliability due to intermittency but are highly sustainable and affordable. On the other hand, the thermoelectric ST-regime is unsustainable and expensive but highly reliable, providing stability and reliability to the whole system. The large hydroelectric ST-regime is moderately sustainable, affordable, and somewhat stable. Finally, the nuclear ST-regime can be considered sustainable in GHG emissions but unsustainable because of its risks. It

[54] Thermoelectric power plants can be started much quicker than hydroelectric power plants (TOLMASQUIM, 2016).

is more expensive than renewables but as reliable as thermoelectric plants. Therefore, the solar, wind, thermoelectric, large hydroelectric, and nuclear ST-regimes can be considered partly aligned. All the other ST-regimes should be regarded as well aligned, as shown in Figure 4.3.

Figure 4.3 – Alignments and misalignments of the electricity ST-system and its ST-regimes*



*Not all alignments between ST-regimes are represented in the image.

Source: Developed by the author

It is common for the large companies of the Brazilian ST-electricity system to be part of many of these ST-regimes. For example, Copel and Neoenergia are part of the transmission, distribution, trader, wind, large hydroelectric, thermoelectric, and solar ST-regimes. This characteristic contributes to the alignment of the ST-regimes and the stability of the electricity ST-system.

There are few opportunities for niche innovations to challenge these internally aligned ST-regimes, especially in this well-aligned ST-system. Nonetheless, there are many niches in the electricity ST-system. Liga Ventures (2020) mapped 189 startups in the electricity ST-system and divided them into eleven categories according to their primary technology. Considering the MLP, some of these technologies are considered niche innovations, while others are 'only' incremental innovations to the existing ST-regimes. Besides, one of the categories used by Liga Ventures, electromobility, is a niche from the urban mobility ST-system and not the electricity ST-system.

Therefore, only five of these technologies have the potential to disrupt the ST-regimes and should be considered niches: (i) battery; (ii) energy commercialization and financing; (iii) energy efficiency; (iv) shared management; and (v) consumption management. Besides, a sixth niche should be added to this list: distributed generation[55]. This technology follows significantly different rules and logic from the other electricity generation ST-regimes. Moreover, distributed generation can considerably disrupt many of the existing ST-regimes in the electricity ST-system.

4.2 The Brazilian urban mobility ST-system

The Brazilian urban mobility ST-system comprises many ST-regimes that offer people different services to fulfill their mobility needs. There are some regional differences depending on socio-economic factors such as cities' population and economic resources. Nonetheless, buses, cars, motorbikes, and non-motorized modes of transportation are present in most Brazilian cities. Other modes of public transport, such as rail and metro, are often present in the largest cities. Some cities also have urban water transport, such as Rio de Janeiro ferry boats. Still, this type of mobility is only present in a small percentage of Brazilian cities, especially when considering the large ones. Thus, urban water transport is not considered in the characterization of the Brazilian urban mobility system.

Therefore, six ST-regimes can be distinguished in the Brazilian urban mobility ST-system: walking, cycling, car, bus, train/metro, and motorbike. The walking ST-regime was responsible for almost 40% of the approximately 223 million daily commutes made by the Brazilian population in 2018. Cars and buses were responsible for 25.9% and 24.0% of these commutes. However, commutes by walking are usually much shorter than those by motorized modes of transportation. Thus, buses were responsible for 44.8% of

[55] Only solar and wind sources are considered as distributed generation in the thesis, even though some authors also consider SHPs a type of distributed generation. As described before, SHPs are considered a ST-regime.

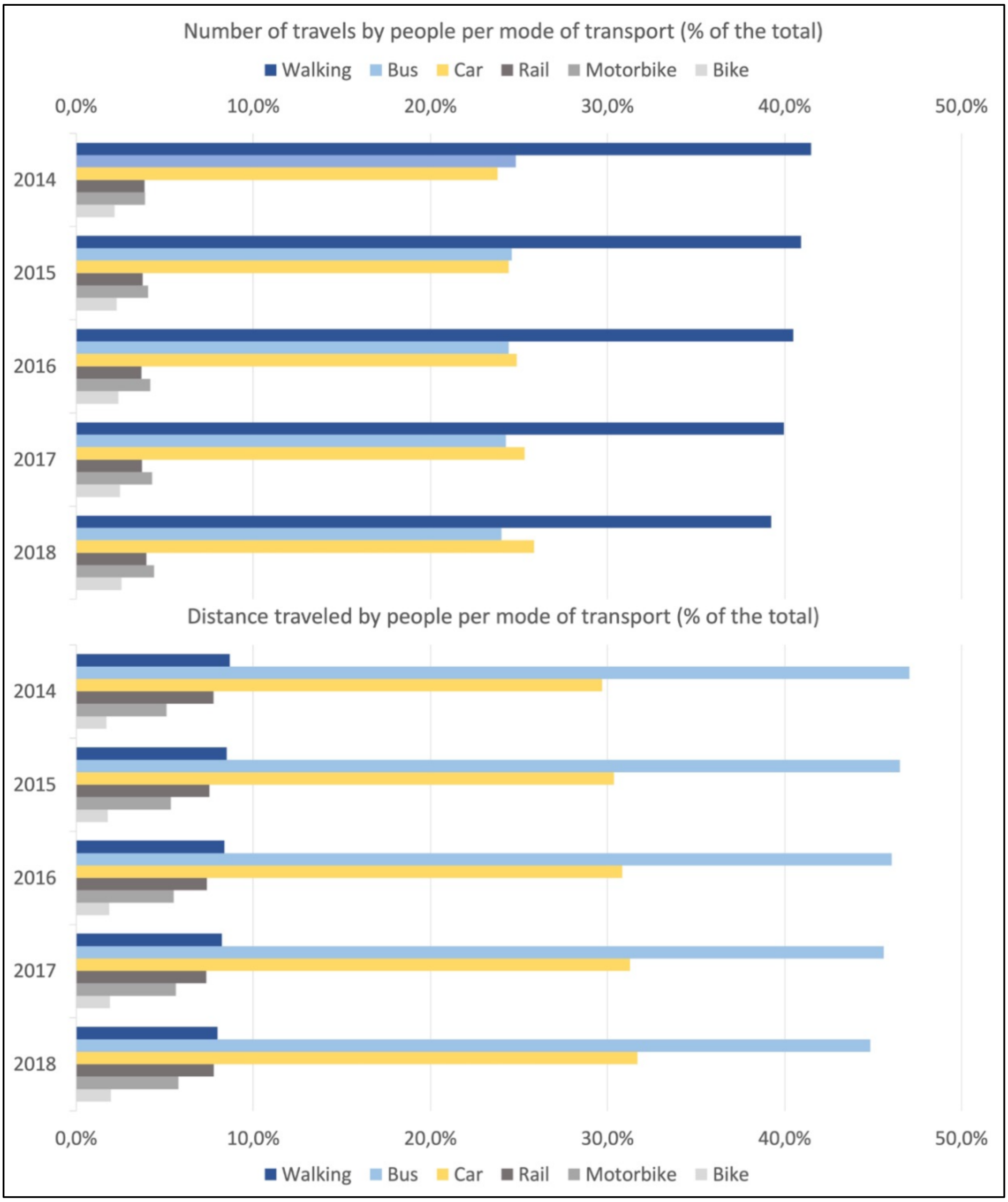
the distance traveled by people in 2018. Cars accounted for 31.7% and walking for only 8.0% (ANTP, 2020a, 2020b).

Nonetheless, the Brazilian urban mobility ST-system is dominated by the private car ST-regime (MARX et al., 2015; VASCONCELLOS, 2018; PINHATE et al., 2020), despite the walking ST-regime being responsible for most commutes and the bus ST-regime accounting for most of the distance traveled. This dominance results from many decades of policies favoring the private car to the detriment of public and non-motorized modes of transportation (BENNERTZ; RIP, 2018; VASCONCELLOS, 2018). These policies date back to the 1930s but gained strength in the 1950s with President Juscelino Kubitschek's incentives to develop a national automotive industry and promote the car use (PINHATE et al., 2020). Later, these policies started focusing on shaping cities according to the mobility needs of a middle-class significantly reliant on the use of the car (VASCONCELLOS, 1997). The mode of transportation is closely related to social-economic status in Brazil, and car ownership is a significant symbol of wealth (PINHATE et al., 2020).

The policies used to promote automobility include subsidizing the manufacturing of cars and petrol prices, reducing licensing costs, providing free parking, and allocating many public resources for the development of road infrastructure, including expanding roads and building bridges, tunnels, and viaducts (VASCONCELLOS, 2018). These policies are also standard in many countries that have followed this same path of favoring automobility, such as the USA, Australia, South Africa, and Russia (SEUM; SCHULZ; KUHNIMHOF, 2020).

The result of these policies is an urban mobility ST-system focused on fulfilling the needs of the private car ST-regime to the detriment of the ST-regimes that provide mobility to most of the Brazilian population. These policies led to an increase in the commutes and distance traveled by cars and a decrease of those by walking and buses, as shown in Figure 4.4. Another consequence is that more than 60% of the Brazilian population rates the quality of the urban mobility ST-system as 'very poor' or 'poor' and evaluates it as unsafe, unfair, and unsustainable (MENDOZA; TUSZEL; JARDIM, 2020; FGV TRANSPORTES, 2021).

Figure 4.4 – Number of travels (a) and distance traveled (b) by people per mode of transport (2014 to 2018)[56]



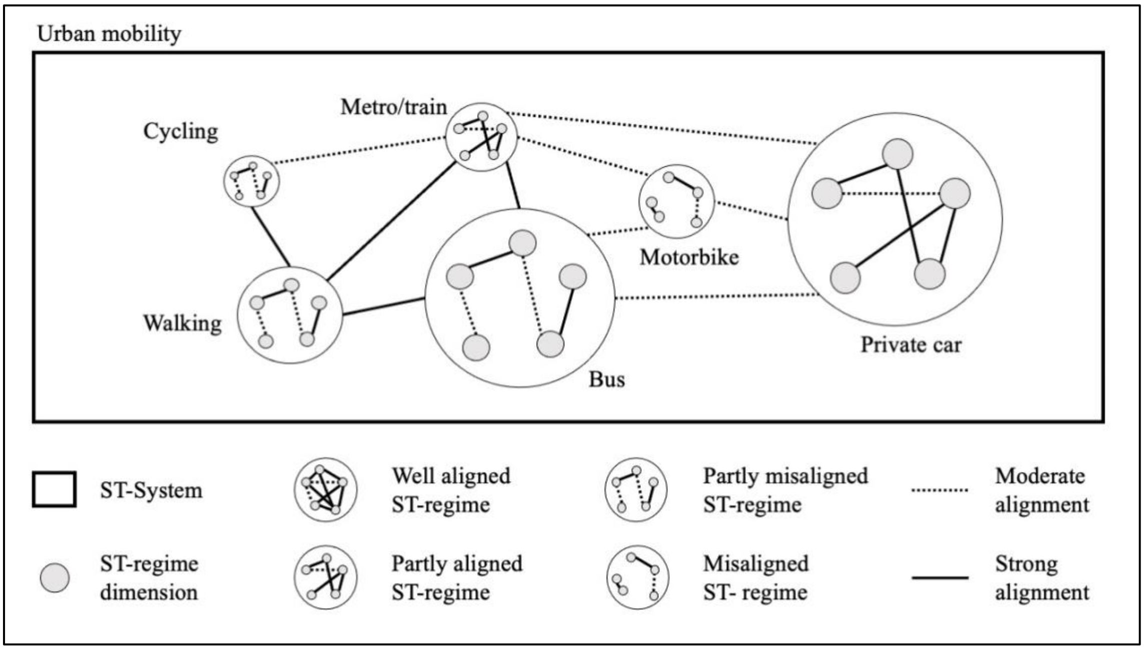
Source: Developed by the author based on ANTP (2018a, 2018b, 2018c, 2020a, 2020b)

This dominance of the private car ST-regime makes the urban mobility ST-system not well aligned (see Figure 4.5). There is limited complementarity between most ST-

[56] ANTP has data on the number of travels by people per mode of transport and the distance of travel by people per mode of transport for the period between 2003 and 2013 (ANTP, 2016). However, this data is not considered in the graphic because ANTP updated the data collection method in 2014. Therefore, it is not possible to compare data collected after 2013 with the previous year.

regimes. Few ST-regimes have the necessary interconnection infrastructure to allow users to exchange between transport modes properly. And only a few of the ST-regimes share their infrastructure with other ST-regimes in a synergic way (see Table B.1). Besides, there is no well-aligned ST-regime. The private car and metro/train ST-regimes can be considered partly aligned (see Table B.2 and Table B.4). The bus, cycling, and walking ST-regimes are regarded as partly misaligned, and the motorbike ST-regime is considered misaligned (see Table B.3, Table B.5, Table B.6, and Table B.7).

Figure 4.5 – Alignments and misalignments of the urban mobility ST-system and its ST-regimes*



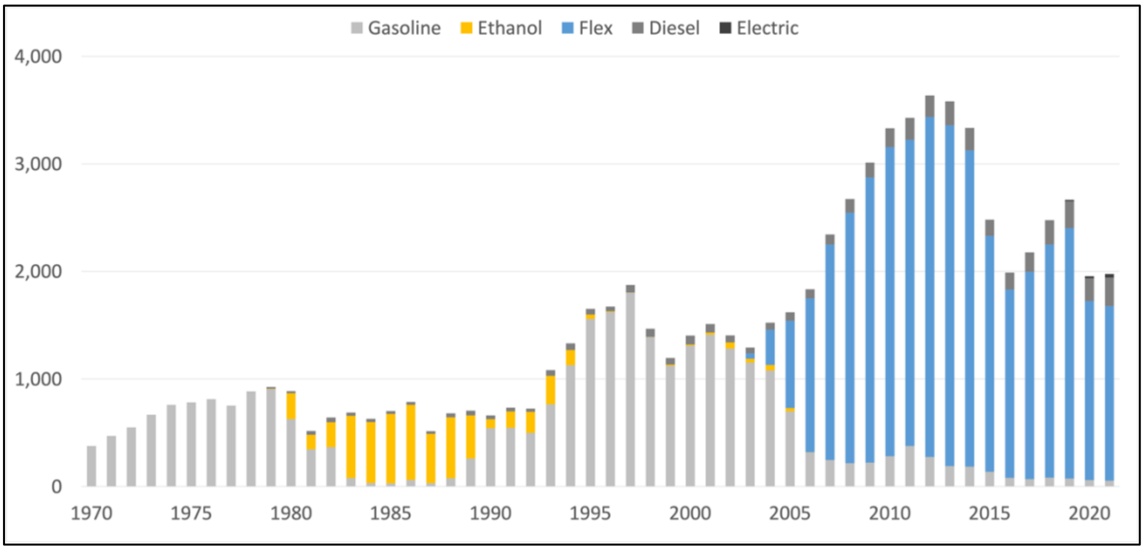
Source: Developed by the author

*Not all alignments between ST-regimes are represented in the image.

Most of the solutions to achieve sustainable urban mobility discussed in Section 2.2 have been proposed in Brazil. Still, none have been fully implemented, and only a few (car sharing, integrated public transport, and ICT) have become relevant niches of the urban mobility ST-system. The only exception is biofuels.

The first experiments using ethanol as a fuel for cars in Brazil date back to 1903. In 1931, the government issued a decree establishing a mandatory blend of 5% ethanol to all imported gasoline (DUNHAM; BOMTEMPO; FLECK, 2011). After the oil crisis of 1973, the government financed the development of cars fueled exclusively by ethanol, increased the percentage of ethanol in the blend with gasoline, and subsidized ethanol's production. As a result, ethanol became a relevant fuel in the Brazilian private car ST-regime in the 1980s (BENNERTZ; RIP, 2018), as shown in Figure 4.6. Most of these policies were abandoned after Brazil's re-democratization in 1989. Although the mandatory ethanol-gasoline blend was maintained, ethanol lost some of its relevance in the 1990s.

Figure 4.6 – Brazilian car licensing per year (1970-2021) by fuel in thousand of units



Source: Developed by the author based on ANFAVEA (2021a, 2022).

Ethanol became a critical fuel again in the 2000s, with the development of the Flexible Fuel Vehicle (flex-fuel cars), i.e., a vehicle that can be fueled by gasoline and ethanol. Flex-fuel cars became popular in the 2000s, and they were the leading technology of the Brazilian private car ST-regime by 2020, as shown in Figure 4.6. Therefore, biofuels should not be considered a niche in Brazil. They should be regarded as a ST-regime like the fossil fuel ST-regime. However, as the fossil fuel ST-regime, they are not considered part of the urban mobility ST-system in the characterization of the urban mobility ST-system. These regimes should be regarded as part of the energy ST-system or even as ST-systems themselves.

Due to this large investment in ethanol and the production chain already established in Brazil for its production, there is much debate about whether biofuels are a better option than electric cars to make urban mobility sustainable in Brazil.

Gonçalves et al. (2022) affirmed that the flex-fuel vehicle is a better option than HEV, PHEV, and BEV in economic, environmental, and social aspects. They believe that Brazil should focus on improving the flex-fuel ICEVs instead of transitioning to EVs. Malaquias et al. (2019) stated that a quick transition to EVs in Brazil is not realistic. They affirmed that flex-fuels ICEVs will still be part of the Brazilian fleet for a long time because there would not be enough electricity to power a full transition to EVs[57]. They also argued that flex-fuels ICEVs are not 'villains of the environment' and believed that combining recent advances on internal combustion engines with advances on biofuels, notably ethanol, is a better alternative than the electrification of the transport means.

Lavrador and Teles (2022) did a life-cycle assessment of BEVs and ICEVs powered only by ethanol (ICEVe) in Brazil. They concluded that ICEVes are better than BEVs in terms of environmental impacts through their life cycle. However, according to the authors "there is an environmental limit above which the impacts linked to the indirect land use related to sugarcane farming overcome the benefits of using ICEVe" (LAVRADOR; TELES, 2022, p. 11). Therefore, they advised policymakers to foment both EVs and biofuels in Brazil.

Yamamura et al. (2022) view the flex-fuel ICEV and the ethanol HEV as technologies that will bridge the transition towards electrification of the urban mobility ST-system. Nonetheless, they highlighted that Brazil must not lose sight of electrification and believed that the future of this ST-system will be composed of BEVs and ethanol FCEVs.

Dranka and Ferreira (2020) pointed out many synergies in the use of bioresources between the urban mobility and electricity ST-systems. They affirmed that the transition to EVs can be coupled with a shift of the use of biofuels from the urban mobility ST-system to the electricity ST-system. According to them, this shift would maximize the benefits of the electrification of the urban mobility ST-system.

Glensor and Munoz (2019) compared the conversion of car and urban bus fleets from ICEVs to 100% electric (BEV) or 100% biofuel (flex fuel ICEVs) and concluded that electrification resulted in significantly lower GHG emissions. Therefore, they believe that the government should promote EVs in Brazil. However, they recognize the relevance of the biofuel industry in Brazil and that this ST-system should be included in the planning of the transition.

Furthermore, some authors fear that if Brazil chooses not to invest in EVs, the country will lag behind other countries and will not be able to compete with them in the future, becoming a 'technology island' (GLENSOR; MUÑOZ, 2019; VARGAS et al., 2020; SCHIAVO et al., 2021). Vargas et al. (2020) highlighted that Brazil needs to overcome any negative impact on the biofuels ST-system in order to harness the potential

[57] This argument has been contested by many authors including the MME and EPE (2020), who claim that there is enough energy even if the entire Brazilian fleet of cars is replaced by EVs.

of this new market (EVs), for example by exploring the use of bio-plastics (CORINNE DRENNAN, 2018).

Car sharing is a niche that has considerably increased with the introduction of car-sharing mobile applications in the middle of the 2010s. The number of 'app drivers,' i.e., self-employed drivers that use mobile apps such as Uber or 99 Taxi, has increased 137.6% between 2012 and 2019 in Brazil, surpassing 1 million drivers (CARDIN, 2020). Besides, Uber and 99 Taxi had 22 million and 16 million registered Brazilian users in 2020, respectively (99 TAXI, 2020; UBER, 2020). This number of users represents more than 10% of the population even considering a total overlap of users of these two platforms. It is one of the most relevant niches of the urban mobility ST-system in Brazil.

Some cities, such as Brasília, Curitiba, Rio de Janeiro, and São Paulo, have implemented integrated public transport solutions. The main advances in this niche are the installation of integrated fare systems and the construction of some interchange (or transfer) stations to integrate bus, BRT, and metro. However, only 18 of the 5,570 Brazilian municipalities had at least one interchange station in 2019, and there were only 200 of these stations in the whole country (NTU, 2019).

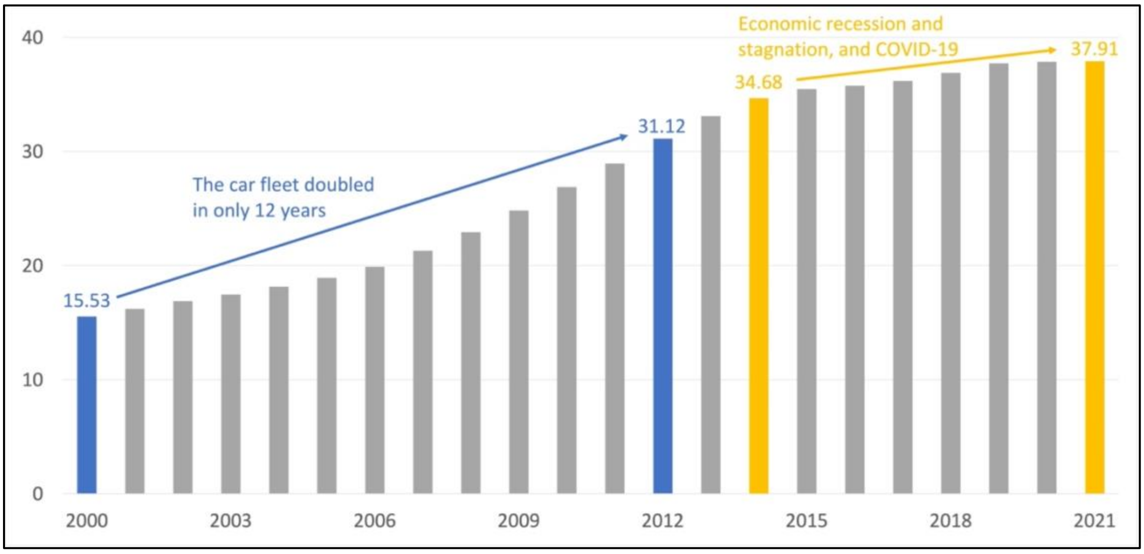
Information and communication technologies (ICT) is another niche that has been considerably impacting the urban mobility ST-system, especially after the start of the COVID-19 pandemic. The focus here is on teleworking (home working). Other applications of ICT should be considered incremental innovations to the existing ST-regimes and not niches (e.g., systems to purchase bus and metro tickets online). The number of people working from home increased from approximately 4.6 million to 7.3 million from March to November 2020 (GÓES et al., 2020; GÓES; MARTINS; NASCIMENTO, 2021), which means that almost 10% of the working force was doing teleworking. Besides, the number of workers in home working arrangements peaked at 8.7 million in May 2020 (GÓES; MARTINS; NASCIMENTO, 2021).

The other alternatives to reach sustainable urban mobility (see Section 2.2) are nascent in Brazil, without any potential to disrupt the existing ST-regimes soon. One exception is the electric car niche, which has been increasing exponentially in the last five years. This niche is detailed in Section 4.2.2.

4.2.1 The Brazilian private car ST-regime

The Brazilian car fleet was approximately 37.9 million units in 2021. It more than doubled in only 12 years, as there were only 15.5 million cars in Brazil in 2000 and more than 31.1 million cars in 2012 (ANFAVEA, 2021a), as shown in Figure 4.7. Nonetheless, the vehicle fleet growth rate in Brazil slowed down significantly after 2013, mainly due to the economic recession and, later, the COVID-19 pandemic.

Figure 4.7 – Brazilian car fleet per year (2000-2021) in millions of units



Source: Developed by the author based on ANFAVEA (2022).

Despite the reduction in the vehicle fleet growth rate after 2012, the motorization rate has considerably increased between 2000 and 2021, going from 0.1 to 0.18 car/inhabitant, given that in this period the Brazilian population increased by only 12.9% (IBGE, 2021). However, this motorization rate still is much lower than most developed countries, e.g., Germany (0.58 car/inhabitant), Italy (0.66 car/inhabitant), and Australia (0.76 car/inhabitant) (AUSTRALIAN BUREAU OF STATISTICS, 2020; ACEA, 2021). It is also lower than other developing countries, such as Argentina (0.32 car/inhabitant), Chile (0.25 car/inhabitant), México (0.26 car/inhabitant) and South Africa (0.21 car/inhabitant) (GLOBAL FLEET, 2021).

Although there are many actors in the private car ST-regime, such as auto parts suppliers, repair shops, and dealerships, the main actors of this ST-regime are the car corporations[58] (MARX et al., 2015; DAUDT; WILLCOX, 2018). They are the driving force of the ST-regime, capturing most of the revenues and profits. These corporations' economic power gives them significant political power and the capacity to influence policies for the urban mobility ST-system (VANALLE et al., 2020; SILVA; CHIARA; GUIMARÃES, 2021). Besides, the Brazilian government's interests are often dependent

[58] Car corporations are large multinational companies that owns one or more car manufacturers or brands.

on satisfying the car corporations' interests. These intertwined interests give the corporations the ability to 'change the rules of the game,' i.e., the "actions and policies by governments that attract and regulate the development of an industry" (DUARTE; RODRIGUES, 2017, p. 3). This condition has resulted in many benefits for the car corporations and private car ST-regime, such as tax reductions, subsidies, tax incentives for car purchase, control of fuel prices, and trade barriers to protect local manufacturers.

Brazil is the world's eighth-largest producer of automobiles and the sixth-largest car market. The automotive industry is one of Brazil's leading industrial and economic forces. In 2019, it represented 20% of the industrial GDP and 2.5% of the total GDP. This industry is also responsible for 1.2 million direct and indirect jobs (ANFAVEA, 2022). There are 16 leading car corporations in the Brazilian market (FENABRAVE, 2021). They own 24 car brands in Brazil and are represented by more than 3,500 dealerships (ANFAVEA, 2021a). Fifteen of these car corporations have factories in Brazil, totaling 32 units (ANFAVEA, 2021a), as shown in Table 4.2.

Table 4.2 – Car corporations in Brazil

Car corporation	Car brands in Brazil	Factories in Brazil	Market share in Brazil (%)
Stellantis[59]	Fiat, Jeep, Peugeot, Citroen	5	19,26%
General Motors	Chevrolet	5	18,89%
Volkswagen Group	Volkswagen, Audi, Porsche, JAC Motors	5	17,63%
Hyundai Group	Hyundai, Kia	1	10,33%
Groupe Renault[60]	Renault	4	7,43%
Ford Motor Co.	Ford	0	7,39%
Toyota Motor Corp.	Toyota	4	6,53%
Honda Motor Co.	Honda	3	5,21%
Nissan Motor Corp.	Nissan	1	3,28%
CAOA Chery	Chery	1	1,24%
BMW Group	BMW	1	0,77%

[59] Groupe PSA and FCA have merged in January 2021, forming a new automobile company called Stellantis (GROUPE PSA; FCA, 2021).

[60] Renault has a partnership with Nissan and Mitsubishi, called Renault-Nissan-Mitsubishi Alliance. However, they do not form a single corporation, although they share some resources, such as joint investments in R&D.

Car corporation	Car brands in Brazil	Factories in Brazil	Market share in Brazil (%)
Mitsubishi Motors Corp. [61]	Mitsubishi	1*	0,49%
Zhejiang Geely Holding Group Co.	Volvo	0	0,48%
Daimler AG	Mercedes-Benz	0	0,42%
Tata Motors	Jaguar, Land Rover	1	0,29%
Suzuki Motor Corp.	Suzuki	1*	0,16%
Total	-	32	99,8%

*Shared factory

Source: Developed by the author based on ANFAVEA (2021a) and FENABRAVE (2021).

The five largest car corporations in Brazil, General Motors, Stellantis, Volkswagen Group, Hyundai Motor Group, and Groupe Renault, have approximately 74% market share. These five companies own 20 factories and are represented by over 2,400 dealerships (ANFAVEA, 2021a; FENABRAVE, 2021). Nonetheless, this concentration of the market share with a few car corporations is similar to other countries, such as the USA (the five largest corporations have 67% of the market share) (GOODCARBADCAR, 2021), Canada (the five largest corporations have 63% of the market share) (GOODCARBADCAR, 2020), and the European Union (the five largest corporations have 63% of the market share) (ACEA, 2020).

None of the car corporations operating in Brazil is Brazilian. They are all multinational corporations incorporated abroad. BMW Group, Daimler AG, Groupe Renault, Stellantis, and Volkswagen Group are European. Honda Motor Co., Mitsubishi Motor Corp., Suzuki Motor Corp., Nissan Motor Corp., and Toyota Motor Corp. are Japanese. Ford Motor Co. and General Motors are North American. CAOA Chery and Zhejiang Geely Holding Group Co. are Chinese. The last two are South Korean (Hyundai Group) and Indian (Tata Motors).

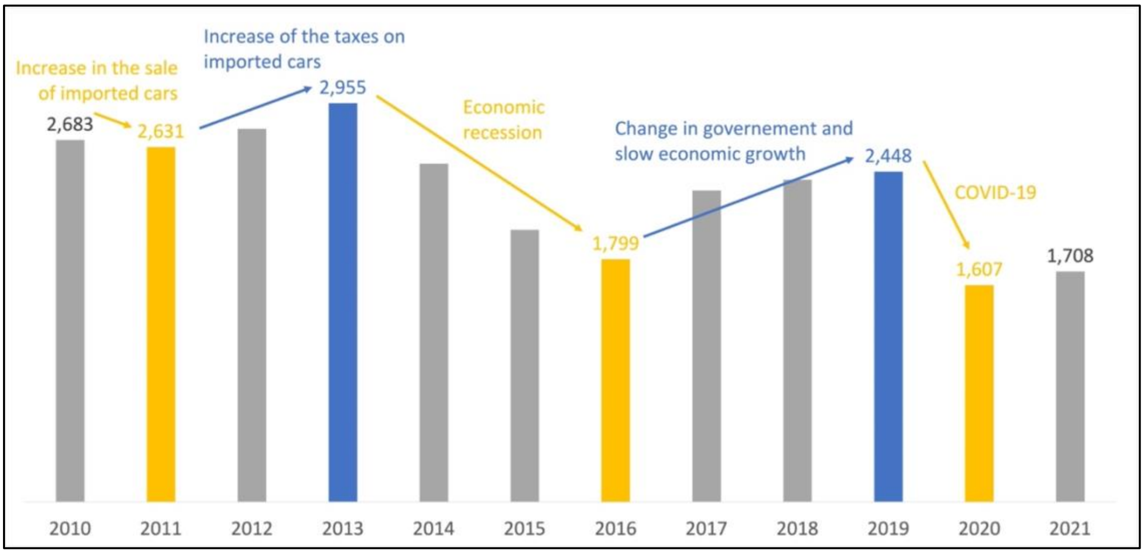
Therefore, the Brazilian private car ST-regime is susceptible to the impacts of foreign countries' decisions that may not be the best for the country (DAUDT; WILLCOX, 2018). For example, Ford's decision to close its three Brazilian factories and concentrate its production to the South American market in Argentina and Uruguay led

[61] Mitsubishi and Suzuki are represented by HPE Automotores in Brazil. Cars from both brands are produced in HPE's factory in Catalão, Goiás.

to the loss of five thousand jobs in Brazil in 2021 (SODRÉ; BRIGATTI; VALADARES, 2021).

After many years of a constant increase in car production and sales between 2000 and 2010, the Brazilian car industry has suffered some setbacks in the last decade. In 2011, it experienced the first decrease in car production compared to the previous year in over ten years due to decreased demand and increased sales of imported vehicles (see Figure 4.8). Car production rose again in the following two years, reaching its historic peak in 2013. Then, the industry was considerably impacted by the economic crisis between 2014 and 2016.

Figure 4.8 – Brazilian car production per year (2010-2021) in thousand of units



Source: Developed by the author based on ANFAVEA (2022).

The car industry was recovering after the change in government in 2016 and the period of slow economic growth that followed when it was deeply affected by the COVID-19 pandemic (see Figure 4.8). New cars' production decreased 34.4%, from 2.45 million in 2019 to 1.61 million units in 2020. New car sales have dropped 28%, from 2.08 million units in 2019 to 1.50 million units in 2020. Both car imports and exports also suffered negative impacts, with 34.6% and 24.3% reductions, respectively (ANFAVEA, 2021b; FENABRAVE, 2021). In 2020, ANFAVEA (2021c) predicted an increase of 25% in car production for 2021, which would still be insufficient for the resumption of pre-pandemic levels. However, the real increase was much lower than this, of only 6.26% (ANFAVEA, 2022).

4.2.2 The Brazilian electric car niche

There is no registry of electric cars in Brazil at the start of the 19th Century, as was the case in Europe and the USA. However, electric vehicles have been tested in Brazil long before the current hype. The entrepreneur João Augusto Gurgel, owner of the car company Gurgel Motores S/A, presented an electric car prototype, the Itaipu Gurgel (see Figure 4.9), in 1974. The name was a tribute to Brazil's largest hydroelectric power plant at the time: Itaipu Binacional. The car was never mass-produced, though, because of its low autonomy and long charging time, related to the weak battery system (SCHAUN, 2021).

Figure 4.9 – The first Brazilian electric car, Gurgel Itaipu

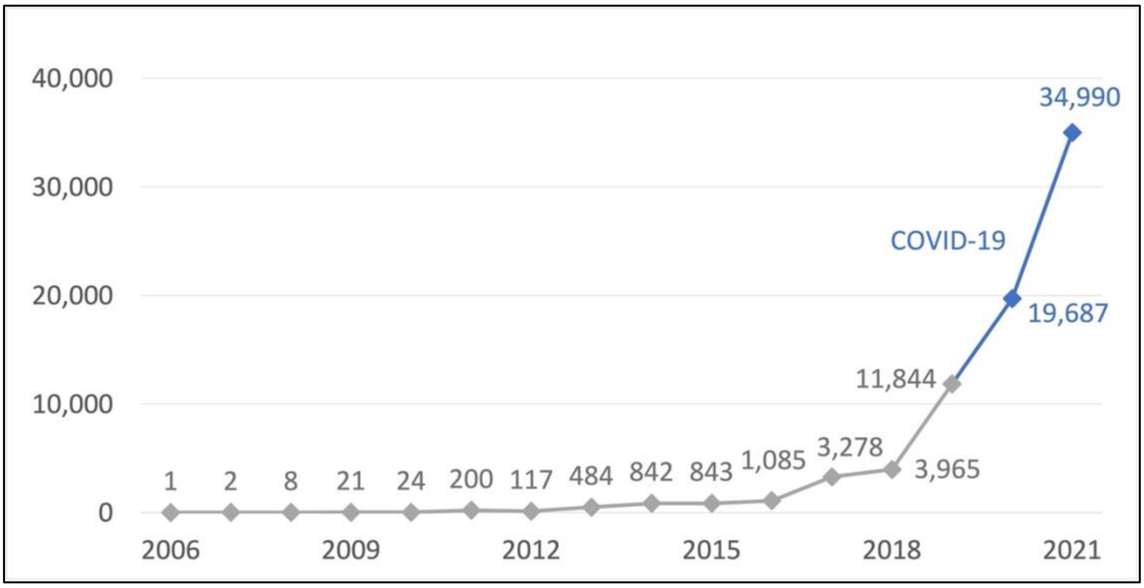
Source: https://pt.wikipedia.org/wiki/Gurgel_Itaipu.

In the 1990s, Fiat tested an electric car, the Panda Elettra Park, in Curitiba. This project was a partnership with the electricity company Copel (ARANTES, 1997). In 2007, Fiat made some new tests with electric vehicles, this time in collaboration with Itaipu Binacional (MORENO, 2009). These experiments were isolated from each other and did not help the structuration of an electric car niche in Brazil.

Electric cars started to become slightly relevant in Brazil only in 2010. The company Obvio! announced its plan to produce electric cars the following year (MIRANDA, 2010). Besides, the Brazilian government discussed financing electric cars' development and creating a public car company to develop and sell electric cars (SALOMON, 2010). These facts may be considered the birth of the Brazilian electric car niche. Although they didn't have any short-term impact, they represent the initial articulation of expectations and visions for the electric car in Brazil.

The Brazilian electric car niche already has few designs, with BEV and PHEV dominating the electric car market. Besides, the niche is starting to have some stabilized rules. For example, ANEEL published, in 2018, resolution nº 819 that establishes the procedures and conditions for activities related to the charging of electric vehicles. Moreover, the niche is already supported by many powerful actors, such as companies from the electricity ST-system. These facts and the exponential growth of sales (see Figure 4.10) indicate that the Brazilian car niche is moving towards full development.

Figure 4.10 – Electric car licensing in Brazil from 2006 to 2021



Source: Developed by the author based on ANFAVEA (2022).

The number of electric cars has been increasing since 2006 in Brazil, presenting an exponential growth in the last five years, as can be seen in Figure 4.10. In contrast with ICEVs, the licensing of electric cars increased during the COVID-19 pandemic. The licensing of PHEVs and BEVs increased 195% between 2019 and 2021, from 11,844 to 34,990 units (ANFAVEA, 2022). Considering only BEVs, the licensing increased 411% between 2019 and 2021, from 559 to 2860 units (SILVEIRA, 2021; ANFAVEA, 2022). Besides, many charging stations have been installed since 2011 in several Brazilian cities, such as Brasília, Belo Horizonte, Curitiba, Fortaleza, São Paulo, and Rio de Janeiro (BARASSA; DA CRUZ; MORAES, 2021).

Some authors, for example Malaquias et al. (2019), fear that there will be an increase in the use of non-renewable energy sources in the Brazilian electricity ST-system if the pace of growth of the electric vehicle fleet continues to accelerate in Brazil in the coming years. However, MME and EPE (2022) estimate that the share of non-renewable sources in the Brazilian energy matrix[62] will fall only 1% between 2021 and 2031 and that the share of renewable sources in the electric matrix[63] will remain stable at 84% in this period. MME and EPE (2020) also estimate that the share of renewable sources in the energy matrix and in the electric matrix in 2050 will be around 45% and 50% and 80% and 85%, respectively. Moreover, MME and EPE (2020) indicate that there are enough unexplored renewable resources to maintain the current share of renewable energy in the energy matrix even in a scenario where the entire Brazilian fleet of light vehicles is electric in 2050.

The increase in EV sales during the COVID-19 pandemic may be a consequence of the pandemic. The cheapest EV in Brazil has the same price as luxury ICEVs, and the sale of luxury cars has also increased in Brazil between 2020 and 2022 (BRITO, 2022). For example, Porsche sales increased approximately 64% in this period (BARBOSA; SETTI, 2021; FERREIRA, 2022). This trend has also been seen in many other countries (ELLIOT, 2021). One possible cause of this increase is that travel limitation due to the pandemic induced wealthy consumers to use the resources usually spent traveling to buy luxury products, including cars (CIPRIANO, 2021). Another explanation is that the stock market volatility during the pandemic made some investors move their resources to hard assets (ELLIOT, 2021). Nonetheless, the increase in EV sales indicates that at least wealthy consumers are willing to transition to electric cars. Many of the best-selling luxury cars in Brazil in 2020 and 2021 were electric (CIPRIANO, 2021; AQUINO, 2022).

However, electric cars' high upfront cost is an issue that still needs to be solved for the niche to get fully structured. This initial high price makes most users perceive that EVs have a worse price/performance relation than ICEVs, although the operation cost of EVs is much lower. Besides, there are few policies to reduce the upfront cost of EVs. BEVs and FEVs have import tax exemptions and a reduced production tax, but there are no incentives for PHEVs. In addition, nine Brazilian states have exempted EVs from the ownership tax. However, these incentives are not as strong as those in countries like Australia, China, Netherlands, and the USA (GONG; ARDESHIRI; HOSSEIN RASHIDI, 2020; SANTOS; DAVIES, 2020; SIEBENHOFER; AJANOVIC; HAAS,

[62] Set of sources available in a country, state or in the world, to meet the need (demand) for energy (EPE, 2022c).

[63] Set of sources available for the generation of electricity. The electric matrix is part of the energy matrix (EPE, 2022c).

2021). Besides, there are no non-monetary incentives for EVs, such as free public charging and parking and access to bus lanes.

Another issue in the Brazilian electric niche is that new car[64] manufacturers are not emerging. Unlike China, the EU, and the USA, where car companies focused on EVs, such as Tesla, BYD, Rivian, Nio, and Nikola Motors, are challenging legacy brands, the latter dominates the Brazilian electric car niche. The main EV sellers in Brazil are BMW, Toyota, and Volvo (BARASSA; DA CRUZ; MORAES, 2021).

Although some Brazilian companies produce electric vehicles, they are limited to ‘micro mobility’ (e.g., e-scooters and e-bikes), motorbikes, and ‘mini cars[65].’ Moreover, only four companies produce mini EVs: Gaia Electric Motors, Mobilis, move, and Movi Electric, according to Liga Ventures startup scanner[66] (see Appendix B). Almost 70% of the companies classified by Liga Ventures in the electromobility sector offer electric chargers (38%) or micro-mobility products (29%).

Therefore, the electric car niche in Brazil is controlled by the same car corporations that already control the private car ST-regime and the urban mobility ST-system. These companies do not seem interested in accelerating the transition to electric cars in Brazil due to sunk costs and lack of pressure from the government. Nonetheless, this ST-transition is already creating opportunities for new actors to challenge these established corporations in Brazil, as is happening in other countries. However, recent trends indicate that legacy companies are more likely to be challenged by multinational electric car companies, such as Tesla and BYD, than by local automakers.

The transition to electric cars can create opportunities for other actors, besides automakers, to enter the private car ST-regime and the urban mobility ST-system. The transition from fossil fuels to electricity as the primary energy source for cars and other vehicles allows electricity companies to expand their operation into a new ST-system. These companies are already heavily involved in the electric car niche (BARASSA; DA CRUZ; MORAES, 2021). The various sustainability experiments with electric cars that have been promoted and financed by electricity companies over the last decade illustrate this involvement.

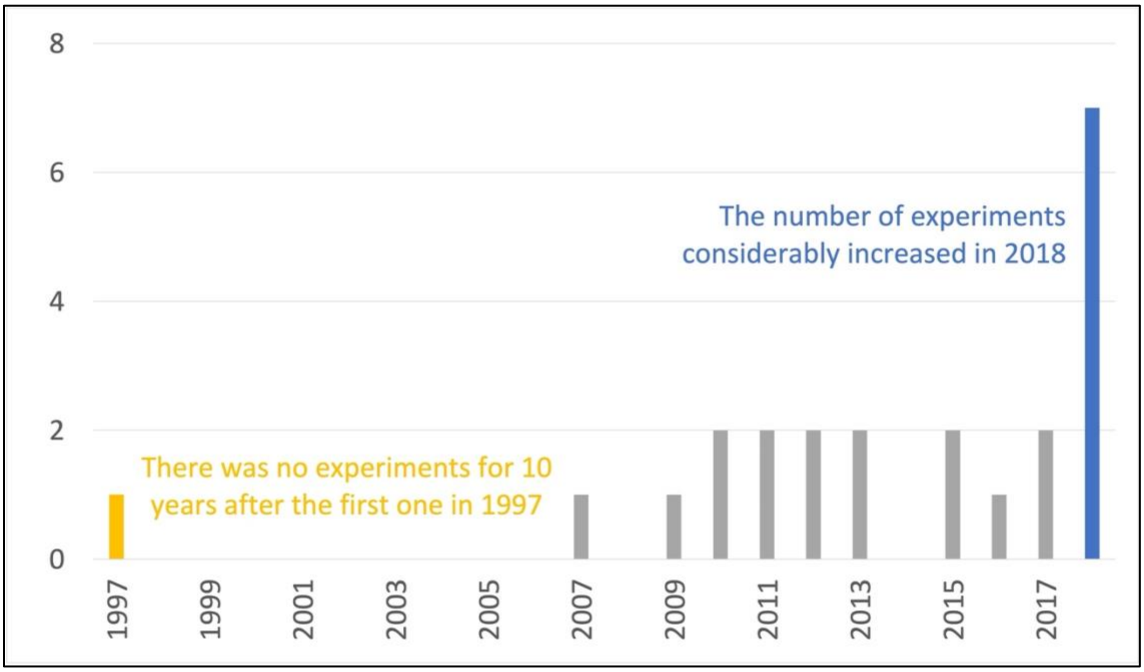
[64] Vehicles classified in EU category M.
[65] Vehicles classified in EU category L.
[66] Available at https://startupscanner.com/.

4.3 Sustainability experiments with electric cars involving actors from the electricity ST-system

Actors from the electricity ST-system have participated in sustainability experiments with electric cars in Brazil for many years. Some of the first experiments with EVs in the 1990s and 2000s involved electricity companies. For example, Itaipu Binacional has a long history of investments in the development of the electric car, participating in seven experiments between 2007 and 2018. The company is recognized as one of the leading promoters of EVs in Brazil, having invested in the development of electric car prototypes, batteries, and chargers. Besides, Itaipu's renowned research center is conducting much research related to electric cars (MELO, 2017).

Many other actors from the electricity ST-system have relevant involvement with the electric car niche. Twenty-four different sustainability experiments with electric cars involving actors from the electricity ST-system were identified through secondary data research (see Section 3.5.1). These experiments happened between 1997 and 2018, i.e., before SRDP-22 started. However, only one was done before 2007, as shown in Figure 4.11.

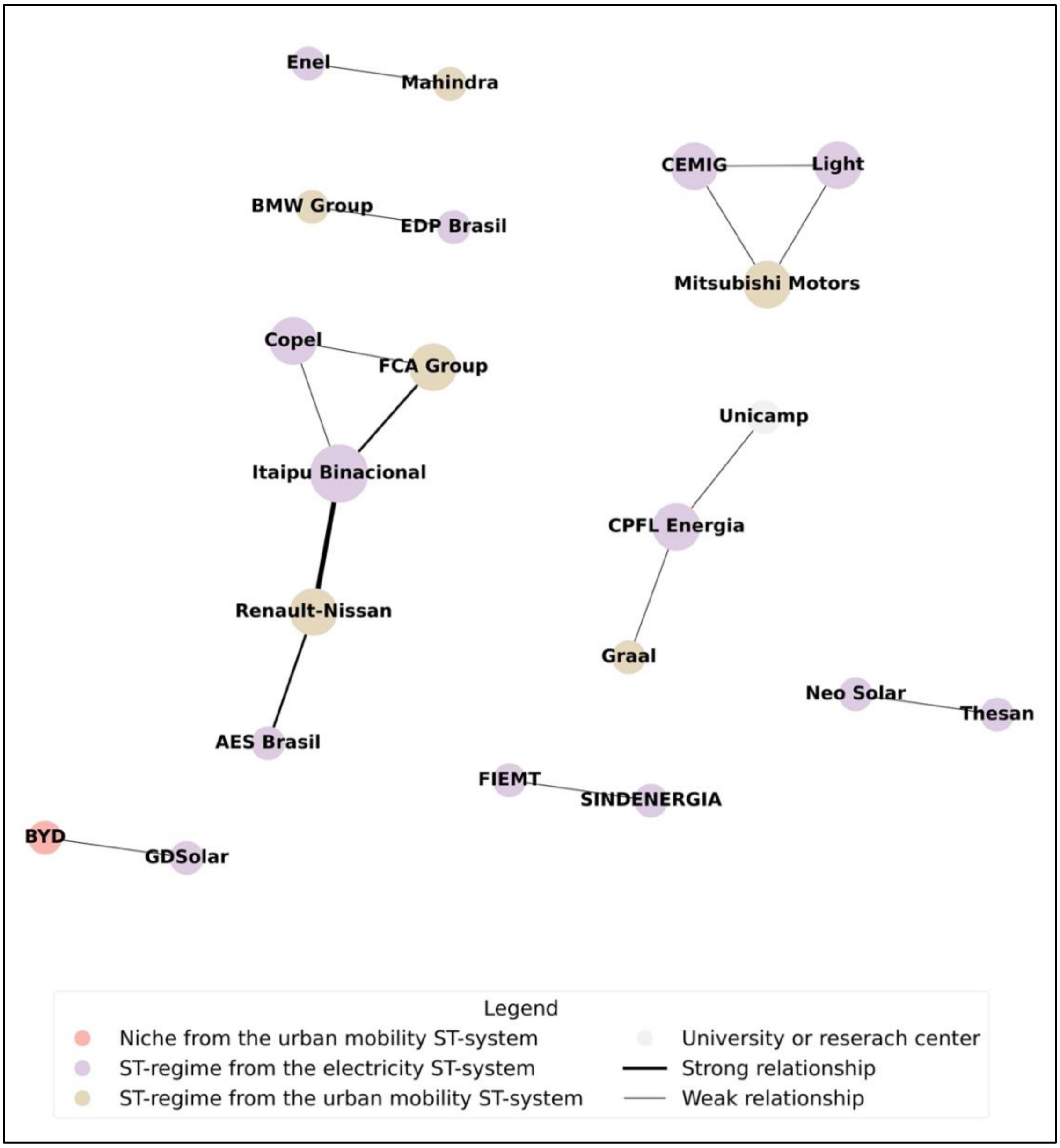
Figure 4.11 – Number of sustainability experiments with electric cars involving actors from the electricity ST-system per year (1997-2018)



Source: Developed by the author

These experiments involved 23 different actors, from which 15 were actors from ST-regimes of the electricity ST-system, 7 were actors from the private car ST-regime, and 1 was an actor from the electric car niche. The collaboration network of sustainability experiments with electric cars involving actors from the electricity ST-system (see Figure 4.12) shows that most of these experiments were isolated initiatives from a few actors.

Figure 4.12 – Collaboration network of sustainability experiments with electric cars involving actors from the electricity ST-system between (1997 and 2018)



Source: Developed by the author

The collaboration network also shows that the electric car market leaders, BMW, Volvo, and Toyota, are not relevant actors in the sustainability experiments. Toyota has not been involved in a single experiment. On the other hand, most of the leading companies of the electricity ST-system, such as Itaipu, EDP Brasil, CPFL Energia, CEMIG, Engie, Copel, Enel, and Neoenergia, have participated in experiments with electric cars. There are even experiments that were conducted exclusively by companies of the electricity ST-system. However, not a single niche actor of this ST-system has been involved in experiments with electric cars[67].

Besides, only one university, Universidade Estadual de Campinas (Unicamp), have participated in the experiments identified. This finding corroborates Barassa's (2019) observation that the scientific production related to electric cars is still developing in Brazil. Nonetheless, universities and research centers are relevant actors of the electric car niche in Brazil (CONSONI et al., 2018). One possible explanation for their low participation in the experiments is that Brazilian universities and research centers' collaboration network on electric cars might have been concentrated in partnerships between themselves, with few partnerships with other ST-regime and niche actors, as pointed out by Consoni et al. (2018).

Finally, it should be emphasized that government actors are not indicated in the collaboration network because they are not part of one specific ST-system. Nonetheless, state, and municipal governments, such as the government of the Federal District and the government of the São Paulo municipality, had relevant participation in many of the sustainability experiments identified.

4.4 Strategic Research and Development Project nº 22 from ANEEL

In 2000, the Brazilian government sanctioned the Law nº 9.991, of July 24, 2000, which stablished that companies that have contracts with the government to generate, transmit or distribute electricity must apply between 0.2% and 0.4% of their annual revenue in R&D projects regulated by ANEEL[68]. 4,247 R&D projects, including 21 Strategic Research and Development Projects[69], were implemented between 2008 and 2019, with a total investment of US$ 1.5 billion[70]. These projects focused on themes such

[67] Some authors may classify the companies working on the electric car charging infrastructure as niche actors of the electricity ST-system, instead of the urban mobility ST-system. In this case, some of the niche actors presented in the collaboration network would be considered actors of a niche of the electricity ST-system.

[68] The companies must set aside the resources for R&D in a specific account. These resources can only be used when the company has a R&D project approved by ANEEL. See http://www2.aneel.gov.br/cedoc/aren2018830_Proret_Submod_5_6_V1.pdf for more details.

[69] In a Strategic Research and Development Project, ANEEL defines a main theme of research and selects R&D projects proposed by the electricity companies to be part of the strategic project.

[70] Considering the currency rate between Real and Dollar at the time of writing.

as developing renewable energy, preparing the electricity sector for extreme climate events, improving the electricity system quality, and advancing energy storage technologies.

In 2017, ANEEL asked the CGEE to do a study to identify and select R&D themes in the electricity sector that could provide solutions to overcome the sector's future challenges (ANEEL, 2018a). The study established 5 main thematic groups for the electricity sector, divided into 48 macro themes, 181 themes, 46 technological routes and 2,767 topics of research, development and innovation (CGEE, 2017). The macro themes were classified and ranked according to their priority for the strategic planning of the electricity sector. Electromobility was recognized as the highest ranked macro theme that had not yet been the subject of an ANEEL's Strategic Research and Development Project (CGEE, 2017).

The result of this study motivated ANEEL to further explore the electromobility theme. In 2018, the agency hired the German development agency *Deutsche Gesellschaft für Internationale Zusammenarbeit* (GIZ) to do a study on the governance and policy of EVs around the world (ANEEL, 2018a). The study showed that Brazil did not have the same drivers that are motivating the investments in EVs in places such as China, the EU, and the USA. Nonetheless, the study indicated that investing in EVs should be considered an opportunity to contribute to Brazil's development and its insertion in global value chains. The conclusion was that to take advantage of this opportunity, the government must build a national consensus around EVs, directing actions in their favor, setting goals, and creating more effective actions than those undertaken so far (CONSONI et al., 2018).

In 2018, ANEEL promoted a meeting of the *Rede de Inovação no Setor Elétrico* (RISE, Electric Sector Innovation Network)[71] focused on electromobility. RISE identified the need for more government incentives for EVs and the development of the charging infrastructure as the main challenges for the diffusion of EVs in Brazil (ANEEL, 2018b).

Meetings between ANEEL's officials and electromobility experts resulted in the draft of SRDP-22 (ANEEL, 2018a). This draft was the subject of a public consultation between November 2018 and January 2019, when anyone could submit contributions to the draft. ANEEL received 314 contributions from 39 actors. 118 of these contributions were accepted in full or in part (ANEEL, 2019a). Almost half of the contributions were made by universities or research centers, such as the Janeiro (UFRJ) and Instituto de

[71] This meeting was the first meeting of RISE, which was created in 2018.

Tecnologia para o Desenvolvimento (Lactec). Thirteen companies from the electricity ST-system and two companies of the electric car niche (Brave Brasil and Mobilis) also made contributions (ANEEL, 2019a).

Most contributions were proposals to change the requirements for participation in SRDP-22. A relevant one, which was accepted by ANEEL, was the inclusion of FCEVs in the final version of SRDP-22. Only HEVs, PHEs and BEVs were considered as EVs in the draft. Another point that was questioned by many actors was the requirement that the project manager had a PhD in electromobility. UFRJ suggested that this requirement would prevent startups from participating in SRDP-22. Neoenergia and Lactec argued that many engineers without a PhD had the necessary expertise to manage this type of project. However, these contributions were not accepted by ANEEL, and the requirement maintained.

The final version of SRDP-22 public notice was approved by ANEEL's board and published in April 2019. The program main objective is to prepare the Brazilian electricity ST-system for the transition to EVs and to make this transition feasible in Brazil (ANEEL, 2019b). SRDP-22 also has the following objectives (ANEEL, 2019b):

a) Make the development and production of EVs with national content economically viable.
b) Encourage the development of the entire production chain of EVs in the country with the nationalization of all technology used.
c) Promote the training and qualification of technicians specialized in electromobility in universities, technical schools, and companies.
d) Identify possibilities for optimizing the use of energy resources, considering the integrated planning of energy resources use with energy storage and renewable energy generation.
e) Induce the reduction of EVs production costs to enable them to compete with ICEVs.
f) Develop business models capable of generating value to consumers and investors through efficient electromobility technologies.
g) Propose and justify regulatory improvements and/or tax breaks that favor the economic viability of efficient electromobility.

There were many requirements that sustainability experiments must meet to be accepted in SRDP-22. Some of the main ones are:

a) The experiment's results must reach the last stages (prototype refinement or beyond) of ANEEL's innovation chain[72] .
b) As least 10% of the experiments financing must come from resources external to SRDP-22.
c) The experiment must contribute to the demonstration of the technical and economic feasibility of electromobility in Brazil.
d) The experiment must also provide subsidies for the improvement of the current regulations to secure the development of electromobility in Brazil.

Besides, the sustainability experiments in SRDP-22 must provide at least one of the following results (ANEEL, 2019b):

a) Development of methodologies to evaluate the technical and economic performance of electromobility solutions, allowing the comparison with existing technologies.
b) Analysis of the impact of EVs in the electricity grid and how these impacts can be mitigated.
c) Analysis of the electricity sector legislation, including environmental regulation, related to EVs.
d) Determination and description of the best locations for the deployment of EVs.
e) Development, fabrication, and installation of EVs components.
f) Development of EVs charging technologies.
g) Proposal of a regulatory framework that promotes the diffusion of EVs.
h) Energy efficiency solutions for electromobility.
i) Integration of electromobility with energy storage and renewable energy technologies.
j) Installation and monitoring of at least one EV charging station.

ANEEL classified the experiments in six categories: (i) energy efficiency in electromobility, (ii) renewable energy and electromobility integration, (iii) light EVs, (iv) heavy EVs, (v) EVs charging infrastructure, and (vi) energy storage for electromobility. The experiments could have a maximum duration of 48 months. The companies interested in submitting proposals had 15 days after the publishing of SRDP-22 public notice to

[72] ANEEL's innovation chain has six stages (ANEEL, 2012): (i) basic research, (ii) applied research, (iii) experimental development, (iv) prototype refinement, (v) pilot project, (vi) product launch.

notify ANEEL about their interest and more two months to submit the proposal. 100 companies showed interest in participating of SRDP-22 (see Appendix B), but only 38 submitted a proposal (see Table 4.3). Many companies submitted more than one proposal.

Table 4.3 – Proposals for SRDP-22

Proposal number[73]	Proponent	Result
PD-00387-0022	Rio Paranapanema Energia S.A.	Approved
PD-00391-0039	EDP São Paulo Distribuição de Energia S.A.	Approved
PD-02866-0516	Copel Distribuição S.A.	Approved
PD-02866-0519	Copel Distribuição S.A.	Approved
PD-07625-0119	Parnaíba I Geração de Energia S.A.	Approved
PD-00043-0087	Companhia Energética de Pernambuco - Celpe	Approved
PD-00047-0087	Companhia de Eletricidade do Estado da Bahia - Coelba	Approved
PD-00051-0119	DME Distribuição S.A.	Approved
PD-00063-3059	Companhia Paulista de Força e Luz - CPFL	Approved
PD-00063-3061	Companhia Paulista de Força e Luz - CPFL	Approved
PD-00063-3062	Companhia Paulista de Força e Luz - CPFL	Approved
PD-00372-9985	Centrais Elétricas do Norte do Brasil S.A. – Eletronorte	Approved
PD-00382-0123	Light Serviços de Eletricidade S.A.	Approved
PD-00385-0069	Elektro Redes S.A.	Approved
PD-00553-0061	Petróleo Brasileiro S.A. - Petrobras	Approved
PD-00673-0021	Lajeado Energia S.A.	Approved
PD-00678-0001	EDF Norte Fluminense	Approved
PD-02866-0518	Copel Distribuição S.A.	Approved
PD-04950-0724	CEMIG Distribuição S.A.	Approved
PD-04950-0725	CEMIG Distribuição S.A.	Approved
PD-04951-0726	CEMIG Geração e Transmissão S.A.	Approved
PD-05160-1906	CEB Distribuição S.A.	Approved

[73] Proposal number in the ANEEL's filing system.

Proposal number[73]	Proponent	Result
PD-05697-0219	Celesc Distribuição S.A.	Approved
PD-05785-2019	CEEE Distribuição	Approved
PD-06585-1912	Energisa Minas Gerais – Distribuidora de Energia S.A.	Approved
PD-06899-6925	Serra do Facão Energia S.A.	Approved
PD-06961-0010	Candeias Energia S.A.	Approved
PD-07267-0021	Porto do Pecém Geração de Energia S.A.	Approved
PD-07427-0319	Norte Energia S.A.	Approved
PD-10381-0022	Rio Paraná Energia S.A.	Approved
PD-00063-3060	Companhia Paulista de Força e Luz - CPFL	Approved
PD-00064-1058	AES Tietê S.A.	Approved
PD-02866-0517	Copel Distribuição S.A.	Approved
PD-03052-0004	Monel Monjolinho Energética S.A.	Approved
PD-00394-1902	Furnas-Centrais Eléticas S.A.	Reproved
PD-00394-1903	Furnas-Centrais Eléticas S.A.	Reproved
PD-05697-0119	Celesc Distribuição S.A.	Reproved
PD-06072-0664	Celg Distribuição S.A.	Reproved

Sources: ANEEL (2019c, 2019d, 2019e, 2019f, 2019g, 2019h)

The companies were invited to present their proposals to an evaluating committee at ANEEL's offices in Brasília between July 31 and August 2, 2019. Each company had 20 minutes to do the presentation and more 10 minutes to answer questions from the evaluating committee. This committee was formed by ANEEL's officials and members of other institutions that are part of RISE, such as MME, ONS, and GIZ. The experiments were evaluated for originality, applicability, relevance, and reasonableness of the costs. 34 of the 38 experiment proposals were approved (see Table 4.3).

Each of the 38 sustainability experiment proposals submitted to ANEEL to be part of SRDP-22 are detailed in Appendix E. The objective and scope of the experiments are briefly described, and the evaluation of the proposals by ANEEL is also presented. Then, the experiments are characterized following the categories defined in Section 3.6. The experiments are referred to by their number in the ANEEL's filing system, as shown in

Table 4.3. The results of the compilation of the data gathered in the research are presented in the next chapter.

5. CASE STUDY - RESULTS

This section presents a compilation of the primary and secondary data collected during the research. The data was organized following the analytical framework presented in Section 3.6. First, there is a characterization of the actors participating in SRDP-22. Then, the levels of interaction present in the experiments are detailed. The following section presents the main modes of interaction in the experiments. The fourth section depicts the value-chain levels of interaction in SRDP-22. The next section details the resources exchanged in the experiments, while the sixth section presents the influence of transnational linkages on SRDP-22. The following section focus on the impact of the experiments on the transition to EVs in Brazil. The eighth section details the interest of the electricity ST-system in electric mobility based on data from the interviews. Finally, the last section presents the main impacts of COVID-19 in the experiments.

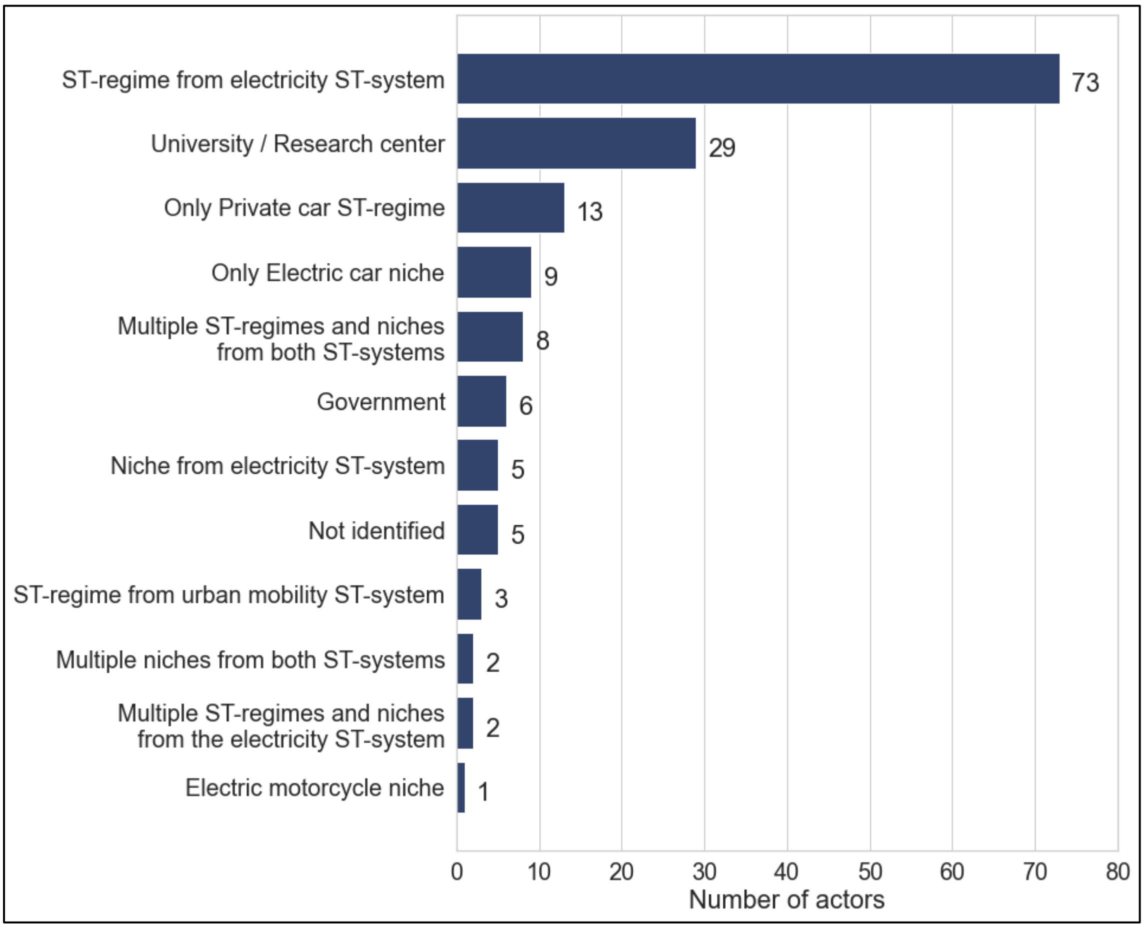
4 of the 38 proposals received by ANEEL for SRDP-22 were not approved: PD-00394-1902, PD-00394-1903[74], PD-05697-0119, and PD-06072-0664. Besides, according to information provided to the author by ANEEL on May 19th, 2022, through the Access to Information Law (see Annex B), other two experiments have been cancelled since the start of the program: PD-00678-0001 and PD-03052-0004. PD-00678-0001 did not even start (MARTINS, 2020). Therefore, the results presented in this section only consider the 32 experiments that are ongoing, although all the 38 proposals are detailed in Appendix E.

5.1 Characterization of the actors participating of SRDP-22

There are 156 institutions participating in SRDP-22. Most of them (73) are actors of one or more ST-regimes from the electricity ST-system (see Figure 5.1). Besides, there are 29 universities and research centers participating in this program. 8 actors are part of ST-regimes or niches from both the electricity and urban mobility ST-systems and 2 actors are part of ST-regimes and niches from the electricity ST-systems. There is small participation of actors from niches and ST-regimes from the urban mobility ST-system other than the private car ST-regime and the electric car niche.

[74] ANEEL informed that this experiment is delayed but in progress. However, all documents available in ANEEL website indicate that this experiment was not approved and have not started. Information available on the website of FURNAS, proponent of the experiment, also indicates that this experiment never started.

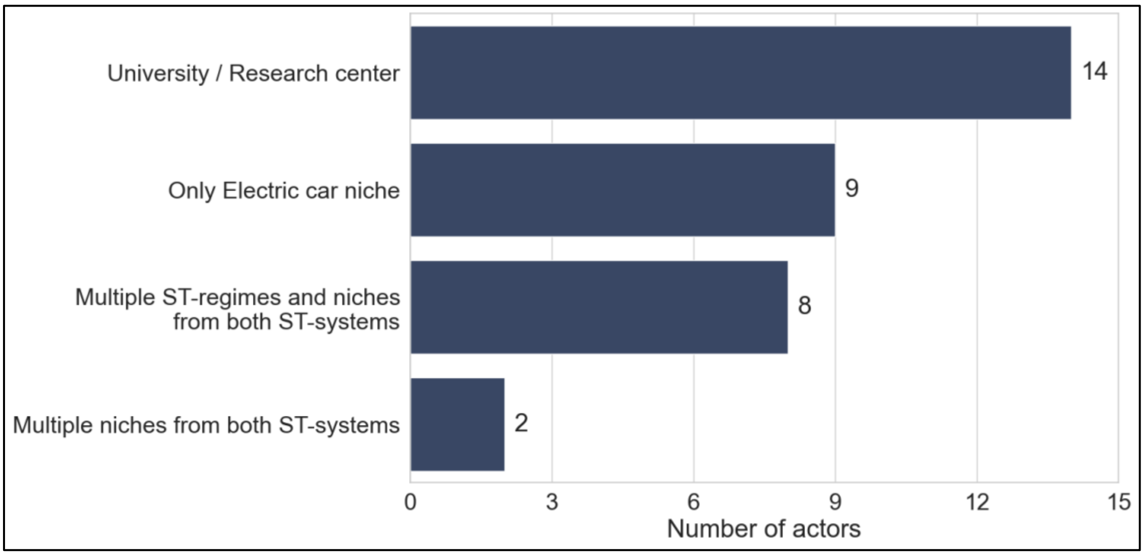
Figure 5.1 – Niche or regime of the actors participating in SRDP-22



Source: Developed by the author

14 of the universities and research centers participating in SRDP-22 can be considered part of the electric car niche in the context their experiments. Therefore, almost half of the 33 actors from the electric car niche involved in SRDP-22 are universities or research centers (see Figure 5.2). 9 actors are only part of the electric car niche, while 10 are also part of other ST-regimes and niches, such as the battery niche from the electricity ST-system.

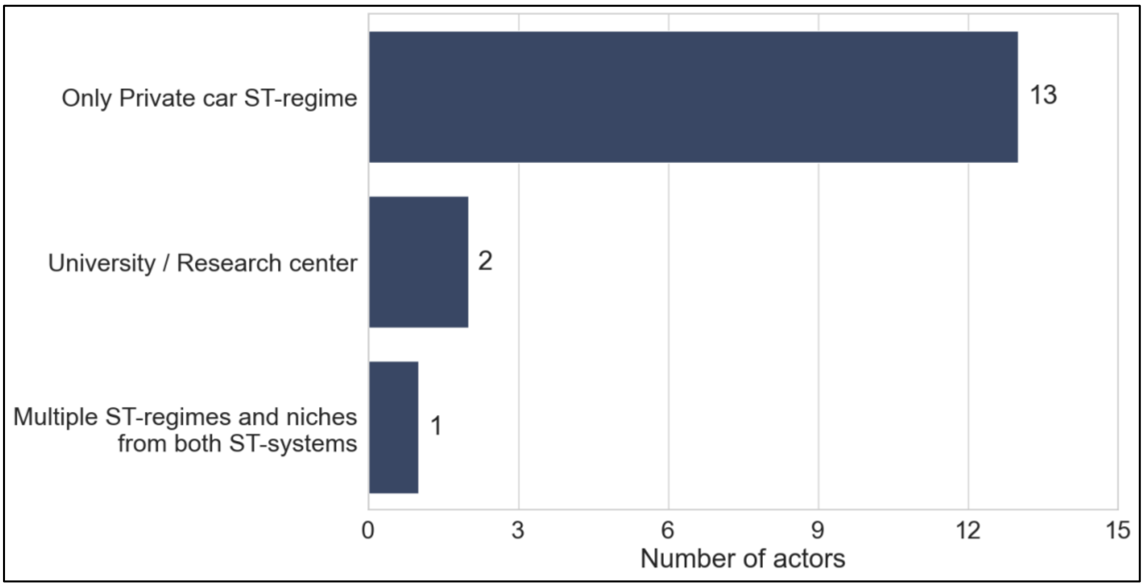
Figure 5.2 – Actors from the electric car niche in SRDP-22



Source: Developed by the author

There are 16 actors from the private car ST-regime participating in SRDP-22. Most of these actors are only part of the private car ST-regime (13), while two are universities or research centers, and one, Moura, is part of both the private car ST-regime and the battery niche of the electricity ST-system (see Figure 5.3).

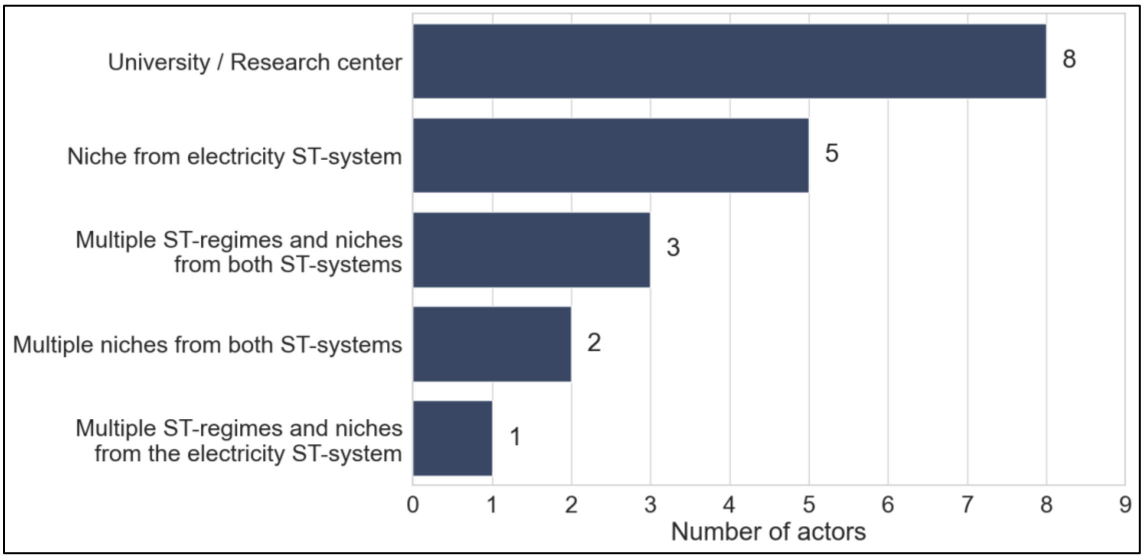
Figure 5.3 – Actors from the private car ST-regime in SRDP-22



Source: Developed by the author

There are 19 actors participating in SRDP-22 that are part of one or more niches of the electricity ST-system (see Figure 5.4). 8 of them are universities or research centers, 5 are part of only one niche of the electricity ST-system, and 6 are part of multiple regimes or niches from the electricity and urban mobility ST-systems.

Figure 5.4 – Actors from niches of the electricity ST-system in SRDP-22

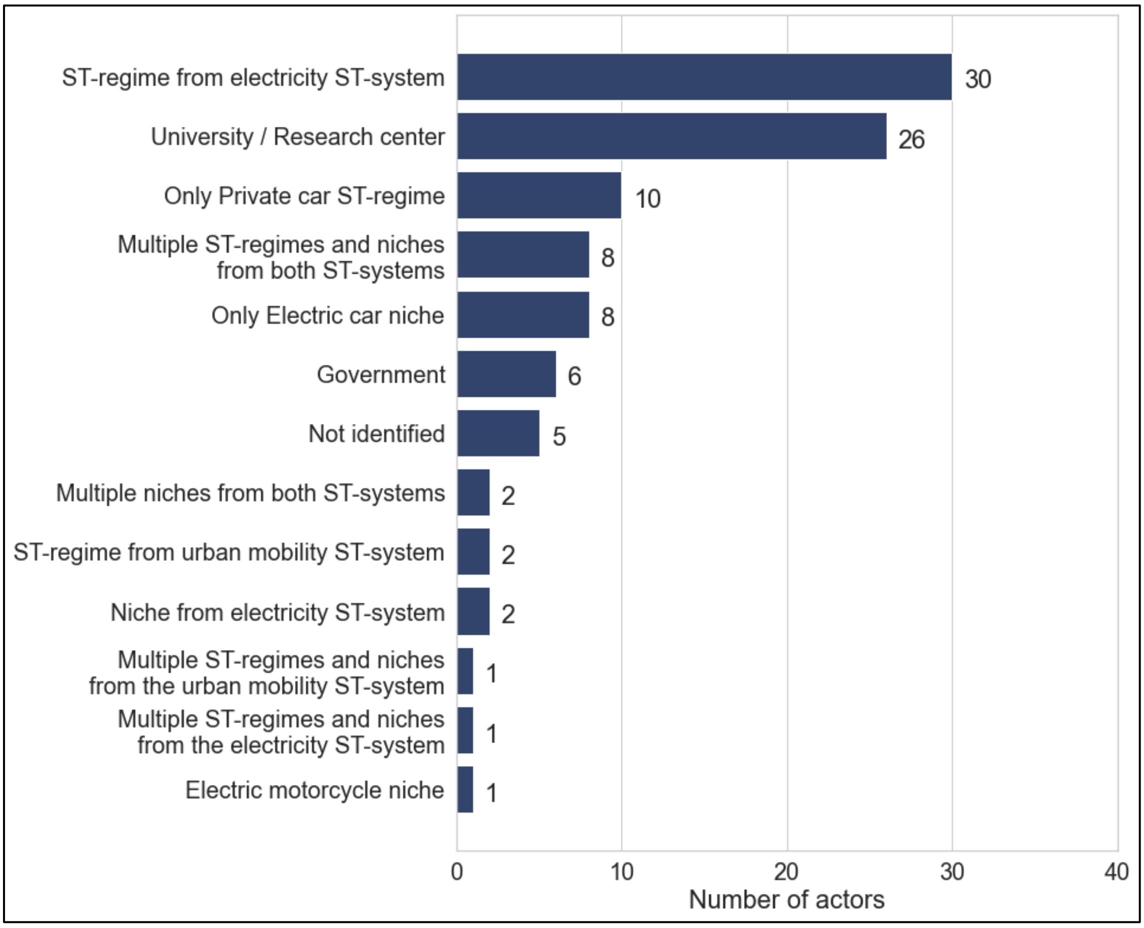


Source: Developed by the author

If we consider only the parent companies, there are 102 institutions participating in SRDP-22. There are many subsidiaries from the same electricity company participating in each experiment[75] (see Appendix E). For example, there are five subsidiaries of EDP Brasil participating in experiment PD-00391-0039. Therefore, there are less actors from the electricity ST-system (37) participating in SRDP-22 when only the parent companies are considered (see Figure 5.5).

[75] It is common that only one of the subsidiaries gets truly involved in the experiment. The other subsidiaries only participate in the experiment so that they can make their mandatory investments in R&D in a project that is easier to be approved by ANEEL. According to one of the interviewees, this procedure is also a way to have a bigger budget for the experiment (allowing the execution of larger experiments), because the R&D budget of each of the companies participating can be combined into a single experiment. Any company of the electricity ST-system can be a cooperator of the experiment proposed by the leading company, i.e., they do not need to be subsidiaries of the same parent company. This shared investment in the experiment also makes its accountability easier according to the interviewee.

Figure 5.5 – Niche or regime of the actors (only parent companies) participating in SRDP-22

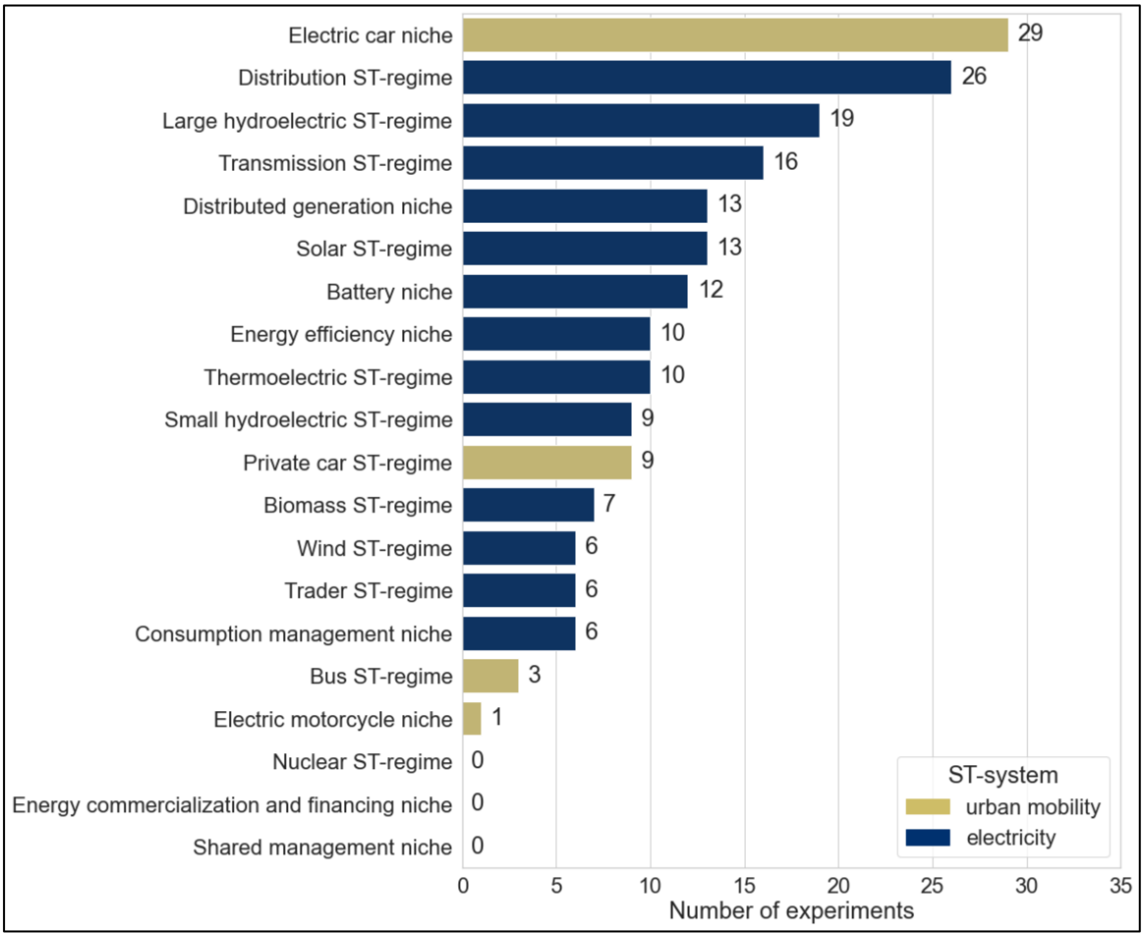


Source: Developed by the author

Although there are only 33 actors from the electric car niche involved in SRDP-22, 29 of the 32 experiments have the participation of at least one actor from this niche (see Figure 5.6). On the other hand, only 9 experiments have the participation of actors from the private car ST-regime. Besides, there is only one experiment with the participation of both legacy brands and EV manufacturers (PD-00553-0061).

The most relevant ST-regimes from the electricity ST-system in SRDP-22 are the Distribution and the Large hydroelectric ST-regimes (see Figure 5.6). Actors from these ST-regimes are involved in 26 and 18 of the 32 experiments, respectively. Considering the niches from the electricity ST-system described in Section 4.1, the Distributed generation and Battery niches are the ones whose actors are involved in more experiments, 13 and 12, respectively (see Figure 5.6).

Figure 5.6 – Number of experiments with the participation of at least one actor from the specified regimes and niches

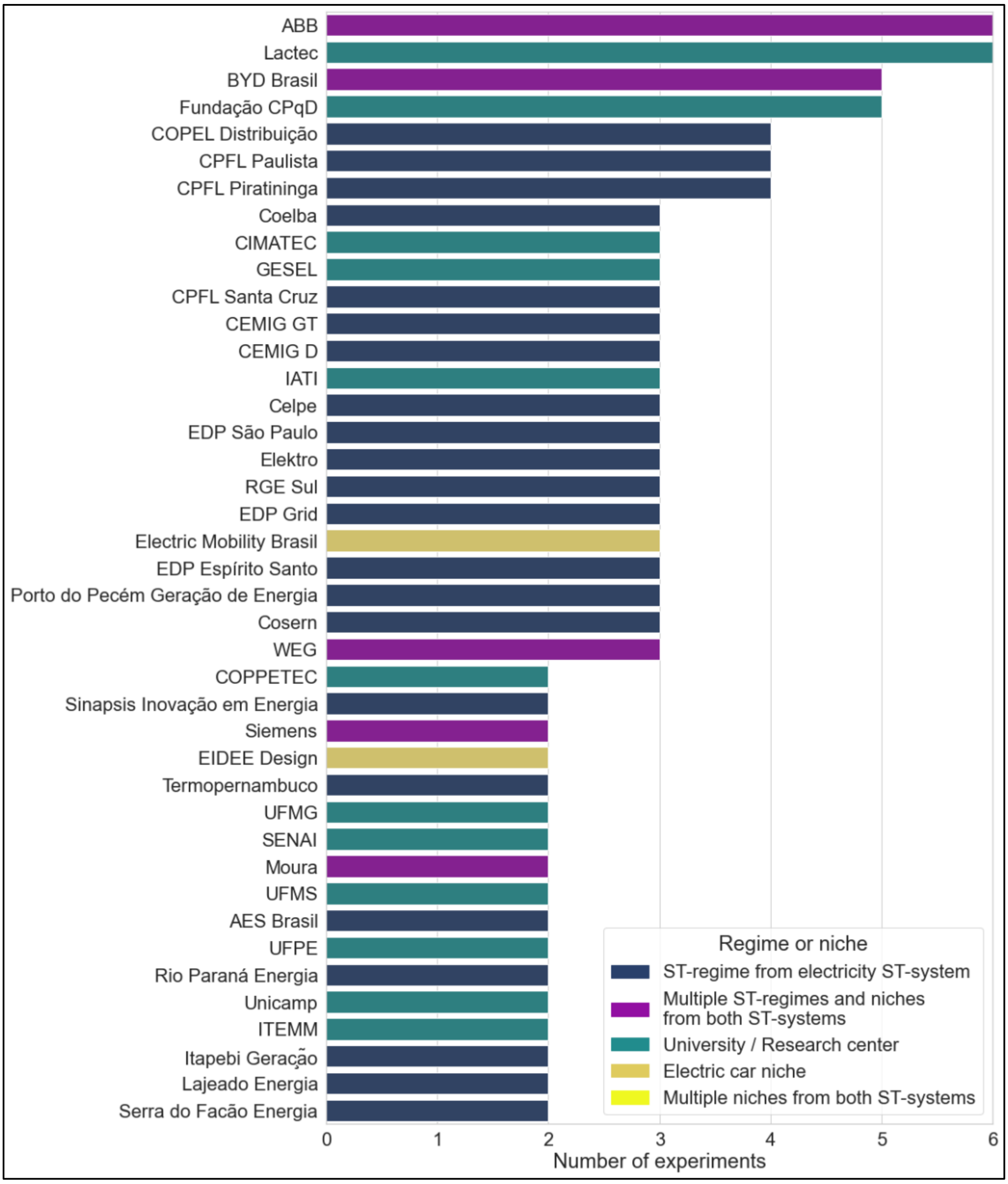


Source: Developed by the author

41 of the 156 actors participating in SRDP-22 are participating in two or more experiments (see Figure 5.7). Most of these actors (27) are part of one or more ST-regimes of the electricity ST-system. Besides, 13 actors participating in two or more experiments can be considered part of the electric car niche (6 of them are universities or research centers), while only one actor from the private car ST-regime, Moura, is involved in two or more experiments.

ABB, BYD, WEG, and Siemens are the only actors that are part of the urban mobility ST-system participating in more than one experiment. Besides, 12 actors that are part of the electric car niche are involved in more than one experiment, while only one actor that is part of the private car ST-regime (Moura) is participating in more than one experiment.

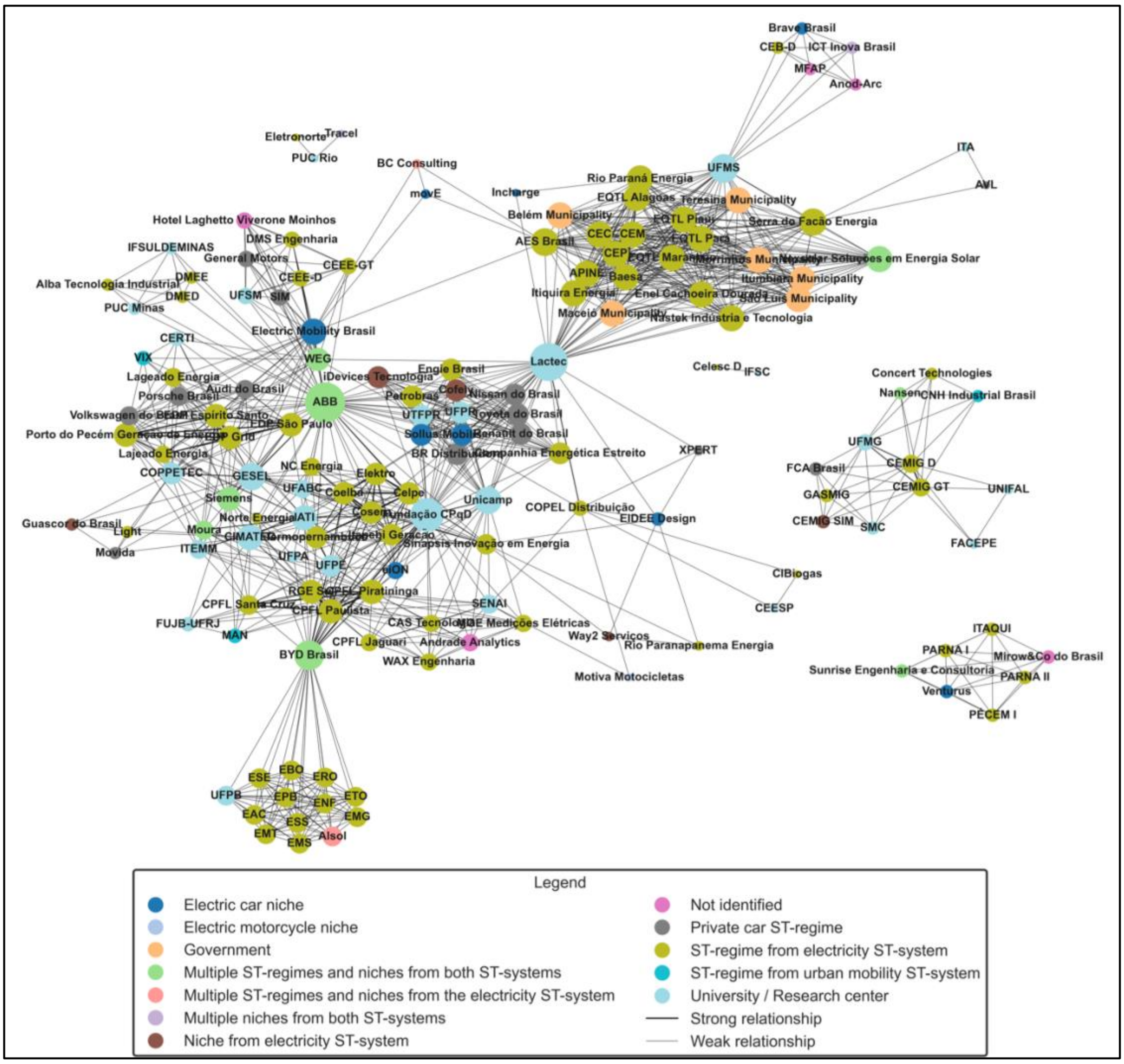
Figure 5.7 – Number of experiments that each actor is participaing in (showing only actors involved in two or more experiments)



Source: Developed by the author

Actors who participate in various experiments act as links between these experiments, leading to the creation of clusters of experiments. Figure 5.8 shows the network of actors participating in SRDP-22. In this network map, the size of each node is proportional to the number of connections it has.

Figure 5.8 – Network of actors participating in SRDP-22



Source: Developed by the author using NetworkX[76]

Examining the network of actors participating in SRDP-22, it is possible to identify five independent clusters (see Figure 5.8). Four of them are small and related to the experiments lead by CEMIG D and CEMGI-GT (PD-04950-0724, PD-04950-0724, and PD-04950-0726), PARNA I (PD-07625-0119), Eletronorte (PD-00372-9985), and Celesc (PD-05697-0219). The fifth cluster is a large one, in which all the other experiments are connected.

A few clusters can be identified within this fifth cluster. On the top of the map, there is one small cluster that represent an experiment led by CEB-D (PD-05160-1906). This cluster is connected to another cluster through UFMS, which is participating in this

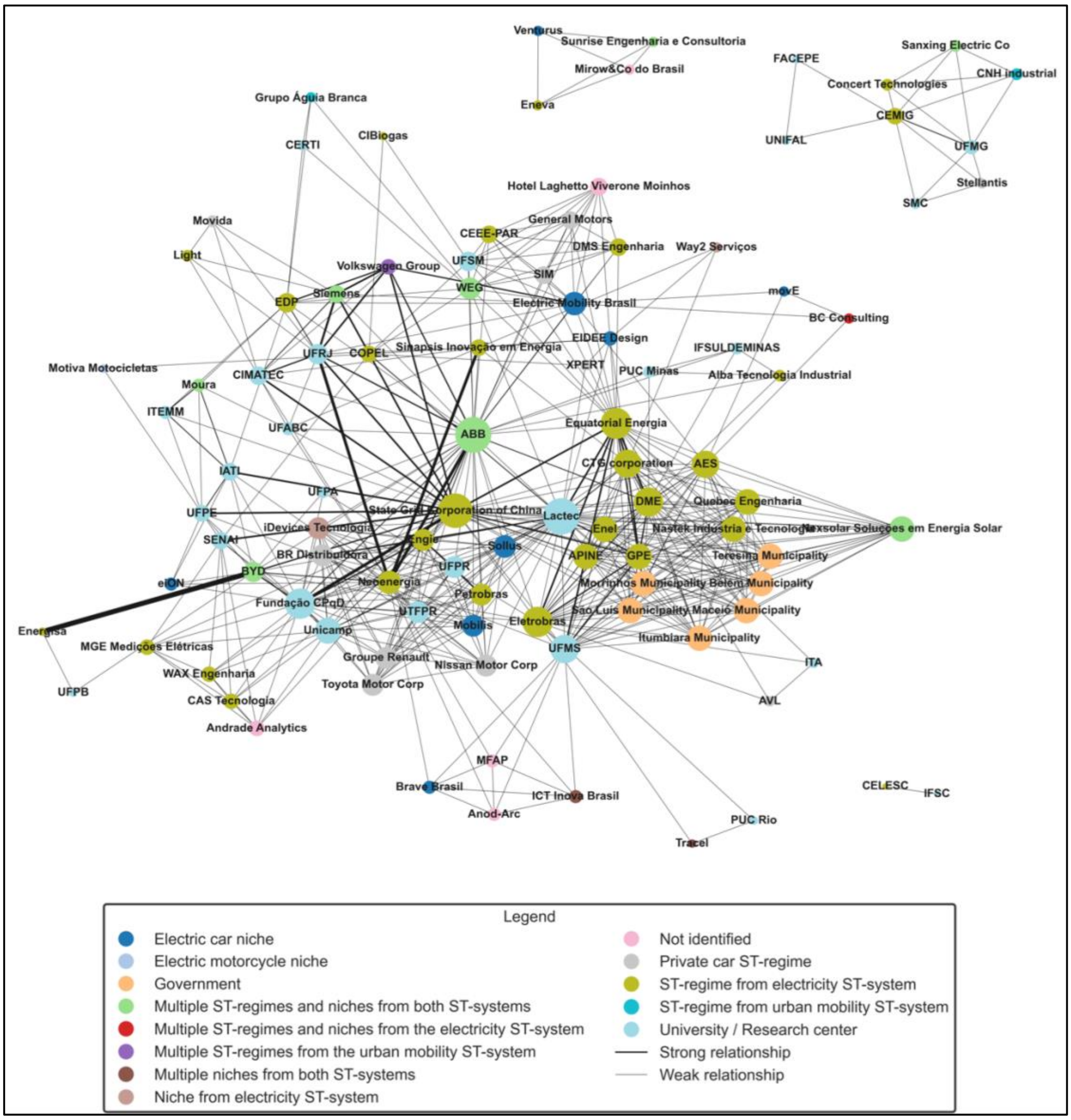
[76] NetworkX is a Python package for the creation, manipulation, and study of complex networks. For more details see https://networkx.org/.

experiment, but also in an experiment led by CEC (PD-06961-0010). This cluster is connected to the core of the large cluster by Lactec, which is participating in several experiments. Besides, there is another small cluster in the bottom of the map, related to the experiment led by EMG (PD-06585-1912). This cluster is connected to the core of the large cluster through BYD Brasil, who is another actor that is involved in several experiments.

Although a few clusters can be identified within the large cluster in Figure 5.8, that is not the case when only the parent companies are considered (see Figure 5.9). The large cluster in Figure 5.8 becomes just one single cluster in Figure 5.9. Besides, when only the parent companies are considered there are only four independent clusters. As in the case of Figure 5.8, the size of each node is proportional to the number of connections it has in Figure 5.9.

Moreover, the network maps indicate that some companies have a more significant role in SRDP-22 than others. ABB, BYD Brasil, Lactec, Fundação CPqD are the ones with the greater number of connections and responsible for interconnecting actors from several different experiments. Moreover, the actors' network map (Figure 5.8) highlights that actors from ST-regimes of the electricity ST-system and universities and research centers are the most relevant actors in SRDP-22. The map also shows the limited participation of actors from the electric car niche and the private car ST-regime. The parent companies' network map (Figure 5.9) shows the relevance of a few other actors, such as Neoenergia, State Grid Corporation of China, Equatorial Energia, and a few universities, such as Unicamp and UFMS.

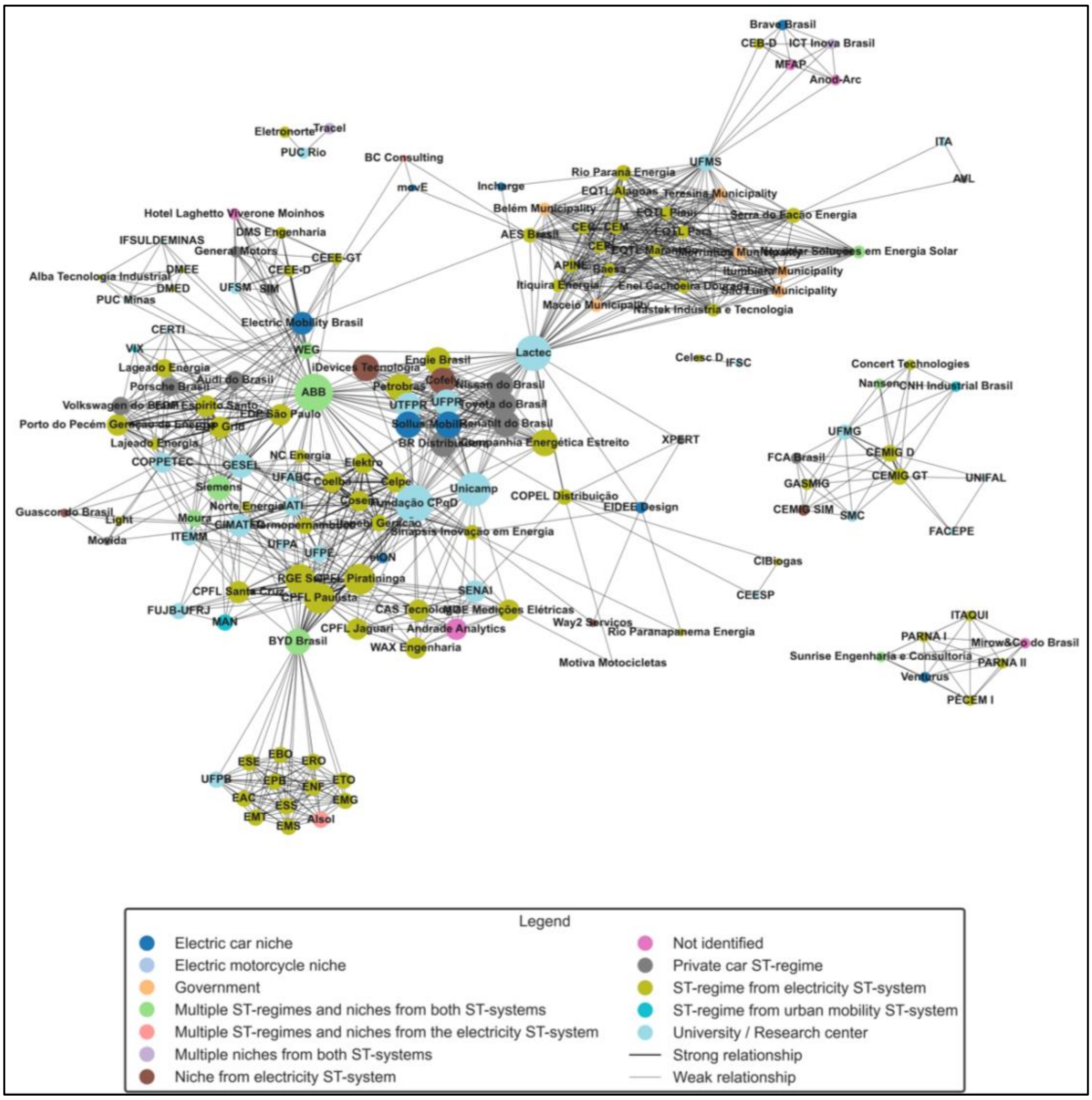
Figure 5.9 – Network of actors participating in SRDP-22 (only parent companies)



Source: Developed by the author using NetworkX

Another way to visualize the relevance of each actor in SRDP-22 is to look at the total estimated cost of the experiments in which they are involved. In Figure 5.10 and Figure 5.11, the size of the nodes in the network map are not proportional to the number of connections, as was the case in Figure 5.8 and Figure 5.13, but to the total estimated cost of the experiments in which the respective actor is participating.

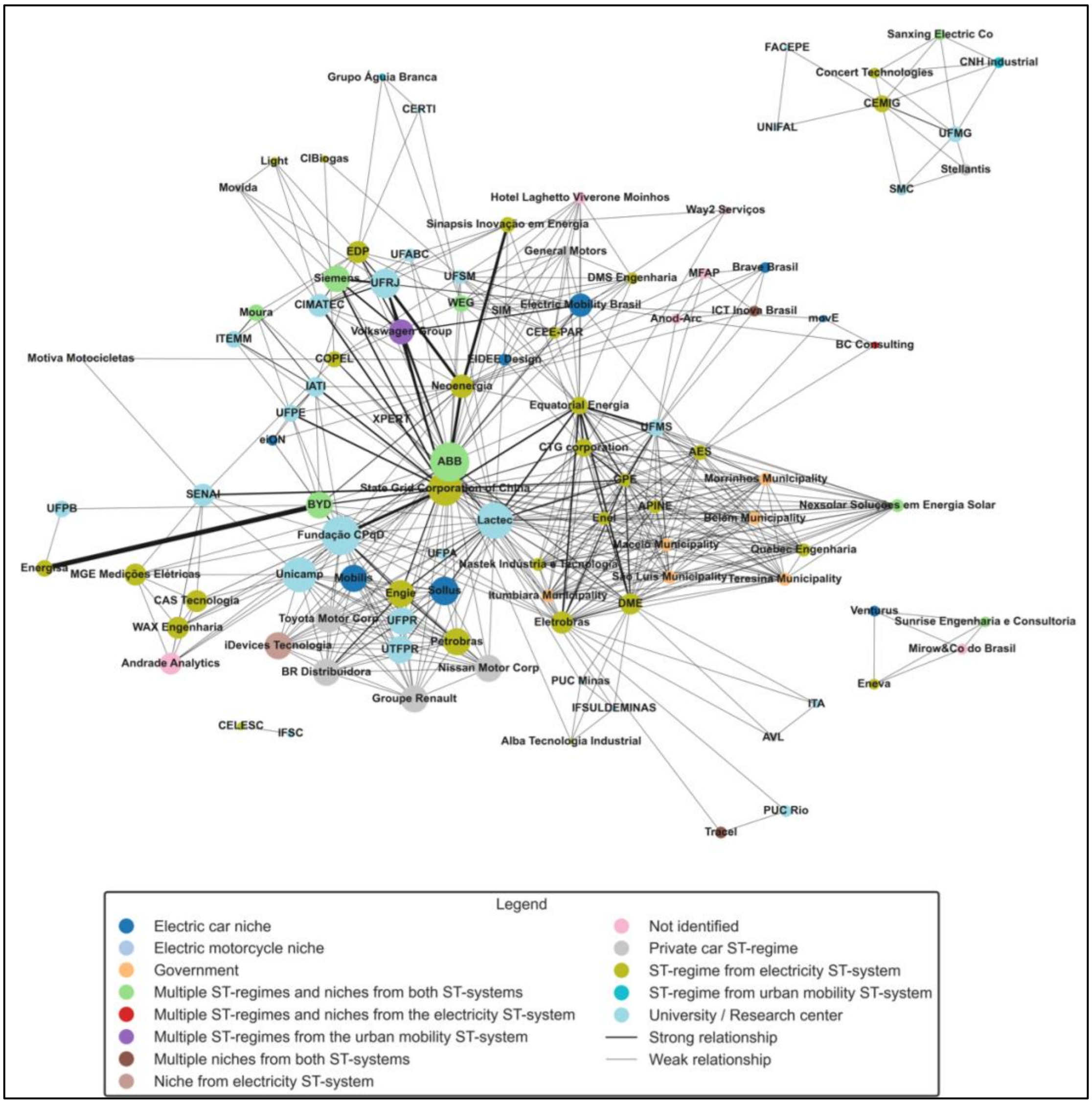
Figure 5.10 – Network of actors participating in SRDP-22 (by total estimated cost)



Source: Developed by the author using NetworkX

Figure 5.10 shows that Fundação CPqD, ABB, Unicamp, Lactec, CPFL Paulista, CPFL Piratininga, and RGE Sul are relevant actors in SRDP-22 when the total estimated cost of the experiments in which the actors are involved is used as the main criteria in the evaluation. This network map also shows that legacy companies have a relevant role in SRDP-22, as well as some actors from the electric car niche, such as BYD Brasil, Sollus, Mobilis, and Electric Mobility Brasil. Besides, the map shows that many actors that have several connections are involved in experiments with low estimated cost.

Figure 5.11 – Network of actors participating in SRDP-22 (by total estimated cost and only parent companies)



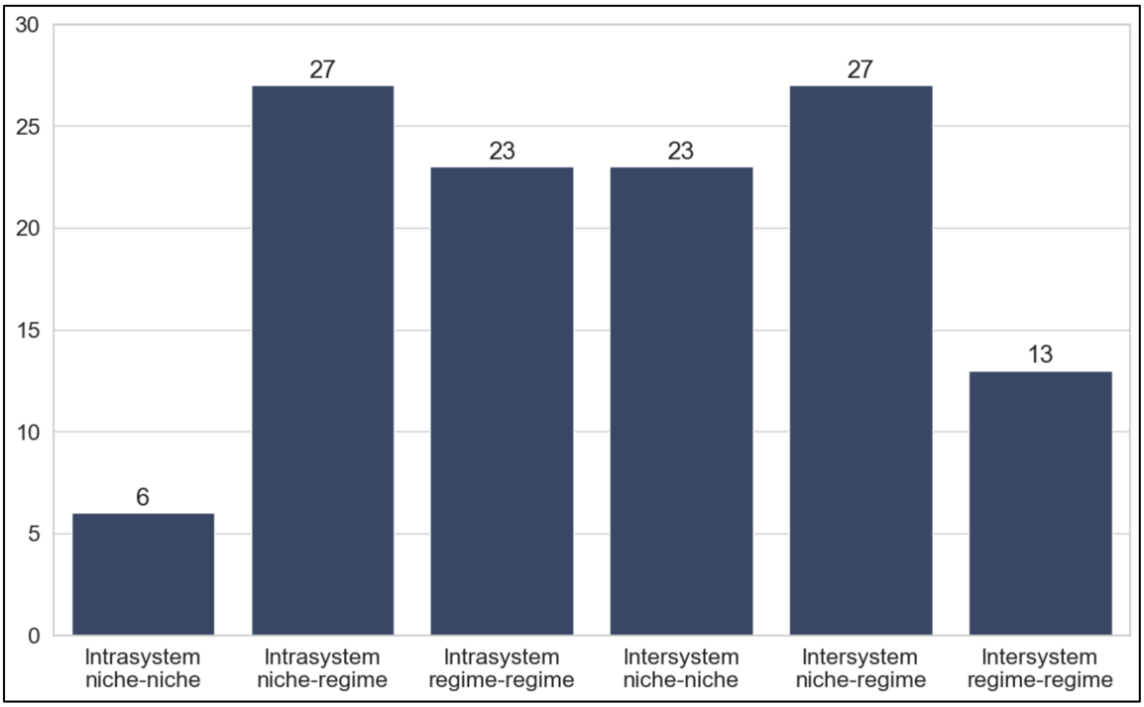
Source: Developed by the author using NetworkX

Figure 5.11 shows that the most relevant actors when only parent companies are considered are Fundação CPqD, Lactec, ABB, Unicamp, and State Grid Corporation of China. This figure also shows the relevance of the legacy brands when the estimated cost of the experiments is considered, as was the case in Figure 5.10. Toyota Motor Group, Groupe Renault, Nissan Motor Group, and Volkswagen Group are among the actors involved in the experiments with the higher estimated cost.

5.2 Levels of interaction

The interconnections between distributed generation and battery niches and the electric car niche are reflected in the high number (23) of experiments with the presence of intersystem niche-niche interactions. Most experiments also have the presence of intrasystem niche-regime, intrasystem regime-regime, and intersystem niche-regime interactions (see Figure 5.12). Most of these interactions are between actors from different ST-regimes of the electricity ST-system among each other or with actors of the electric car niche.

Figure 5.12 – Experiments by level of interaction



Source: Developed by the author

Few experiments have intrasystem niche-niche and intersystem regime-regime interactions. There are not many experiments in which actors from different niches of the same ST-system are participating. Besides, the low number of experiments with intersystem regime-regime interactions is the result of the small participation of actors from the ST-regimes of the urban mobility ST-system in SRDP-22. There are eight legacy brands (Volkswagen, Audi, Porsche, Toyota, Nissan, Renault, FCA Brasil, and General Motors) in SRDP-22, but they are involved in only five experiments. Besides, there are only three actors (MAN, VIX Logística, and CNH Industrial Brasil) from other ST-regimes of the urban mobility ST-system.

There is also small participation of EV manufacturers[77]. There are only four EV manufacturers participating (BYD, Brave Brasil, Mobilis and eiON). They are involved

[77] Companies that produce EVs but not ICEVs, e.g., BYD.

in eight experiments. Most of the actors from the electric car niche involved in SRDP-22 are EV charging station manufacturers (e.g., Electric Mobility Brasil).

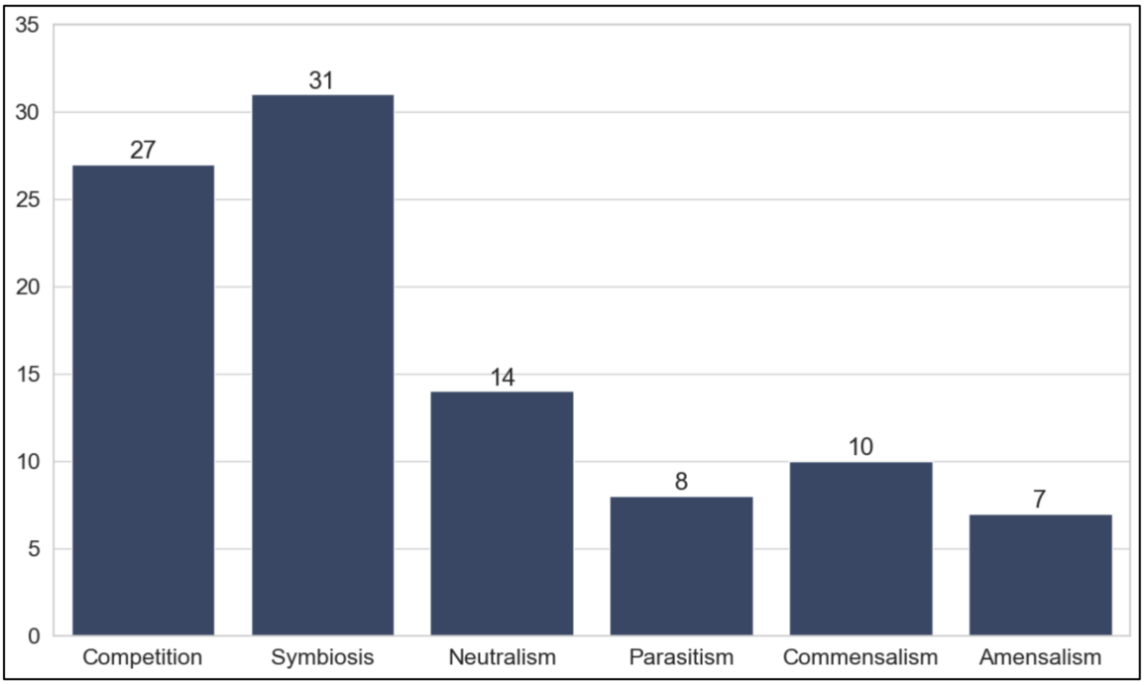
Only two experiments (PD-00553-0061 and PD-07427-0319) have the participation of both EV manufacturers and EV charging station manufacturers. However, only one of the experiments involving legacy brands do not have the participation of an EV charging station manufacturer (PD-04951-0726).

Although legacy brands are involved in only six experiments, three of the four most expensive experiments in SRDP-22 have their participation. Besides, the most expensive experiment (PD-00553-0061) is the only one that have the participation of both legacy brands (Toyota, Renault, and Nissan) and EV manufacturers (Mobilis).

5.3 Modes of interaction

Symbiosis, i.e., relationships where the parts benefit from each other, is present in almost all experiments (see Figure 5.13). This reflects the great synergy between renewable energy and the electric car niche, whose actors are present in most experiments, and between this niche and some of the niches of the electricity ST-system.

Figure 5.13 – Experiments by mode of interaction



Source: Developed by the author

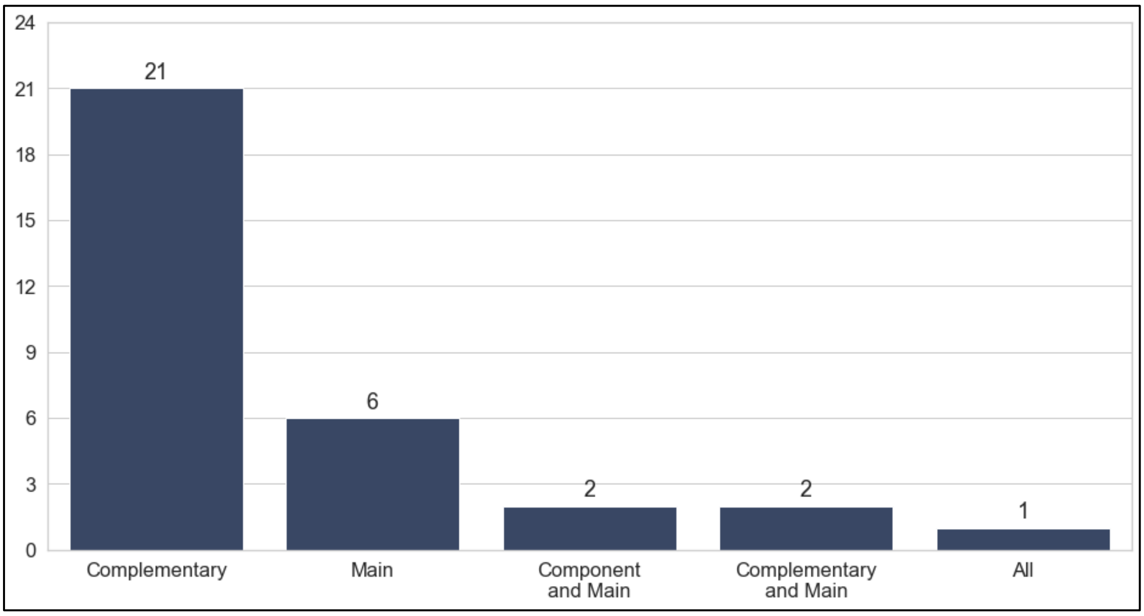
Besides, there is competition in several experiments. For example, in experiments where actors form both the electric car niche and the Private car ST-regime are participating. There are also many experiments in which actors of different ST-regimes of the electricity ST-system are participating, for example, Large hydroelectric and Wind ST-regimes. Although it makes sense for these actors to collaborate in the experiment, these are technologies that compete to fulfill society need for electricity. Thus, the interaction between these ST-regimes is considered competition.

The other modes of interaction between ST-regimes and niches are not as common as competition and symbiosis (see Figure 5.13). All these interactions are detailed in in Appendix E.

5.4 Value-chain level of interaction

Most experiments in SRDP-22 focus on complementary technologies to EVs (see Figure 5.14), notably the charging stations. Just a few experiments focus on the EVs or component technologies, such as batteries. Moreover, only three experiments focus on component technologies. Two of them have the participation of both legacy companies and EV manufacturers. Nonetheless, most experiments involving EV manufacturers (five) focus on complementary technologies. In fact, only two experiments with the participation of EV manufacturers focus on EVs.

Figure 5.14 – Experiments by value-chain level of interaction

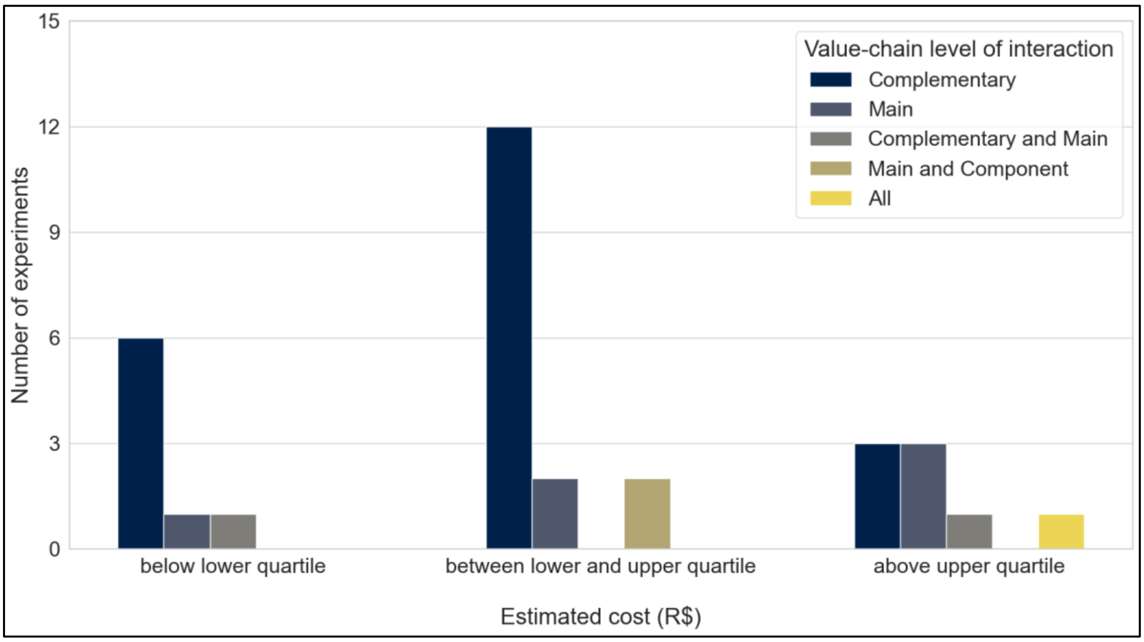


Source: Developed by the author

On the other hand, all six experiments with the involvement of legacy companies focus on the EV (main technology) or the battery (component technology). This fact is particularly relevant because only eleven SRDP-22 experiments focus on the main technology (see Figure 5.14). Therefore, more than 50% of the experiments that focus on EVs have the participation of legacy brands.

Besides, experiments with higher estimated cost usually focus on main or component technologies, while experiments with lower estimated cost focus more on complementary technologies (see Figure 5.15). 75% of the experiments with an estimated cost below the lower quartile (R$ 6.38 mi) and 75% of the experiments with an estimated cost between the lower quartile and the upper quartile (R$ 15.49 mi) focus on complementary technologies. On the other hand, only 37.5% of the experiments with an estimated cost above the upper quartile focus on complementary technologies.

Figure 5.15 – Number of experiments x estimated cost by value chain level of interaction



Source: Developed by the author

Therefore, there is strong correlation between the participation of legacy companies, the estimated cost of the experiment and the value-chain level of interaction. Experiments with the involvement of legacy companies have higher estimated cost and focus on the main technology. On the other hand, most of the experiments EV automakers are participating in have lower estimated cost and focus on complementary technologies.

5.5 Resources exchanged

The secondary data suggests that all experiments have the exchange of capital and knowledge between the participants. The experiment's main proponent, a company from the electricity ST-system, is the one which is usually investing in the experiment, as explained in Section 5.1. Therefore, this actor will pay the other actors which are participating in the experiment for their work (e.g., universities and research centers) or for what they are providing to the project (e.g., EV chargers' suppliers). This kind of relationship is present in all the experiments, which is why the exchange of capital between the participants is present in all of them.

This exchange of capital is significant to some actors involved in SRDP-22, especially niche actors. One interviewee who works at a startup of the electric car niche said that the investment they are receiving to participate in the experiment is crucial for the survival and consolidation of their business.

Most experiments in SRDP-22 involve the combination of many different technologies, for example solar energy generation and EV charging. These kind of multidisciplinary experiment demands some level of knowledge exchange between the participants. This understanding was confirmed in the interviews, as all interviewees said that there is an exchange of knowledge in the experiments in which they participate.

Besides, one of the interviewees also said that it is not only knowledge that is exchanged in the experiments, but also technology. For example, this interviewee said that there is technology transfer from legacy companies to the university and research center involved in the experiment he is taking part. Moreover, there is one case in which the company headquarters transferred technology and knowledge to the Brazilian subsidiary because of the SRDP-22 experiment, according to one interviewee. Another interviewee said that this kind of technology transfer from the foreign headquarters to the local subsidiary also happened regarding EV charging stations. In this case, the headquarters transferred to the local subsidiary the necessary technology and knowledge to produce EV charging stations in Brazil. Therefore, it is quite likely that more cases such as these have occurred in other experiments.

Most of the interviewees believe that ANEEL aim of creating a network of knowledge around electric mobility is working and is a positive aspect of SRDP-22. This network is helping to disseminate knowledge and bring industrial companies to the experiments. For example, in many experiments, the researchers, technicians, engineers, and other people involved exchanged knowledge and learnings in workshops. Some universities are even promoting courses on electric mobility to the other actors involved in the experiment.

However, some of the interviewees argued that this network of knowledge is still restricted to each experiment. They said that there is little interaction between participants of different experiments. One of the interviewees even suggested that, to consolidate the RISE, ANEEL should promote workshops between the participants of all the experiments, so that they could share what they learned.

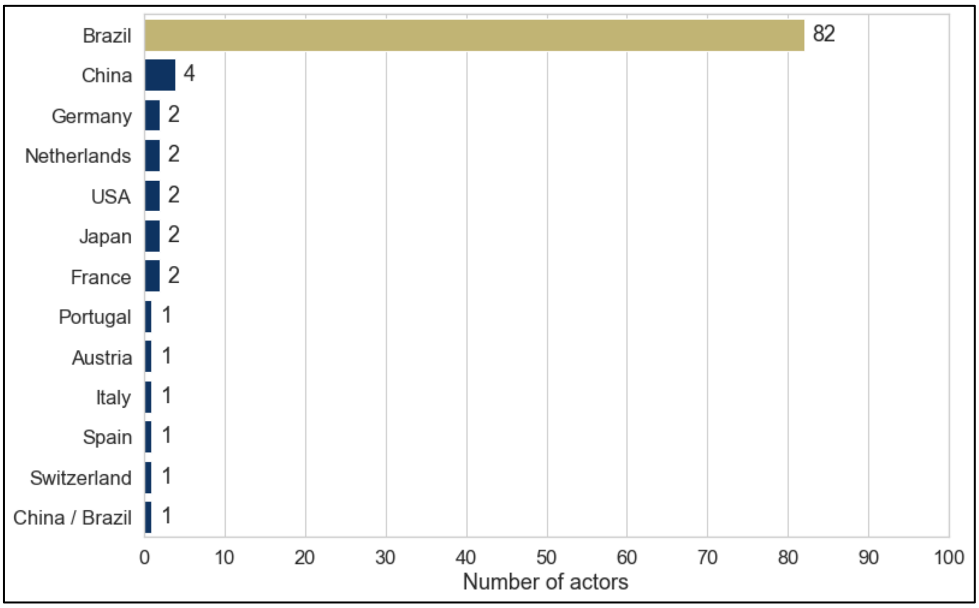
5.6 Transnational linkages

Secondary data indicate that transnational linkages are present in 21 experiments, but only 6 of them are influenced by these linkages. In 5 of these experiments, the transnational linkages influence in the experiment is due to the presence of foreign legacy brands or EV manufacturers in the experiment.

The main type of transnational linkages identified in the experiments is the presence of transnational corporations. As detailed in the previous section, there is at least two cases of technology transfer from a multinational headquarters to the local Brazilian subsidiary because of the SRDP-22 experiment in which the company is involved.

As previously described, there are 102 institutions participating in SRDP-22 when only parent companies are considered. 82 (80.4%) of them can be considered Brazilian, while 19 (18.6%) are foreign institutions, as shown in Figure 5.16. Besides, one company, Baesa, is co-owned by the Brazilian DME and Chinese State Grid Corporation of China. Most foreign institutions (13) are from the so-called Western countries, while four are Chinese and two Japanese.

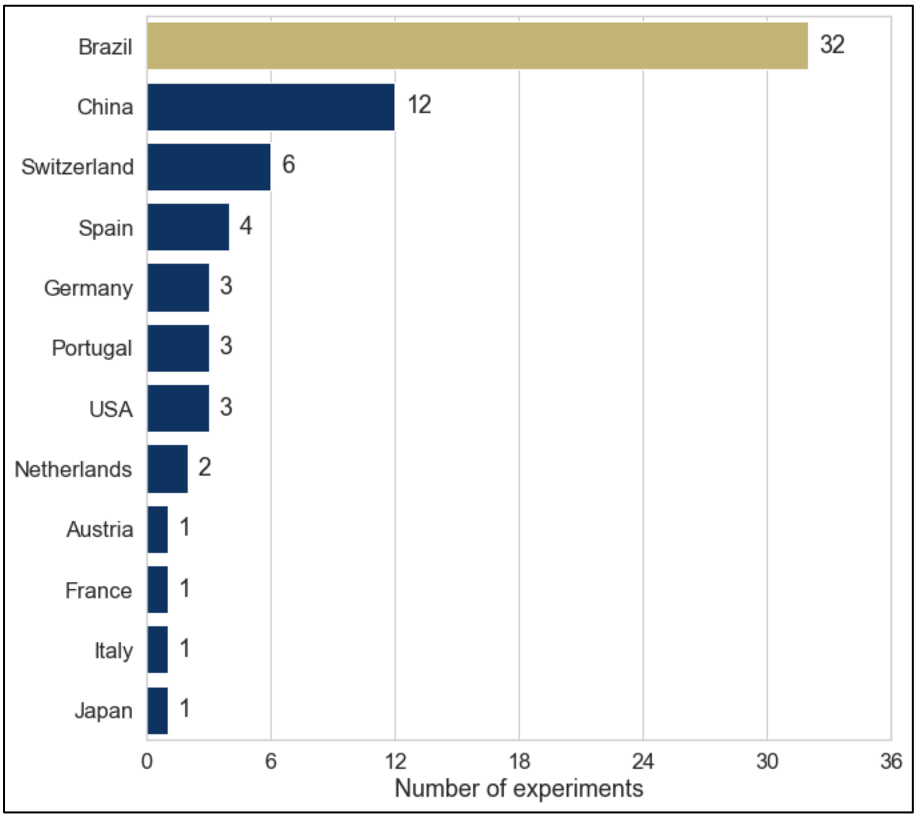
Figure 5.16 – Origin country of the parent companies



Source: Developed by the author

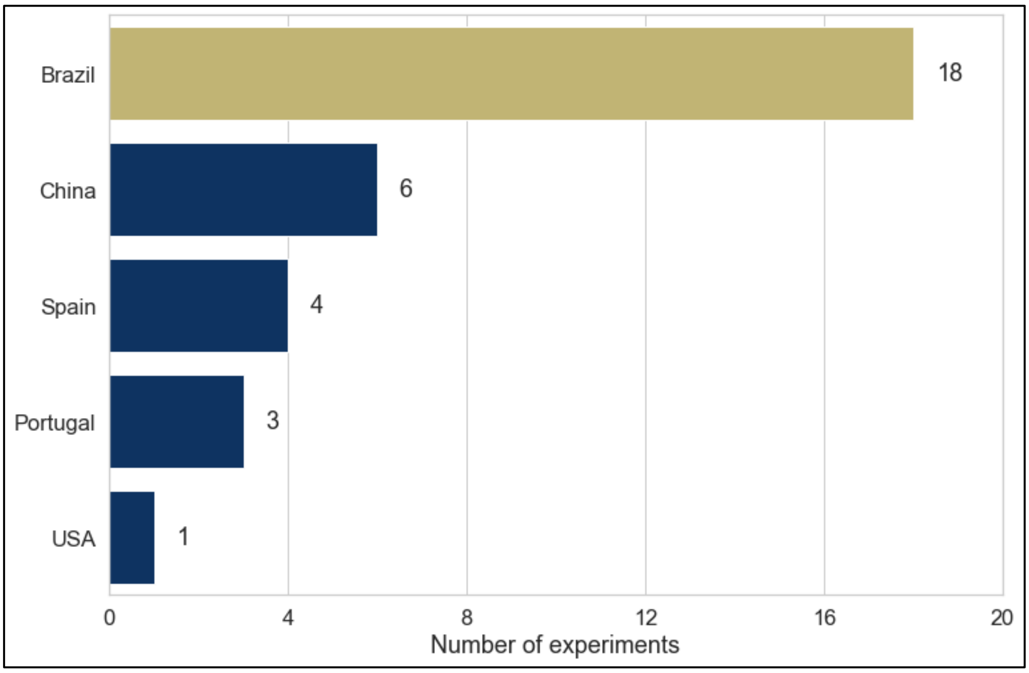
Despite the low participation of foreign actors in SRDP-22, 26 experiments have the participation of at least one foreign actor. 12 experiments have the participation of one or more Chinese actors and 24 experiments have the participation of at least one actor from a Western country, as shown in Figure 5.17. Besides, almost half of the experiments are led by subsidiaries of companies incorporated abroad, including six experiments led by Chinese companies (see Figure 5.18).

Figure 5.17 – Number of experiments with the participation of at least one actor from the specified countries



Source: Developed by the author

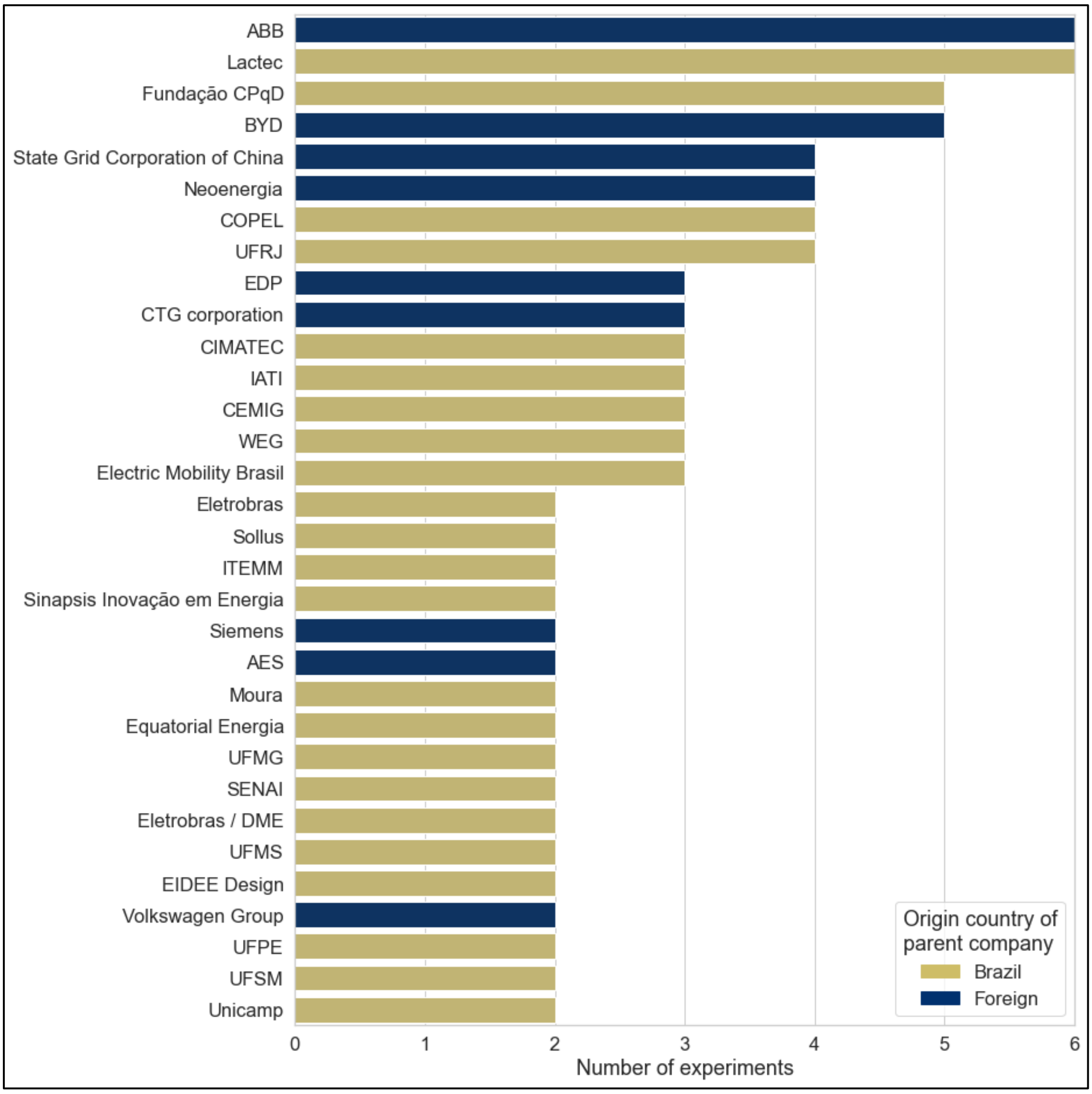
Figure 5.18 – Country of the experiments' leading actor



Source: Developed by the author

Four (ABB, BYD Brasil, CPFL Piratininga, and CPFL Paulista) of the seven companies participating in four or more experiments are subsidiaries of companies incorporated abroad. If only the parent companies are considered, half the institutions participating in four or more experiments are incorporated abroad. Two of them are Chinese (BYD and State Grid Corporation of China), and the other two European (ABB, Neoenergia), as shown in Figure 5.19.

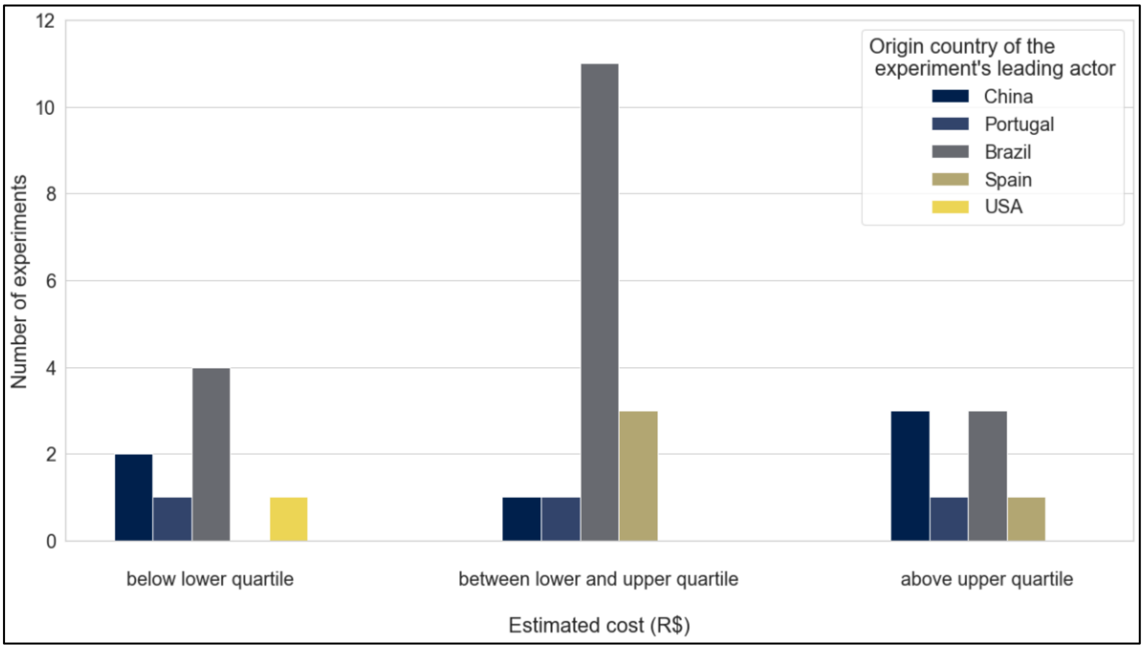
Figure 5.19 – Number of experiments that each actor (only parent companies) is participaing in (showing only actors involved in two or more experiments)



Source: Developed by the author

Moreover, 62.5% of the experiments with an estimated cost above the upper quartile are led by foreign companies, while more than 62.5% of the experiments with estimated cost bellow the upper quartile are led by Brazilian companies (see Figure 5.20).

Figure 5.20 – Number of experiments x estimated cost by origin country of the experiments' leading actor



Source: Developed by the author

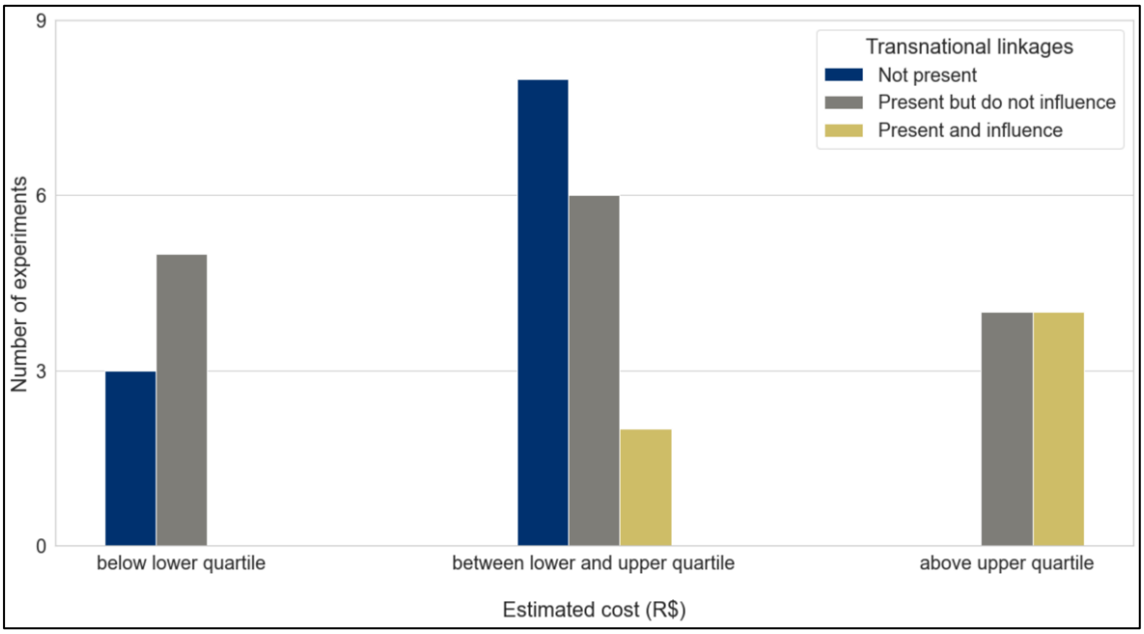
Besides, the presence and influence of transnational linkages is directly related to the estimated cost of the experiment and the number of actors involved (see Table 5.1 and Figure 5.21).

Table 5.1 – Number of actors and estimated cost of the experiments versus the presence and influence of transnational linkages

Transnational linkages	Number of actors			Estimated cost (R$ million)		
	min	mean	max	min	mean	max
Not present	2	4.2	7	2.0	8.8	14.9
Present but do not influence	3	7.4	24	3.3	13.2	48.3
Present	10	12.8	17	11.1	29.8	73.5

Source: Developed by the author

Figure 5.21 – Number of experiments x estimated cost by transnational linkages

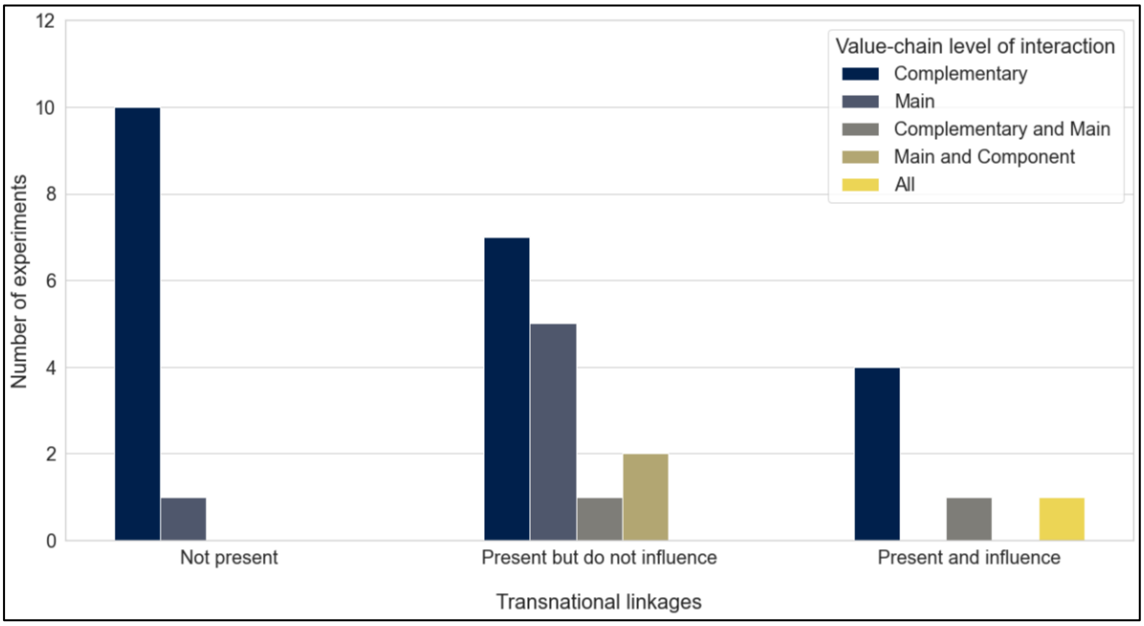


Source: Developed by the author

If universities and research centers are not considered, the actors involved in the experiments with the higher estimated cost are almost all incorporated abroad (ABB, State Grid Corporation of China, BYD, Engie, Toyota Motor Group, Groupe Renault, Nissan Motor Group, and Siemens). The exceptions are Sollus, Petrobras and BR Distribuidora.

Another relevant aspect regarding transnational linkages in SRDP-22 is that experiments without the presence of transnational linkages focus more on complementary technologies than those with the presence of these linkages (see Figure 5.22). Therefore, more than 90% of the experiments without the presence of transnational linkages focus only on complementary technologies, while less than 55% of the experiments with the presence of transnational linkages focus only on complementary technologies.

Figure 5.22 – Number of experiments x transnational linkages by value chain level of interaction



Source: Developed by the author

Therefore, the secondary data suggests that there is significant influence of transnational linkages on SRDP-22 experiments. However, primary data indicates the contrary. Most interviewees said that the there is no influence from foreign actors in the experiments. The few exceptions are the transfer of knowledge from multinational headquarters to the Brazilian subsidiaries and a few cases of international collaborations between researchers. There are even cases where the company's headquarters were contacted by the local subsidiary to help with the experiment but refused to participate.

Besides, according to several interviewees, there is limited or no influence from the headquarters in the Brazilian subsidiaries choice to participate in SRDP-22 and other R&D projects. In most cases the subsidiary only had to do a risk analysis of the experiment, but just if they would need to invest financial resources. According to the interviewees, the local subsidiaries have full autonomy to invest in R&D.

5.7 Impact of the experiments on the transition to EVs

All the experiments focus on consolidating the electric car niche. As detailed in section 5.5 one of the main results of the SRDP-22 is the creation of the RISE, i.e., the network of actors, which is an important step in consolidating a niche. The creation of this network is also seen in the actors' network maps (Figures Figure 5.8, Figure 5.9, Figure 5.10, and Figure 5.11).

Many interviewees highlighted the important role of SRDP-22 in creating a network of actors related to electromobility. One interviewee said that "the main legacy of SRDP-22 is the success of the innovation networks", while another one affirmed that "[the creation of] the research network is the main gain [of SRDP-22]". One interviewee believed the RISEs are changing the way the electricity and urban mobility ST-systems relate to each other. Besides, an interviewee said that SRDP-22 reunited the best players to work on electric mobility.

SRDP-22 is also helping to create learning processes at multiple dimensions. The exchange of knowledge between the participants is an example of this process, and it was mentioned by several interviewees. Besides, some interviewees pointed out the importance of SRDP-22 to train the workforce on electromobility. This is happening not only in the work involved in the experiments, but also on training courses in electromobility that are part of many of these experiments. For example, one interviewee said that SRDP-22 is encouraging companies to capacitate its workforce to give maintenance to EV equipment (e.g., EV chargers). Other interviewee affirmed that SRDP-22 is contributing to the training of professionals in all the different levels of the EV value chain.

SRDP-22 experiments are also contributing to articulate expectations and visions on EVs too. The program is helping to consolidate EVs as the main alternative to mitigate GHG emissions in the Brazilian urban mobility ST-system. Many of the interviewees highlighted that the experiments increased EVs visibility in the media. For example, one interviewee said that "the inauguration of EV charging stations draws a lot of attention from the media and politicians. It arouses curiosity about this technology". Other interviewees pointed out that the experiments are bringing electric mobility closer to the public, helping demystify EVs to them. Many experiments are offering people their first contact with an EV. According to an interviewee, "people only started talking about electric mobility here after our project to SRDP-22". Besides, some interviewees affirmed that SRDP-22 is showing to both individuals and companies that investing in EVs is economically viable.

There are a few other ways in which SRDP-22 is contributing to the transition to EVs in Brazil according to the interviewees. First, many interviewees highlighted the importance of the EV charging infrastructure that is being installed in the experiments. One interviewee affirmed that the improvement of the EV charging infrastructure "is a great positive impact of SRDP-22". According to this interviewee, "this infrastructure will be one of the main legacies of the program”. Besides, an interviewee stated that the investments in EV fast chargers will be the greatest legacy of SRDP-22 because “the lack of EV fast chargers on Brazilian highways is a big problem for EV owners.” According to him, “without SRDP-22 there would not be this investment in EV chargers”.

Secondary data corroborate the argument of the interviewees. Figure 5.23 and Figure 5.24 show maps of EV charging stations in Brazil at the beginning of 2019 and mid 2022, respectively. In these figures, the charging stations marked in green are standard chargers, while those marked in orange are fast chargers. The figures clearly indicate that the number of EV charging stations has considerably increased since the start of SRDP-22.

Although not all these charging stations were installed through SRDP-22 experiments, there clearly is a correlation between the program and the increase of EV charging stations available in Brazil. Besides, the *Associação Brasileira do Veículo Elétrico* (ABVE, Brazilian Electric Vehicle Association) president, Adalberto Maluf, said during *The 1st Electromobility Debate*[78] that SRDP-22 had a great impact on the number of EV charging stations available in Brazil[79].

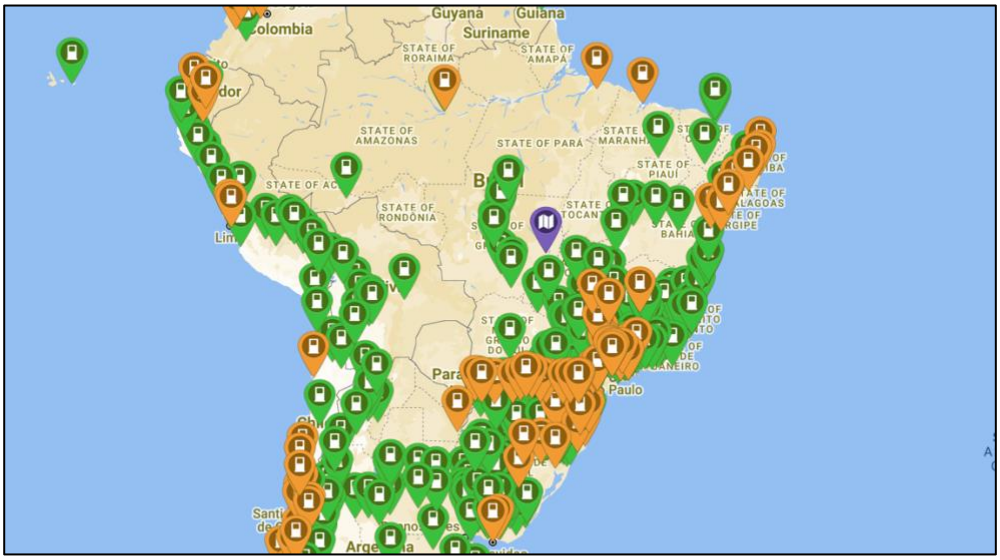
Figure 5.23 – EV charging stations available in Brasil in April 2019 (not including residencial chargers)

Source: Available at https://carroeletrico.com.br/blog/plugshare/. Accessed on 02/08/2022

[78] Event promoted by *Instituto de Engenharia* and ABVE in July 2022, during which experts and political leaders discussed the effects of clean and sustainable transport on the future of Brazilian industry, generation of jobs, quality of life in large cities and mitigation of global climate change.

[79] The speech is available at https://www.youtube.com/watch?v=9NEVYhfSFFw.

Figure 5.24 – EV charging stations available in Brasil in August 2022 (not including residencial chargers)



Source: Available at https://www.plugshare.com. Accessed on 02/08/2022

Moreover, one interviewee pointed out that SRDP-22 raised an important debate about the precariousness of the infrastructure to receive EVs in Brazil. This debate may drive even more investments to the installation of EV charging stations. Other interviewee said that the number of EV chargers that will be implemented by SRDP-22 experiments might be sufficient to solve the EV chargers' investment versus demand issue[80].

In addition, several interviewees indicated that the development of new business models to make EV charging a profitable business is also an important impact of SRDP-22. According to one interviewee, the experiments are allowing companies to test innovative business models in a "secure environment". These tests may allow the companies to "lose fear" of investing in EVs in Brazil.

Finally, many interviewees also highlighted the importance of SRDP-22 experiments to improve the existing regulation on EVs, notably on EV charging. One interviewee affirmed that one of the main results of SRDP-22 will be suggestions for improving the current regulation. He believed that regulatory changes are necessary to make new business models for EV charging viable. Besides, another interviewee pointed out that SRDP-22 will not only help improve the current regulation but will also play an important role in influencing public policies towards EVs.

[80] Companies do not want to invest in EV chargers because there is not sufficient demand to justify these investments. On the other hand, consumers are wary about buying EVs because there is no significant network of chargers.

On the other hand, primary and secondary data indicate that SRDP-22 contribution to destabilize the private car ST-regime is limited. The only relevant impact may be to change the public perception of the ST-regime. This is because EVs are often depicted in the media as better than ICEV. The recent increase in fossil fuels prices in Brazil has contributed to this type of news.

5.8 Interest of the electricity ST-system in electric mobility

The participants were asked if the companies of the electricity ST-system would be investing in electric mobility without SRDP-22. This question was also an opportunity to discuss with the interviewees the level of interest of the electricity ST-system in the transition to EVs in Brazil.

Most interviewees believed that most companies of the electricity ST-system participating in SRDP-22 would not be investing in electric mobility without this program. One interviewee affirmed that “electric mobility is not a priority of the electricity sector right now”. Another interviewee stated that most of the utility companies have little or no interest in electric mobility. They are only focused on providing electricity and “electric mobility is just another client”. Besides, according to this interviewee, utilities are too passive and have no interest in investing on innovation, such as EVs.

Moreover, these interviewees also believed that even those companies that had previously invested in electric mobility, would probably not be investing in electric mobility anymore without SRDP-22. One interviewee affirmed that his company “might still have invested in electric mobility without SRDP-22, but in a much lower scale”. Another interviewee had a similar answer, affirming that, although the company would be investing in electric mobility anyway, they would not be investing in so many experiments without SRDP-22. Finally, other interview said that “if it weren't for SRDP-22, we certainly wouldn’t have so many R&D projects on this topic now”.

Besides, one interviewee understood that the companies from the electricity ST-system have “a clear interest in spending the money without bothering”. According to this interviewee, when companies do an experiment in an ANEEL program such as SRDP-22, it is rare that ANEEL will later reject the experiment and disallow the spending. Therefore, most companies investing in electric mobility through SRDP-22 would be doing so just because it is a “safe way” to make their mandatory investment on R&D.

Nonetheless, there were a few interviewees who believed that SRDP-22 itself indicates that electric mobility is one of the interests of the electricity ST-system. One of these interviewees affirmed that “the electricity sector would invest in electric mobility regardless of SRDP-22”. Another interviewee indicated that there was low interest from the electricity ST-system on EVs at the beginning of SRDP-22, but things changed with the increase of fossil fuels and ICEVs prices. He said that “there was a ‘boom’ in EV technology” since 2021 and now the companies from the electricity ST-system are more interested on electric mobility. He also believed that the utilities that “doesn't invest in EVs will be out of the game. Those who do not want [to invest in EVs] will be forced to do so”.

Another way to measure the level of interest of the electricity ST-system in the transition to EVs in Brazil is to understand how the experiments submitted to SRDP-22 were conceived. In this case, the companies from the electricity ST-system, notably those from the Distribution ST-regime, behaved differently depending on whether they had participated in experiments on electric mobility before SRDP-22.

The companies that already had some experience on electric mobility experiments usually conceived the initial idea of the experiment to SRDP-22 and then invited other actors to participate. On the other hand, the companies that had never invested in electric mobility were usually reached by a research center or university who presented them an experiment idea and proposed a partnership to submit a proposal to ANEEL.

Moreover, the companies that had some experience with electric mobility experiments prior to SRDP-22 often got involved in more than one experiment, while this was not common in the case of the companies without this previous experience.

There are a few companies that had experience in electric mobility before SRDP-22, but decided not to participate in the program, despite been reached by research centers and universities. An interviewee that works for one of this companies said that they decided not to participate in SRDP-22 because the company was already doing its mandatory investments in R&D on other projects. Besides, it was more interesting to the company to do this investment by itself. The interviewee argued that the current model of ANEEL R&D programs only benefited the researchers because “their true objective is not innovation, but research”. The interviewee believed that “the focus of the innovation in the electricity sector should be in the industry, not in the research centers and universities”.

Finally, none of the niche actors from the electricity or the urban mobility ST-systems interviewed, except for universities and research centers, proposed experiments. These actors were usually invited to participate in the experiment(s) in which they are involved.

5.9 Impact of the COVID-19 pandemic

The COVID-19 pandemic delayed most experiments and led to several changes in their scope. Many companies withdrew from the experiments because they had to significantly reduce their costs, and investments in R&D were one of the first to be cut. According to an interviewee, "a lot of money from R&D went to the 'COVID budget'[81]". Besides, many field research activities, such as inspections, field tests and some laboratorial activities were cancelled or delayed due to lockdowns in most Brazilian cities. Other significant impacts were the disruption of the global supply chain, which delayed the delivery of some equipment such as EV chargers, and the devaluation of the Real, which increased some experiments' cost and reduced the purchasing power of Brazilian consumers.

However, most interviewees considered that these negative impacts were not significant. Many of the interviewees reported that most part of the work could be done remotely and that "using virtual tools worked well". One of the interviewees even said that the "[the digitalization of the work] made the share of information faster and the work model more agile" within the experiment. For example, monthly face-to-face meetings between project participants were replaced by weekly virtual meetings, significantly increasing the exchange of information and knowledge.

Besides, the experiments' schedule usually could be adjusted to accommodate the delays in field research activities and equipment delivery. An interviewee said that "many of the field visits [to choose locations to install EV chargers] were replaced by the use of Google Earth".

The COVID-19 also had positive impacts on electric mobility according to the interviewees. The disruption of the global supply chain and the devaluation of the Real made it more advantageous to develop EV chargers in Brazil than to import them from abroad. Many national companies took this opportunity to develop their own EV charging

[81] ANEEL approved, in 2020, a regulation that authorized the electricity companies to loan money from banks to postpone increases in the electricity tariff during the pandemic. Therefore, the necessary raises in the tariff caused by COVID-19 impact in the electricity sector costs will be diluted in the next five years, instead of being implemented right way.

stations. In addition, the devaluation of the Real caused a significant increase in fossil fuel prices in Brazil. This increase has made the total cost of ownership of EVs equal or even lower than ICEVs, despite the higher purchase cost of EVs. This fact gave EVs a lot of visibility. For example, one interviewee said that, since the rise of fossil fuels prices, she and her team have been called to present their experiment on the media many times and have received several inquiries about EVs from many companies, such as taxis cooperatives and delivery.

Finally, many interviewees pointed out that the pandemic increased people's interest in decarbonization because the pandemic is strongly related to climate change. One interviewee said that the pandemic "opened the eyes of the population to environmental problems, motivating them to look for better alternatives", such as renewable energy and electric mobility. Another interviewee suggested that the status of having an EV considerably increased after the pandemic. According to him, the combination of high prices and environmental appeal made EVs a status symbol.

6. CASE STUDY - ANALYSIS

The results of the case study presented in Chapter 5 are analyzed and discussed in the present chapter. First, the role of the electricity ST-system in the transition to EVs in Brazil is explored, focusing on how this ST-system is interacting with the electric car niche. In this first section, the case study results are also used to discuss the current conceptualizations of multi-system sustainability transitions, which were presented in Section 2.1.2. The next section analyzes the current normative orientation of sustainability in the urban mobility ST-system in Brazil, and how it is impacting the transition to EVs. The third section explores the role of incumbents in the transition to EVs, taking into consideration the way both the private car ST-regime and the ST-regimes of the electricity ST-system are interacting with the niches that are involved in the case study. Finally, the last section discusses the impact of transnational linkages in the transition to EVs in Brazil. This last section focuses on the role of multi-national companies, notably Chinese actors, in SRDP-22.

6.1 The role of the electricity ST-system in the transition to EVs in Brazil

The results from the case study show that the electricity ST-system interacts with the electric car niche in many ways. Even considering the restricted scope of the case study, it was possible to identify interactions between almost all ST-regimes and niches of the electricity ST-system and the electric car niche. Besides, these ST-regimes and niches have many different modes of interaction with the electric car niche. Counterintuitively to what would be expected from a program such as SRDP-22, there are several interactions between actors whose mode of interaction can be classified as competition. This includes experiments in which actors from the electric car niche are interacting with actors of the Private car ST-regime. Moreover, there are also interactions in all levels of the value-chain, although most experiments focus on complementary technologies.

It is not only between the ST-regimes and niches of the electricity ST-system that there are different types of interaction with the electric car niche. There are different patterns of interaction inside the ST-regimes and niches. Actors from the same ST-regime or niche have different, and sometimes even opposite, ways of interacting with the electric car niche.

The Distribution ST-regime is the most involved in SRDP-22 from all the ST-regimes of the electricity ST-system. 45 actors from this ST-regime are participating in

SRDP-22, and they are present in 26 of the 32 experiments in the program. Besides, 14 of the 24 actors participating in three or more experiments are part of the Distribution ST-regime. Moreover, many of the main actors of SRDP-22 are part of this ST-regime, such as ABB, CTG Corporation, State Grid Corporation of China, and Equatorial Energia. The second ST-regime most involved in SRDP-22 is the Large hydroelectric ST-regime. Nonetheless, from the 19 actors of this ST-regime involved in SRDP-22, 18 are subsidiaries of companies that are also part of the Distribution ST-regime.

The utility companies, which are the main actors of the Distribution ST-regime, are the interface between the electric car niche and the electricity ST-system. Although supplying electricity to EVs, or any other consumer, is the role of this entire ST-system, the actors of the Distribution ST-regime are who interact the most with the consumers. The utilities companies are much closer to EVs than other companies of the electricity ST-system. Besides, they are already dealing with EVs, as one of the interviewees pointed out. Therefore, the Distribution ST-regime is the most interested in SRDP-22 because it will be the most impacted by the transition from ICEVs to EVs.

The Distribution ST-regime can be considered well-aligned, as explained in Section 4.1. According to the MLP, the actors of this ST-regime should behave in a coherent and homogeneous way, at least in relation to issues that are relevant to the ST-regime. Given the potential impact that a transition to EVs can have on the Distribution ST-regime, this is exactly the kind of issue that one should expect the ST-regime actors to have a cohesive behavior. Nonetheless, the results from the case study, notably the primary data gathered in the interviews, show just the opposite.

It is possible to divide the actors from the Distribution ST-regime in three groups based on their position towards EVs. First, there are the actors that have been investing in electric mobility before SRDP-22 and are fully committed to supporting the transition, such as CPFL, Copel, and Enel (see Section 4.3). Many of these companies are involved in several experiments in SRDP-22.

The second group is composed by actors who are participating in SRDP-22, but probably would not invest in electric mobility without this program. There was almost a consensus among the interviewees that most companies of the electricity ST-system participating in SRDP-22 would not be investing in electric mobility without this program, including actors from the Distribution ST-regime. In other words, most actors of this ST-regime are not interested in the transition to EVs, as pointed out by some of the interviewees. Moreover, these actors will likely no longer invest in electric mobility after SRDP-22.

Finally, there are actors who are not only not interested in the transition to EVs, but also fear this transition. According to one of the interviewees, these actors are afraid of the transition because EVs are a mobile and unpredictable load. Dealing with this new load would require significant investments from the utility companies in infrastructure without the guarantee of a return on these investments. Thus, this last group would like to avoid, or at least delay, a transition to EVs.

The different types of relationships between actors from the Distribution ST-regime and electric car niche suggest that there is not only one pattern of interaction between them. Moreover, there are other examples in the case study of actors from the same ST-regime interacting differently with the electric car niche.

As explained in Appendix E, the EVs have a great synergy with renewable energies and many scholars see a transition to EVs as part of the energy transition (STOKES; BREETZ, 2018; VAN DER KAM et al., 2018; ARCOS-VARGAS, 2021; TORABI; GOMES; MORGADO-DIAS, 2021; YUAN et al., 2021). Therefore, a transition to EVs could increase the pressure on the Brazilian government to reduce the use of thermoelectric power plants, even though Brazil already produces most part of its electricity from renewable sources, as detailed in Section 4.1. Thus, it is reasonable to expect that no actor from the Thermoelectric ST-regime would be interested in electric mobility. On the contrary, this ST-regime would probably try to avoid the transition from ICEV to EV, given that the mode of interaction between the Thermoelectric ST-regime and the electric car niche can be characterized as parasitism (see Appendix E).

Nonetheless, there are 13 actors from this ST-regime participating in SRDP-22. Two of them are even involved in more than one experiment. Many of these actors are subsidiaries of companies that also invest in renewable energies or are part of the Distribution ST-regime. However, five of them are subsidiaries of companies from the fossil fuels ST-system, such as Petrobras and Eneva. Besides, many of these companies proposed to ANEEL the experiments they are involved in, i.e., they have not joined other companies experiments just to do their mandatory investment in R&D.

Another example of the contradictions in the way the electricity ST-system is interacting with the electric car niche is how different government actors from this ST-system see the transition to EVs.

It is clear in the case study that ANEEL is interested in promoting the transition to EVs. Although the SRDP-22 was conceived after many studies to identify which topics are relevant to the electricity ST-system, with contributions from several actors of this ST-system, the case study data suggest that ANEEL is particularly keen on the transition.

According to Brazilian legislation, ANEEL's role is to regulate and supervise the Brazilian electricity sector and implement the policies and guidelines of the federal government regarding the exploitation of electric energy. Therefore, the agency is not supposed to develop and promote policies for the electricity ST-system, which is the role of the MME. Nonetheless, some of the interviewees understand that the agency is doing exactly that by promoting electric mobility through SRDP-22.

One of the interviewees believed that agencies' role as command-and-control entities is outdated and will not make Brazil move forward. This interviewee argued that the agencies should propose public policies and guide their respective sector development in some specific themes. The agencies should be able to induce policy when it balances the relationship between companies and consumers. According to the interviewee, this was the idea behind SRDP-22.

In this case, most utilities are not interested in investing in EV's, but this investment is in the interests of consumers. So, ANEEL should promote these investments. Moreover, the interviewee said that ANEEL understands that the energy transition is inevitable. This transition would include smart grids, distributed generation, virtual grids, digitalization, EVs, among other technologies. Therefore, ANEEL would have to prepare the electricity sector to the inevitable transition to EVs

The role of ANEEL is that of an intermediary, which helps to create opportunities for the emergence of new technologies (STEWART; HYYSALO, 2008) and can also be important in destabilizing ST-regimes, as detailed in Section 2.1.1.4.5. Following Kivimaa et al. (2019) topology of intermediaries in socio-technical transitions, ANEEL can be classified as a regime-based transition intermediary[82].

Although the agency is part of the established institutions in the electricity ST-system, it is pushing for transformative changes in this and other ST-systems because it believes that the energy transition is inevitable. This finding gives an innovative

[82] A regime-based transition intermediary "is tied through, for example, institutional arrangements or interests to the prevailing socio-technical regime but has a specific mandate or goal to promote transition and, thus, interacts (often) with a range of niches or the whole system" (KIVIMAA et al., 2019, p. 1060). According to Kivimaa et al. (2019), government agencies often act as regime-based transition intermediaries.

contribution to the sustainability transitions literature, i.e., intermediaries from one ST-system can significantly impact the transition in another ST-system during multi-system sustainability transitions.

However, other actors in the Brazilian government have a different strategy and, to some extent, contrary to that of ANEEL. A significant part of the government, including the MME, seems to be more interested in promoting biofuels than electric mobility. For example, MME made efforts to insert RenovaBio[83] into the next stage of the Rota 2030[84] automotive program (OLMOS, 2022). Besides, MME launched in 2021 the Future Fuel program which aims to further expand the use of biofuels, such as ethanol, biodiesel, and aviation biokerosene (MME, 2021).

MME also made reservations about a project by the French Development Agency (AFD) and German Agency for International Cooperation (GIZ) to invest US$ 850 million in electric mobility in Latin America. MME positioned itself in favor of the project, only if it did not interfere with the Brazilian national planning, which prioritizes biofuels (MACHADO, 2021).

Besides, the Brazilian National Energy Plan[85] predicts that between 8% and 15% of the national vehicle fleet will be electric by 2035 (MME; EPE, 2020). However, in this forecast, the majority of these EVs (7% to 11%) would be biofuel HEVs, i.e., only 1% to 4% of the vehicles would be BEVs or PHEVs in 2035. For comparison, a study from the Boston Consulting Group for ANFAVEA (2021d) projects that between 8% and 23% of the Brazilian car fleet will be BEVs or PHEVs by 2035. Besides, sugarcane experts predict a 40% reduction in demand for sugarcane for ethanol production in Brazil by 2035 (BATISTA; LARA; ALMEIDA, 2021).

Therefore, the government projection is considerably different from those by market experts and reflects the government preference for biofuels over EVs. This position is in line with statements by MME representatives, who recognized that the electrification of the urban mobility ST-system is inevitable, but argued that “in Brazil, it is going to have to be with biofuels and it will be a bio-electrification” (EPBR, 2021).

[83] RenovaBio is a program launched by MME in 2016 that aims to improve the policies and regulatory aspects of biofuels, in order to contribute to overcoming the technical and economic challenges faced by the sector (BRAZIL, 2020a).

[84] Rota 2030 is a federal program that seeks, through tax incentives, to support technological development and innovation in the automotive industry in exchange for the development of safer, more economical, and less polluting vehicles. This program was launched in 2018 (BRAZIL, 2020b).

[85] Set of studies and guidelines for the design of a long-term strategy for the Brazilian energy sector.

Moreover, according to ABVE's president the government does not have a clear transition strategy to electric mobility (ABVE, 2022a). Barassa, da Cruz, and Moraes (2021) also indicate the need for more robust public policy instruments for the promotion of EVs. This would build an institutional framework that allows and facilitates EVs dissemination in the market.

Therefore, actors from the Brazilian government also do not have a unified approach towards electric mobility. This is different from what is happening in China and the EU, where there is strong alignment inside the government to promote the transition to EVs (BARASSA; DA CRUZ; MORAES, 2021; ABNETT, 2022; CONRAD, 2022).

The few groups of actors from the electricity ST-system who seem to have a more united stance on the electric car are those from some of the niches of this ST-system. The most relevant are the battery, distributed generation, and energy efficiency niches (see Chapter 5). 19 of the 32 experiments in SRDP-22 have the participation of at least one actor from one of these niches. As detailed in Appendix E, there is strong synergy between these niches and the electric car niche. Moreover, all these technologies can be considered part of the energy transition alongside EVs (IRENA, 2021). However, even in this case, it should not be expected that all actors from these niches are supporting the transition to EVs. Nonetheless, the case study data suggest that there is a greater alignment to promote EVs between the actors in these niches than between the other actors in the electricity ST-system.

The results from the case study indicate that there is not a single form of interaction between actors from ST-regimes of the electricity ST-system and actors from the electric car niche, even considering well-aligned ST-regimes. It is not possible to define a single type of interaction between the electricity and urban mobility ST-systems regarding the sustainability transition from ICEVs to EVs. In other words, the relationship between the actors of these two ST-systems is complex rather than one-dimensional. There are some actors supporting the electric car niche, most actors are not interested on EVs, and a few others are even trying to inhibit this niche. The electricity ST-system does not play a single role in the transition to EVs, but many.

However, this complexity is often ignored in studies on multi-system sustainability transitions (see Section 2.1.2). Most of these studies fail to acknowledge the multiple types of interaction between ST-regimes and niches from different ST-systems during sustainability transitions. The typologies used to characterize these interactions assume that all actors of ST-regimes and niches behave in the same way. This simplification ignores the many contradictions and divergent views inside the ST-regimes and niches, notably regarding transitions in other ST-systems.

Rosenbloom (2020) is one of the few authors to acknowledge the complexity of the interactions during multi-system sustainability transitions. His *multi-system perspective* considers that these interactions are diverse, layered, and evolving. As detailed in Section 2.1.2, this author recognizes that different ST-regimes of the same ST-system can have different types of interaction with ST-regimes and niches from another ST-system. This is exactly what was seen in the case study, i.e., each ST-regime and niche of the electricity ST-regime has its own type of interaction with the electric car niche, as detailed in Appendix E.

However, Rosenbloom (2020) only considered the different types of interaction at the level of the ST-regimes and niches. He did not acknowledge that actors from the same ST-regime or niche can have different types of interaction with actors from a ST-regime or niche from another ST-system. Nonetheless, the case study results indicate that this is not only possible, but also common during a transition.

The characterization of the interaction between ST-regimes and niches as a single pattern can be useful when studying multi-systems sustainability transitions that are finished. In this case, it can be expected that one single type of interactions between the actors of one ST-regime and a niche will become dominant. For example, it is reasonable to expect that all actors from the Distribution ST-regime will support the electric car niche at some point. If this is the case, their interaction could be characterized as intersystem niche-regime symbiosis. Nonetheless, this is not the case during the transition. As already detailed, some actors from this ST-regime are supporting the transition to EVs in Brazil, while others are ignoring or blocking it.

Another relevant point is that the mode of interaction between ST-regimes and niches do not define how actors from these ST-regimes and niches will interact with each other. For example, the relationship of the Distribution ST-regime and the electric car niche could be considered symbiosis (see Appendix E) using Lin and Sovacool (2020) typology, as these technologies can benefit from each other. Nonetheless, as detailed before, this is not enough to make all actors from the Distribution ST-regime support the electric car niche. In this case, the different set of rules (industry, policy, culture, market and user preference, etc) that make-up the ST-regime cause some actors to ignore the technological aspect.

Therefore, actors of one ST-regime may chose not to support the transition to a new technology in another ST-regime even if they could benefit from this transition. When taking into consideration other factors, such as politics, regulation, or culture, actors may decide that the technological benefits are not enough to support the transition, even when it is happening in another ST-system. According to Köhler et al. (2019, p. 6), “transitions are inherently political processes, in the sense that different individuals and groups will disagree about desirable directions of transitions.”

Hence, the interactions between a single ST-regime or niche from one ST-system with a ST-regime or niche from another ST-system should also not be characterized as a single pattern. There are multiple types of interaction between actors of ST-regimes and niches of one ST-system with actors from another ST-system during the multi-system transitions. Even well-aligned ST-regimes do not show a cohesive behavior in relation to ST-regimes and niches of another ST-system. Besides, only a few actors of each ST-system interact with each other.

Thus, it is necessary to go one step further, beyond the ST-regimes and niches level, when analyzing ongoing multi-system sustainability transitions. The different interest groups within the ST-regimes and niches must be considered to explain the contrasting behavior between the actors of two ST-systems during transitions. These groups might have distinct and even opposing political and economic interests regarding new technologies, notably when these technologies are from another ST-system. Understanding these interests is key to explain how they will interact with the actors from the other ST-system.

6.2 Normative orientation impact in the transition to EVs in Brazil

The case study showed that while most actors from the electricity ST-system participating in SRDP-22 are willing to help consolidate the electric car niche, almost none of them want to help to destabilize the private car ST-regime. As detailed in Chapter 5, all three necessary steps to consolidate a niche were promoted by SRDP-22 experiments. On the other hand, only one of the five possible ways the experiments could help destabilize the private car ST-regime were identified in SRDP-22. Even in this case, the fact that experiments may help change the public perception of the private car ST-regime seems to be an unexpected consequence of SRDP-22, rather than something the actors involved were interested in.

There are many reasons why the actors from the electricity ST-system are willing to help consolidate the electric car niche, but do not want to destabilize the private car ST-regime. At least four factors that are causing the actors from the electricity ST-system to behave in this way were identified in the case study.

The first factor is the contradictions within the Brazilian government regarding EVs, as previously detailed. Some interviewees said that these ‘mixed signals’ from the government make the companies insecure to invest in electric mobility in Brazil. Besides, the case study results (see Section 5.8) show that most companies of the electricity ST-system would not even be investing in electric mobility if it were not for SRDP-22. Therefore, given that actors from this ST-system are insecure to invest in EVs, it should not be expected that they would invest in destabilizing the private car ST-regime.

This understanding is in line with Barassa, da Cruz, and Moraes (2021), who affirmed that the electricity ST-system main actions regarding EVs have focused on demonstrative experiments to investigate and understand EV technology applications and implications. Therefore, the electricity ST-system actors are trying to identify possibilities for companies to act in terms of electricity supply, charging infrastructure and the new associated business models.

Another reason why the actors from the electricity ST-system are not willing to help to destabilize the private car ST-regime is that the government still has a strong influence in this ST-system. Although the Brazilian electricity ST-system has been through a process of deregulation, flexibilization and privatization since the 1990s (CAMPOS et al., 2020), many of the main companies of this ST-system are still public or have the Brazilian government as one of its main shareholders. For example, Eletrobras, Eletronorte, Eletrosul, Chesf, Furnas, Eletronuclear, Copel, Cemig, and Itaipu Binacional are all controlled by the government. Given that the government also controls the main company of the Brazilian fossil fuel ST-system, Petrobras, it should be expected that the companies of the electricity ST-system controlled by the government would not be interested in destabilizing the private car ST-regime.

In fact, most of these companies do not show much interest in EVs. Most of them are not participating in SRDP-22 and are not involved in any other experiment on electric mobility. The few exceptions are Copel and Cemig, which were already investing in EVs even before SRDP-22. However, these are companies controlled by the state government of Paraná and Minas Gerais, respectively, and not by the federal government. These two states do not produce oil (ANP, 2022a). On the other hand, Paraná is the second largest producer of electricity in Brazil, while Minas Gerais is the third (EPE, 2021). Besides, these states are among the six largest ethanol producing states (ANP, 2022b). So, this could be why these companies are investing in electric mobility, given that oil production is not a source of income for the state governments of Paraná and Minas Gerais, while electricity production is.

In addition, the participation of Petrobras and legacy brands in some SRDP-22 experiments could also be affecting the participants' behavior. As detailed in Section 5.2, although these companies are involved in few experiments, these are among the most expensive experiments in SRDP-22. The total estimated cost of the six experiments in which these companies are participating is approximately R$ 175 million, equivalent to 37% of the total estimated cost of SRDP-22 (R$ 473 million). Therefore, Petrobras and the legacy brands have a considerable influence in SRDP-22. This is likely contributing to limiting the program's experiments to helping consolidate the electric car niche.

Besides, a few interviewees pointed out that Petrobras and the legacy brands' influence is not limited to their participation in SRDP-22. Actors from the fossil fuels ST-system and private car ST-regime have strong lobbying with the Brazilian government and the Parliament. Many interviewees affirmed that these companies are not truly interested in the transition to EVs in Brazil despite their participation in SRDP-22. According to these interviewees, these companies are participating in the experiments to influence the program from within, directing it towards less harmful outcomes for them. In other words, these companies' participation in the experiments is an attempt to guarantee that these experiments will not help destabilize the current ST-regime.

Furthermore, one interviewee also highlighted the impact of the biofuels ST-system lobby in SRDP-22 and the transition to EVs in Brazil. According to this interviewee, the actors from this ST-system are more committed to stopping or at least delaying the transition to EVs in Brazil than the actors of the fossil fuels ST-system and private car ST-regime.

A transition to EVs in Brazil means replacing flex-fuel ICEVs with EVs. This substitution would significantly impact the demand for hydrous ethanol, that is, ethanol that is used directly in ICEVs. Besides, the gasoline used in Brazil is a mixture with 27% of anhydrous ethanol. In 2021, 38.1% of the ethanol produced for use as fuel was used for blending with gasoline (ANP, 2022b). Therefore, the reduction of the consumption of gasoline will not only impact the fossil fuels ST-system, but also the biofuels ST-system.

Transitioning to ethanol powered HEVs instead of BEV or PHEVs is constantly highlighted as an alternative in Brazil. This would minimize the impact of the transition to EVs in the biofuels ST-system. However, one interviewee affirmed that legacy brands are less interested in ethanol HEVs than other EVs, but "are afraid of speaking against the ethanol hybrids in Brazil because of the political power of the ethanol sector".

If the biofuels ST-system has a lobby strong enough to 'intimidate' the legacy brands, it can be assumed that they can also influence the actors of the electricity ST-system. Therefore, it is reasonable to presume that this lobby is one of the reasons why the experiments in SRDP-22 have so few and limited initiatives to help destabilize the private car ST-regime.

There is one point that connects all the reasons why the actors from the electricity ST-regime do not want to destabilize the private car ST-regime presented before: the normative orientation. As detailed in Section 2.1.3.3, the understanding of sustainability varies across societies, and it can significantly impact the objectives and the governance of sustainability transitions. In this context, the debate over what is the better alternative to make urban mobility sustainable in Brazil, electric vehicles or biofuels, seems to be the underlying factor why actors from the electricity ST-regime do not want to destabilize the private car ST-regime.

As detailed before, a considerable part of the government believes that biofuels are the best alternative to make Brazilian urban mobility sustainable. This section of the government understands that electric vehicles, especially BEVs, are a solution for countries that do not have as many natural resources available, nor a production chain for biofuels as structured as Brazil. This understanding of sustainable urban mobility is probably one of the reasons why government-controlled companies from the electricity ST-system are not supporting the transition to EVs in Brazil as much as other companies.

The debate between electric vehicles and biofuels is not limited to the government. This same debate is happening in the public sphere and there is no consensus between experts in this subject, as discussed in section 4.2.

There is a wide spectrum of opinions, ranging from those who see flex-fuel ICEVs as the best alternative for Brazil to those who believe that EVs are the best option, including those who understand that promoting these two technologies is better than betting on just one of them. There are multiple visions of sustainability, or at least of sustainable urban mobility, and it is not clear which one of them will prevail.

Another relevant point to understand the impact of the normative orientation in the transition to EVs in Brazil is the current meaning of owning an EV. As detailed in Chapter 5, some interviewees believe that the COVID-19 pandemic contributed to changing the reputation of EVs in Brazil from a novelty to a status symbol. Moreover, as detailed in Section 4.2.2, the increase in EVs sales in Brazil is related to the growth of the luxury industry during the COVID-19 pandemic. Therefore, people interested in EVs are no longer early adopters, but wealthy consumers.

The issue with this trend is that Brazilian elites may try to coopt the transition to EVs. The government may have less incentive to put forward policies to make EVs more affordable because they became symbols of status and power. In this scenario, this kind of policy could be seen as elitist, i.e., a policy to benefit only the rich. If that is the case, there could be an odd situation in Brazil, where only wealthy consumers have access to EVs, while all the other consumers can only afford ICEVs. Given EVs lower ownership cost, this scenario would contribute to increasing Brazil's inequalities in the long term, notably if fossil fuels and biofuels prices keep increasing more than electricity prices.

The lack of a clear normative orientation is already impacting how the transition to EVs in Brazil is unfolding and may even inhibit it. The case study data showed that the debate between biofuels and EVs has already impacted SRDP-22 and how the electricity ST-system interacts with the urban mobility ST-system, notably with the electric car niche. Besides, if EVs start to be seen only as a status symbol, and not as a better technological option than ICEVs, this can contribute to the government focusing on policies to promote biofuels instead of EVs.

6.3 The role of incumbents in transitions in developing countries

103 of the 156 actors participating in SRDP-22 are part of one or more ST-regimes. From those, 19 are part of at least one ST-regime of the urban mobility ST-system and 84 of at least one ST-regime of the electricity ST-system. Besides, there are only 32 actors who are only part of a niche from one of these two ST-systems. In addition, at least one actor from a ST-regime of the electricity ST-system is present in all experiments and 12 experiments have the participation of an actor from a ST-regime of the urban mobility ST-system.

Therefore, incumbents have a more relevant role in SRDP-22 than niche actors. In fact, the only niche actors that are important in this program are universities and research centers. As presented in Section 5.1, 14 of the 33 actors who can be considered part of the electric car niche and 8 of the 19 actors that are part of a niche of the electricity ST-system are universities or research centers. Most other niche actors have peripheral roles in SRDP-22 The few exceptions are BYD Brasil, Sollus, Mobilis, and Electric Mobility Brasil.

Thus, the case study data do not support the MLP conceptualization of socio-technical transitions as a dispute between ST-regime and niches actors (see Section 2.1.1.4.4). Although some of the MLP transition pathways even consider the participation of incumbents in the development of niche technology, it is assumed that this collaboration would only happen when there is a lot of pressure from the landscape in the ST-regime and it starts to destabilize. Nonetheless, the case study shows incumbents helping consolidate a niche even when the ST-regime is not under pressure.

The case study results are more in line with the findings from Ghosh and Schot (2019), who argued that incumbents can have a more important role than niche actors in transitions in developing countries. Other authors have also recognized the role of incumbents in sustainability transitions in developing countries (see in Section 2.1.3.2) and criticized the MLP for its assumption that incumbents will not participate in the development and consolidation of niche technology.

In SRDP-22, there are actors from several ST-regimes from two ST-systems working together with niches actors in experiments to help consolidate niche technologies. Some of the main actors in the program are legacy brands, such as Toyota, Renault, Nissan, and Volkswagen. Moreover, the main EV sellers in Brazil are legacy brands (see Section 4.2.2).

As detailed in the previous section, the estimated cost of the six experiments in which legacy brands are participating is equivalent to 37% of SRDP-22 total cost. Besides, almost half of the eleven experiments that focus on the main technology have the participation of legacy brands.

In comparison, experiments with the participation of EV manufacturers have an estimated cost equivalent to 33% of SRDP-22 total cost. However, if BYD Brasil is not included, the estimated cost of the experiments in which EV manufacturers are participating is equivalent to only 18% of SRDP-22 total cost. Moreover, only 2 of the eight experiments with the participation of EV manufacturers focus on the main technology.

The MLP premise of the dispute between the ST-regime and niche actors during ST-transitions is rooted in the conceptualization of ST-regimes as uniform, homogeneous, and coherent structures. But that is often not the case, notably in developing countries, as detailed in Section 2.1.3.2. ST-regimes in developing countries are often more heterogeneous and less stable than the ST-regimes in developed countries. And incumbents are usually less committed to less stable ST-regimes (see Section 2.1.1.4.5).

The Brazilian urban mobility ST-system is not well-aligned. Moreover, the private car ST-regime can be characterized as partly aligned, as detailed in Section 4.2.1. According to Van Welie *et al.* (2018), when a ST-regime is not well-aligned, a new ST-regime can emerge. However, this does not mean that this new ST-regime will substitute the previous one. Van Welie *et al.* (2018) showed that the old and new ST-regimes can coexist.

As detailed in the previous section, the coexistence of many different technologies is a possible outcome of the transition of the private car ST-regime in Brazil. Instead of substituting ICEVs, EVs can coexist with them, notably with ethanol ICEVs. Moreover, other technologies may also be part of this future mix of alternatives, such as ethanol HEV and ethanol FCEV. Therefore, the results of the case study also corroborate the findings from Van Welie *et al.* (2018).

However, the case study results also contradict previous studies on sustainability transitions in developing countries. These studies (see Section 2.1.3.2) argue that incumbents have important roles in sustainability transitions in these countries because the ST-regimes there are less uniform and cohesive than in developed countries. Nonetheless, the electricity ST-system is well aligned, and all its ST-regimes are well aligned or at least partly aligned. Despite that, actors from these ST-regimes are participating in SRDP-22, collaborating with niche actors to develop niche technologies.

SRDP-22 focus is on electric mobility, which is a niche technology challenging the private car ST-regime, not the ST-regimes of the electricity ST-system. However, the case study data show that many actors participating in SRDP-22 experiments are from niches of the electricity ST-system, such as the battery and distributed generation niches. 22 of the 32 experiments in SRDP-22 have the participation of at least one actor of a niche of the electricity ST-system. Therefore, actors from ST-regimes of the electricity ST-system are also collaborating with niche actors from their own ST-system.

Moreover, although SRDP-22 focus on EVs, many of the experiments are also developing niche technologies of the electricity ST-system. For example, there are eight experiments (PD-00043-0087, PD-00063-3059, PD-04950-0725, PD-05160-1906, PD-

06585-1912, PD-07267-0021, PD-07427-0319, PD-02866-0517) that focus on developing battery, distributed generation, or consumption management technologies. All these experiments have the participation of at least one actor from the battery, energy efficiency, consumption management, or distributed generation niches.

Thus, there are actors from well-aligned ST-regimes collaborating with niche actors from their own ST-system in more than two-thirds of SRDP-22 experiments. Besides, in eight of these experiments the focus is on technologies that are the core of some of these niches.

Considering only parent companies, 40 of the 102 actors participating in SRDP-22 are part of ST-regimes of the electricity ST-system. From these 40 actors, almost half (19) are part of more than one ST-regime. Many of these actors are part of ST-regimes whose mode of interaction between them is competition. For example, CEMIG and EDP are part of both the Large hydroelectric and Thermoelectric ST-regimes. Investing in competing technologies is not an uncommon behavior for actors from the Brazilian electricity ST-system.

Incumbents were among the first companies to invest in new technologies such as wind and solar energy in Brazil. For example, after many years of limited experiments on wind energy in the 1990s, this technology started to grow in Brazil when the government created the PROINFA program, in 2002, to stimulate the development of biomass, wind, and small hydro electricity generation (GLOBAL WIND ENERGY COUNCIL, 2007, 2008). The first wind farms of this program started operating in 2006. Most of these farms were built and operated by large corporations, such as Neoenergia, Elecnor, Iberdrola, AES, and Tractebel (GLOBAL WIND ENERGY COUNCIL, 2009). Moreover, the companies that supplied the wind turbine to these powerplants were mainly major foreign wind turbine manufacturers, such as Enercon, Suzlon, and Vestas (GLOBAL WIND ENERGY COUNCIL, 2009).

In addition, incumbents from the Large hydroelectric, Distribution, and Transmission ST-regimes are among the main actors of the Wind ST-regime. According to ANEEL (2022), seven of the ten main producers of wind energy in 2022 are subsidiaries of companies that are incumbents from other ST-regimes of the electricity system, such as CPFL, CHESF, Enerfin, Eletrosul, EDP, and Enel.

Incumbents from the Large hydroelectric, Distribution, and Transmission ST-regimes are also relevant in the Solar ST-regime. For example, Enel and CPFL are among the main actors of this ST-regime (ANEEL, 2022). However, there is more space for new entrants in this ST-regime than others because of the lower cost of constructing a solar power plant, in comparison to other type of electric power plants, and the great synergy between this ST-regime and the distributed generation niche. In fact, the solar energy generation from distributed sources surpassed the generation from centralized solar power plants in 2020 (ABSOLAR, 2022a). Nonetheless, the role of incumbents in helping consolidate the distributed generation niche has also been significant (BNAMERICAS, 2022). Therefore, it is not only when the ST-regime or ST-system is unstable that incumbents help niche technologies or push for innovations.

However, ST-regime actors only started investing in wind and solar energy in Brazil after these technologies were consolidated abroad. When Brazilian incumbents started investing in wind energy in the 2000s, this technology had already been developed for many years in other countries, such as Germany and Denmark (GLOBAL WIND ENERGY COUNCIL, 2007). The same is true for solar energy. China and Germany invested in this technology long before its boom in Brazil (REN21, 2021). And this pattern is also observed in the case of EVs. Incumbents only started investing in electric mobility in Brazil after this technology became relevant in other markets, notably in China and the EU.

ST-transitions happen in complex spatial setups, not entirely constrained by national limits. Changes in ST-regimes in other countries can create opportunities for niche technologies to emerge locally, even if the local ST-regime is well-aligned. If incumbents start to believe that a ST- transition that occurred abroad will also happen in the local ST-regime, they can decide to help niche technologies even before the ST-regime becomes unstable. By doing this, incumbents can shape the transition, become relevant actors in the new ST-regime, and retain their economic and political power.

Even if a global sustainability transition starts unfolding and creates opportunities for niche technologies to challenge the local ST-regime, incumbents can not only limit the transition, but also create an alternative local pathway. This understanding is in line with the findings of the previous section, i.e., the normative orientation has a strong influence in the outcome of ST-transitions. For example, the transition from ICEVs to EVs that is happening in many countries, can become a transition from ICEVs to ethanol HEVs in Brazil, as discussed before.

Another relevant factor to understand incumbents’ behavior in Brazil is that they only invested in niche technologies when there were incentives from the government. Investments from incumbents on wind energy technology were driven by the PROINFA program, as detailed before. Initiatives from the government were also important for attracting investments to solar energy. ANEEL Resolution 482/2012, which allowed consumers to produce their own energy, tax exemptions for net-metering, and the first public contracts for centralized solar power generation are among the main drivers of solar energy in Brazil (ORIGO ENERGIA, 2020; ABSOLAR, 2022b).

In the case of EVs, SRDP-22 is one of the main drivers of investments in the electric car niche (BARASSA; DA CRUZ; MORAES, 2021). As detailed in Section 4.3, the interest from actors of the electricity ST-system in EVs was limited before SRDP-22. In addition, many interviewees stated that most companies of this ST-system would not be investing in electric mobility if it were not for SRDP-22. Thus, this program has driven a lot of the investments made by incumbents in electric mobility.

There are a few other incentives from the government to promote EVs, such as reducing the taxes on BEVs and PHEVs, investments through the Rota 2030 program, and a few other tax incentives by state and municipal governments (BARASSA; DA CRUZ; MORAES, 2021). However, Brazil still does not have clear and robust policies for EVs, as some interviewees pointed out. Besides, the participation of the government is important for the success of sustainability experiments in developing countries, as discussed in Section 2.1.3.1. This situation may cause incumbents to postpone or limit investments in EVs and discourage their participation in other experiments focused on electric mobility. The lack of continuity of the experiments can harm the consolidation of the electric car niche.

6.4 Transnational linkage influences in SRDP-22 experiments

It was shown in the previous section that sustainability transitions abroad can influence the ST-regimes and niches in Brazil. This influence could be seen in the consolidation of wind and solar energy, and this pattern is being observed again in the consolidation of the Brazilian electric car niche.

Secondary data from the case study indicate that transnational linkages are also influencing SRDP-22. 21 of the 32 experiments have the presence of transnational linkages and 14 experiments are led by subsidiaries of transnational corporations. Although only 6 experiments are directly influenced by transnational linkages, the 15 experiments that have the presence of these linkages but are not directly influenced by them have a higher estimated cost and the participation of more actors than the 11 experiments in which transnational linkages are not present. Moreover, experiments directly influenced by transnational linkages have even higher estimated cost and focus more on the main technology, as detailed in Section 5.6.

Nonetheless, primary data from the case study show that transnational linkages present in SRDP-22 have limited direct impact on the experiments. As detailed in Section 5.6, most interviewees affirmed that transnational linkages had no influence in SRDP-22 experiments. In the few cases where interviewees acknowledged that there was a transnational linkage influencing the experiment, they also indicated that this influence was limited and not significant. For example, all interviewees said that the companies' headquarters did not interfere in the design of the experiments and that the local subsidiaries had full autonomy in this process.

Transnational linkages have a more indirect impact in SRDP-22. This impact is mainly related to the presence of multinational corporations in some of the experiments. These companies have more resources than most Brazilian companies. Thus, it makes sense that the experiments in which they are involved received more investments than the others. This is the case of the 15 experiments where transnational linkages are present but do not directly influence the experiment. Furthermore, considering the number of experiments each actor is participating and the size of these experiments in terms of the estimated cost and number of participants, the most relevant utility companies in SRDP-22 are almost all transnational actors: State Grid, Engie, CTG, Neoenergia, and EDP (see Figures Figure 5.9 and Figure 5.11).

Therefore, actors participating in these experiments are using them to anchor global resources and shape the development of electric mobility technology to local needs. This behavior corroborates previous studies (see Section 2.1.3.1) that argue that developing countries can shape technology trajectories and have sustainability transitions their way, rather than simply trying to catch-up with developed countries.

Moreover, most of the multinational companies involved in SRDP-22 are incorporated in countries where the transition to EVs is more advanced than in Brazil, such as China, Netherlands, Germany, Switzerland, and Portugal (RICHTER, 2021). According to previous studies on sustainability experiments, transnational linkages allow knowledge transfer from developing to developed countries and vice versa. Hence, it makes sense that this companies are investing in SRDP-22, as they can use the knowledge and technologies produced in the experiments locally, in their origin country and in other countries where they are present.

The case study results also corroborate the findings of studies on sustainability experiments (e.g., Berkhout et al., 2010) that indicated the importance of transnational actors in these experiments. It is these actors that allow the transfer and sharing of resources between countries during the experiments. This flow of technology and knowledge is at the core of sustainability experiments (WIECZOREK; RAVEN; BERKHOUT, 2015).

Three transnational actors are especially relevant in SRDP-22: ABB, State Grid and BYD, as detailed in Section 5.1. Their roles in SRDP-22 are great examples of the importance of transnational actors in sustainability experiments, notably in developing countries, as detailed next.

ABB is participating in 6 experiments in SRDP-22, including two of the five experiments with the highest estimated cost. The total estimated cost of the experiments in which ABB is participating is R$ 154,849,754, which is more than any other actor in SRDP-22 and equivalent to 33.7% of the program total estimated cost. Besides, ABB is also the actor with most connections (51) to other actors in SRDP-22 (see Appendix E).

According to an ABB representative interviewed for the case study, the company has been involved with SRDP-22 since its conception. Besides, ABB participated in the formulation of all the experiments it is participating and has an active role in each of them. This interviewee indicated that ABB is bringing knowledge, technology, and financial resources to the experiments. ABB invested in all the experiments its involved, so the company is not just a supplier of equipment in these experiments. ABB is also transferring knowledge from Europe to Brazil through the experiments. For example, its research center in the Netherlands is providing all the necessary support to the experiments. Therefore, ABB has a significant influence in SRDP-22 and is helping the local actors access global resources.

ABB's active participation in SRDP-22 appears to be part of the company's strategy to expand its electric mobility business and is in line with other of its actions. For example, ABB is planning an IPO of its e-mobility division (ABB, 2022), bought other companies in this segment (FINE, 2022; RUDRA, 2022), invested in electric mobility startups (ABB, 2021a; BELLAN, 2022), and partnered with Shell to create a global EV charging network (KANE, 2022a). Therefore, ABB is a bridge between SRDP-22 experiments in Brazil and other experiments and innovations being developed around the world.

State Grid is the most relevant utility company in SRDP-22, considering the number of experiments it participates in, the money it is investing and the amount of its connections with other actors in the program. The company's subsidiaries are involved in four experiments, leading all of them. State Grid is the company which is making the largest direct investment in SRDP-22, of approximately R$ 100 million and is collaborating with 29 actors in its experiments, the 5th most of all actors participating in the program.

Like ABB, State Grid is also making considerable investments in electric mobility. The company partnered with both BMW and BAIC Group to install several battery replacement stations[86] and more than 300,000 charging stations in China (LI, 2020; ZHENG, 2020b), launched a smart charging network to promote data-sharing between various charging companies integrating 1.03 million charging stations in 273 Chinese cities (ZHENG, 2020a), and developed an action plan to accelerate the construction of charging infrastructure along China's domestic highway system (LIU, 2022).

However, there is limited or no exchange of technology and knowledge with international actors in the experiments lead by State Grid's subsidiaries in SRDP-22. According to representatives of these subsidiaries interviewed for the case study, there was no interference from the company headquarters in the conception of the experiments and no interaction with any Chinese official during the development of the experiments. One of the interviewees pointed out that the main reason for this lack of exchange is the difficulty of justifying to ANEEL the costs of a benchmark, such as bringing Chinese experts to Brazil.

Therefore, the main role of State Grid in the experiments is to fund them. In this case, State Grid's investments in electric mobility in China have certainly contributed to the company's approval of the large investments its subsidiaries are making in SRDP-22. Furthermore, although this transnational actor is not giving the experiments access to experts and innovations in electric mobility from abroad, as ABB is doing, State Grid subsidiaries are providing the experiments access to local experts of the electricity ST-system. Engineers and technicians from these companies are actively involved in the experiments, according to the interviewees.

[86] EV battery replacement stations replace an EV's empty battery with a charged one, instead of charging the used battery. Replacing the battery is faster than charging it, as the replacement usually takes less than 5 minutes. These stations are also called swapping stations (FEIJTER, 2022).

Among the legacy brands and EV automakers participating in SRDP-22, BYD is the most relevant. The company is the automaker involved in the most experiments (5), in which it is the supplier of electric cars, buses, and trucks. BYD is also the automaker with most connections (20) to other actors in SRDP-22.

The role of BYD in the experiments it is participating in is different from those of ABB and State Grid. According to BYD representatives interviewed for the case study, the company had little involvement in the conception of most experiments. Its role is usually restricted to that of a supplier in these experiments, notably those focused on complementary technologies.

Nonetheless, in the experiments focused on advancing EV technology, BYD has a much more active role. In these cases, the company actively participated in the conception and development of the experiments. Moreover, BYD promoted the exchange of knowledge and technology between Chinese and Brazilian engineers for the development of the vehicles. For example, some vehicles' telemetry technology developed in China was transferred to Brazilian engineers during one of the experiments. Therefore, these experiments are examples of the circulation of technologies and knowledge between countries in sustainability experiments.

BYD participation in SRDP-22 seems to be part of its global strategy, as in the case of ABB. BYD has surpassed Tesla as the world's largest EV seller in the first semester of 2022 (KANE, 2022b). Considering only BEVs, BYD increased its market share from 5.5% to 11%, while Tesla and Volkswagen Group both lost market share in the first semester of 2022 (KANE, 2022c). Besides, BYD has strong ambitions in Brazil. The company plans to open 45 dealerships in 2022 and 55 more in 2023 (BALHESSA, 2022; SILVEIRA, 2022). Thus, BYD is another transnational actor that is helping connect the electric car niche in Brazil with global knowledge networks and international markets.

State Grid and BYD's roles in SRDP-22 show that many Chinese actors have great influence on the program. Besides these two actors, CTG Corporation is also one of the most relevant actors in SRDP-22. In fact, China has, through these actors, a great impact on the program. From all the foreign countries present in SRDP-22, China is the most relevant. Subsidiaries of Chinese companies are present in 12 of the 32 experiments, leading 6 of them, as detailed in Section 5.6. These companies are directly responsible for 31% of the direct investments in SRDP-22, and the 12 experiments with their participation have an estimated cost of approximately R$ 209 million, equivalent to 44% of SRDP-22 total estimated cost.

China is one of the world's main investors in electric mobility. EV sales more than doubled in China in 2021 and more EVs were sold in China alone than in the rest of the world that year (IEA, 2022). Besides, the transition to EVs have strong support from the Chinese government (BARASSA; DA CRUZ; MORAES, 2021; CONRAD, 2022). For example, China's latest Five-Year Plan aims to make EVs reach 20% of the local market share by 2025 (IEA, 2022).

Chinese companies such as BYD, SAIC Motor, and Geely are among the world's largest EV sellers in 2022 (KANE, 2022c). As detailed before, BYD is the company that sold the most electric vehicles in the world in 2022, in addition to having considerably increased its share of the BEV market. In Brazil, Chinese automakers are among the main sellers of EVs, notably BEVs. Almost 45% of the BEVs sold in Brazil in the first semester of 2022 were from Chinese brands or subsidiaries of Chinese corporations (ABVE, 2022b). Moreover, approximately 17% of all EVs sold in Brazil since 2015 were from Chinese-owned brands (NEOCHARGE, 2022).

The strong interest that Chinese EV manufacturers are showing in the Brazilian market indicates that there may be geopolitical motivations for the large investments that Chinese electricity companies have made in SRDP-22. After all, a transition to electric cars would considerably benefit companies like BYD and Geely. Although EVs only represent 0.17% of the Brazilian car fleet in 2022 (ABVE, 2022c; MINISTÉRIO DA INFRAESTRUTURA, 2022), a fast transition to EVs would be very significant for EV manufacturers, as Brazil has the 8th largest car market in the world (MUNOZ, 2022).

However, primary data from the case study indicate that a coordinated investment from Chinese companies in the Brazilian electric car niche is unlikely. All interviewees involved in experiments with the participation of Chinese actors affirmed that there was little or no influence from China in the experiments. For example, they pointed out that the local subsidiaries of Chinese corporations had full autonomy to decide whether to participate in SRDP-22.

Moreover, an expert in Chinese investments in Brazil interviewed for the case study indicated that the significant participation of Chinese companies in SRDP-22 is a consequence of past Chinese investments in the Brazilian electricity ST-system. According to this interviewee, Chinese companies, such as State Gird and CTG, reached some limits in the Chinese electricity market due to overcapacity and sought to internationalize their operation in the mid-2000s. In this context, Brazil was the perfect place to go, because of two characteristics: it has large hydroelectric park and hydroelectric potential, and it is a continental country like China[87].

Once these Chinese companies were operating in the Brazilian electricity sector, they were subject to the mandatory investments in R&D (see Section 4.4). According to the interviewee, if it was not for this obligation to invest in R&D, State Grid, CTG, and other Chinese actors would not be participating in SRDP-22 because Chinese companies rarely invest in R&D outside China. This interviewee also affirmed that, in the case of BYD, its participation in SRDP-22 is probably part of the company's interests and business opportunities and not some complex strategy from the Chinese government to accelerate the transition to EVs in Brazil. This view was corroborated by BYD representatives.

Regardless of geopolitical motivations, China's strong participation in SRDP-22 show that sustainability experiments are a way of promoting South-South cooperation, i.e., collaboration between developing countries. This kind of partnership helps to reduce developing countries technological dependency on developed countries, breaking the need for technological diffusion "from North to South". Sustainability experiments are allowing countries that are not at the technological frontier, such as Brazil, to become knowledge and technology producers and shape the way new technologies will unfold.

6.5 The power of sustainability transitions theory to explain the transition to EVs in Brazil

There are a few shortcomings with using sustainability transitions theory to explain the transition to EVs in Brazil. Most of these shortcomings are related to the mainstream MLP framework and its assumptions, notably regarding the MLP's conceptualization of ST-regimes, the role of incumbents, and the outcomes of sustainability transitions. These assumptions are based on research done in developed countries, which can be significantly different from developing countries, as detailed in Section 2.1.3.

The case study showed that there are some ST-systems and ST-regimes in Brazil that are not so uniform and cohesive as assumed in the MLP, for example, the urban mobility ST-system. This finding challenges the MLP premise that ST-regimes are uniform, homogeneous, and cohesive structures. Besides, these findings also corroborate

[87] This aspect is relevant because many of the challenges for the supply of electricity are the same in Brazil and China. For example, in both countries it is necessary to transmit the electricity produced in distant hydroelectric plants over long distances to urban centers.

previous studies on sustainability transitions in developing countries that argued that the MLP needs a more comprehensive conceptualization of ST-regimes. In this sense, Van Welie *et al.* (2018) conceptualization of heterogeneous ST-regimes, detailed in Section 2.1.3.2, proved to be useful in the characterization of the ST-regimes and ST-systems involved in the case study.

The MLP also assumes that socio-technical transitions manifest as disputes between ST-regime and niches actors, as detailed in Section 2.1.1.4.4. However, the research findings show that incumbents are having an important role in the transition to electric cars in Brazil, notably by helping consolidate the electric car niche. Moreover, the case study indicates that incumbents from many different ST-regimes are helping this niche, including actors from the private-car ST-regime.

Therefore, the evidence from the case study refutes the MLP understanding that incumbents will always try to preserve the ST-regime. Thereby, the present research is in line with the findings from Ghosh and Schot (2019), who showed that ST-regime actors may play an even more important role than niche actors in sustainability transitions in developing countries.

In addition, the research findings also contradict previous studies on sustainability transitions in developing countries, detailed in Section 2.1.3.2. These studies argued that incumbents only have significant roles in sustainability transitions in developing countries because the ST-regimes there are less uniform and cohesive than in developed countries. However, the case study results show that actors from a well-aligned ST-system, the electricity ST-system, and well aligned ST-regimes, such as the Distribution ST-regime, are collaborating with actors from several different niches, including many niches from their own ST-system.

The MLP premise that any socio-technical transition will end with a given technology becoming dominant, as explained in Section 2.1.1.4.6, is another premise that is not supported by the research findings. Besides, this premise has already been questioned by many scholars (e.g., Schmid, Knopf and Pechan, 2016; Krätzig, Van Welie *et al.* 2018, Franzkowiak and Sick, 2019; Dumont, Gasselin and Baret, 2020; Gasselin *et al.,* 2020).

Although it is not possible to guarantee how the sustainability transition in the Brazilian private-car ST-regime will end, there is strong evidence that the coexistence of many different technologies is a likely outcome, as detailed in Section 6.2. Brazil will probably have two or more of the following technologies coexisting in the future: ethanol ICEVs, ethanol HEVs, ethanol FCEVs, PHEVs, and BEVs.

A final shortcoming in the MLP are the current conceptualizations and typologies of multi-system sustainability transitions (e.g., Raven and Verbong, 2007; Konrad, Truffer, and Voß, 2008; Papachristos, Sofianos, and Adamines, 2013; Sutherland, Peter, and Zagata, 2015), which characterize the interactions between ST-systems, ST-regimes, and niches as a single pattern. However, this assumption that all actors from one ST-system will interact with another ST-system following the same pattern is not supported by the empirical evidence from the case study.

Therefore, the transition to EVs in Brazil could not be sufficiently characterized using current conceptualizations and typologies of multi-system sustainability transitions. It was necessary to go down one analytical level and consider the different interest groups within the ST-regimes and niches involved in the transition.

The electric car is a complex technology and its impact in the Brazilian electricity ST-system is quite unpredictable at present. Therefore, incumbents of the electricity ST-system have different expectations of how the electric car will affect their ST-regimes, as detailed in Section 5.8. These different and even contrasting expectations led to the emergence of different interest groups within the ST-regimes of the electricity ST-system, notably the Distribution ST-regime. These groups have different political and economic interests in the electric car, which makes them behave differently towards the electric car niche.

However, this shortcoming is more related to the current stage of the sustainability transition to EVs in Brazil than to any other characteristic of this transition. It makes sense that the set of rules that structure, lock-in, and stabilize each ST-regime of the electricity ST-system was disturbed when presented with such a novelty as the electric car, given the various expectations and interests around it. However, as time progress and the impacts of the electric car niche in the electricity ST-system become clearer, it can be expected that each ST-regime, and probably the whole ST-system, will converge to a single view of this new technology. At this point, the ST-regimes will probably behave in a single and cohesively way towards the electric car niche, as indicated in current conceptualizations and typologies of multi-system sustainability transitions.

Therefore, the characterization of the interaction between ST-regimes and niches as a single pattern can be helpful when studying multi-system sustainability transitions that are concluded. However, this characterization is not as useful in the analysis of transitions that are still unfolding. In this case, it is necessary to consider the different interest groups within the ST-regimes and niches.

Nevertheless, the sustainability transitions theory, in particular the MLP, proved very useful in the conceptualization and understanding of the transition to EVs in Brazil despite all the shortcomings presented before. As previously detailed, many studies have already challenged MLP's conceptualization of ST-regimes, the role of incumbents, and the outcomes of sustainability transitions, and proposed new theoretical concepts to deal with the gaps in the MLP to explain transitions in developing countries. Therefore, the contributions of authors such as Van Welie et al. (2018) and Ghosh and Schot (2019) proved able to address most of the MLP limitations in explaining the transition to EVs in Brazil.

Besides, many conceptualizations from transitions theory were helpful in the characterization and understanding of the transition to EVs in Brazil. The concepts of ST-systems and ST-transitions were useful to delimitate the research boundaries. Concurrently, these concepts also indicated all the different aspects of a technological transition that needed to be considered in the research.

The MLP analytical levels were also fundamental to organize the complexity involved in technological transitions. Dividing the electricity and urban mobility ST-systems into different ST-regimes and niches was useful in characterizing these complex systems and their interactions with each other. Moreover, the ST-regime concept was particularly helpful. Considering all the different aspects that encompass a technology and how they help stabilize it and maintain the status quo was key to understanding why technological transitions are so difficult to happen.

Moreover, an important part of characterizing a ST-regime is reflecting on how strong or coherent it is. This is relevant because unstable ST-regimes facilitate the unfolding of ST-transitions, as detailed in section 2.1.1.4.5. Therefore, understanding the coherence of electricity and urban mobility ST-systems and their ST-regimes (see Sections 4.1 and 4.2) was key in explaining the transition to EVs in Brazil.

The dynamics of ST-transitions proposed in the MLP was also insightful. Although the assumption that incumbents will always try to protect the ST-regime was not corroborated by the research findings, the conceptualization of ST-transitions as a dispute between the ST-regime and niche technologies made possible by changes in the landscape is still powerful. It became clear during the research that a transition to EVs in Brazil would not be possible if climate change, which can be considered a landscape event, was not putting pressure on the private car ST-regime, no matter how far the electric car technology advanced.

The concept of intermediaries was also useful to understand the important role that ANEEL is playing in the transition to EVs. This conceptualization was instrumental in explaining why ANEEL has promoted SRDP-22 and is supporting this transition.

Finally, many concepts that have been proposed in transitions literature by researchers focused on ST-transitions in developing countries were important to explain the transition to EVs in Brazil. The concepts of sustainability experiment and transnational linkage are essential to understand SRDP-22. Besides, the notion of normative orientation and how it impacts ST-transitions was key to explaining the dynamics of the transition to EVs in Brazil and how the lack of a clear understanding of sustainable urban mobility is already influencing this transition and may even prevent it from happening, as detailed in Section 6.2.

6.6 Limitations of the research

The research main limitation is that only 20 of the 39 actors selected for interviews agreed to participate. Therefore, almost 50% of the actors considered relevant for the understanding of the case study were not interviewed. Given that these actors were not randomly selected, their non-participation may have introduced bias in the research because only those actors who were willing to participate in the research were interviewed, as discussed in Section 3.7.

Another limitation is that few actors from some ST-regimes of the electricity ST-system were interviewed due to their low participation in SRDP-22. This resulted in less primary data on how these actors are interacting with the electric car niche and made it harder to identify the interest groups within these ST-regimes. Although this reflects the fact that actors from these ST-regimes are not as interested in electric mobility as actors from other ST-regimes, notably the Distribution ST-regime, it also may have resulted in some bias when analyzing the interests of the electricity ST-system in EVs.

However, among the 20 actors interviewed, there were at least one actor of each ST-system, ST-regime or niche that were relevant to the research, as detailed in Section 3.5.2. Therefore, actors belonging to the electricity ST-system, private car ST-regime, and electric car niche participated in the interviews. This includes actors from ST-regimes of the electricity ST-system that are not part of Distribution ST-regime, for example, actors from the Large hydroelectric ST-regime. Besides, both incumbents and intermediaries were interviewed. This contributed to minimizing the no-response bias (see Section 3.7).

Moreover, it should be noted that 20 interviews can be considered sufficient to gather the necessary data to be triangulated with the secondary data in the case study. The triangulation of the data gathered in the interviews with each other and with the secondary data also minimized the no-response bias. Besides, this triangulation highlighted inconsistencies between the primary and secondary data regarding the influence of transnational linkage on SRDP-22, as detailed in Section 5.6. This result led to further research on this topic, which showed that this contradiction was more related to the character of the transnational linkages present in SRDP-22 than to any kind of bias in the research (see Section 6.4)

7. CONCLUSION

This chapter is divided in three sections. The first section answers the research question posed in the Introduction (Chapter 1). The following section presents policy recommendations to help accelerate the transition to EVs in Brazil. Finally, the last section suggests some ideas on how future work can advance the sustainability transitions field.

7.1 Response to the research question

The research question that guided the thesis was "How does the electricity ST-system influence the sustainability transition to the electric car in the Brazilian urban mobility system?". The case study data presented in Chapter 5 and discussed in Chapter 6 show that the electricity ST-system is influencing the transition to EVs in Brazil by helping consolidate the electric car niche. Relevant actors of this ST-system, notably incumbents, are collaborating to the creation of a network of actors related to EVs, helping to create learning processes at multiple dimensions, and contributing to articulate expectations and visions on electromobility. Moreover, these actors are also significantly improving the EV charging infrastructure in Brazil, developing new business models to make EV charging a profitable business, and helping to improve the existing regulation on EVs.

However, the electricity ST-system is interacting in multiple ways with the urban mobility ST-system, particularly with the electric car niche. As discussed in Section 6.1, these interactions cannot be reduced to a single pattern because the electricity ST-system does not show a cohesive behavior towards the electric car. Moreover, even the ST-regimes and niches of this ST-system do not have a single type of interaction with the electric car niche.

Therefore, it is necessary to consider all the different interest groups within each ST-regime and niche of the electricity ST-system to fully answer the research question. Besides, it is also important to identify which of these ST-regimes and niches are in fact interacting with the electric car niche.

The ST-regime that most interacts with the electric car niche is the Distribution ST-regime, as detailed in Section 6.1. Three interest groups were identified within this ST-regime based on their position towards EVs. The first one is fully committed to helping consolidate the electric car niche and have been investing in this niche even before SRDP-22. The second group is made up of actors who are not really interested in the transition and would probably not be investing in electric mobility if it were not for SRDP-22. Finally, there is a group of actors that are trying to avoid, or at least delay, a transition to EVs.

The case study data indicate that the second group is the largest of the three. Most actors of the Distribution ST-regime are waiting for the transition to EVs to become more robust before they commit to it. Nonetheless, this group is more inclined to help the transition than to block it, although this position might still change. The third group is the smallest one, and actors from this group could not be identified in the case study. However, many interviewees indicated that these actors are present in the Distribution ST-regime. On the other hand, many actors from the first group, i.e., actors that are supporting the electric car niche, could be identified, such as CPFL, Enel, and Copel.

Contradictory behaviors toward the transition to EVs were also identified in other ST-regimes of the electricity ST-system. However, there are far fewer actors from these other ST-regimes participating in SRDP-22, as detailed in Chapter 5. Thus, fewer actors from these ST regimes were interviewed and these ST regimes were also mentioned less frequently in the interviews. This makes it difficult to identify interest groups within these ST regimes. Nonetheless, actors from almost all the ST-regimes of the electricity ST-system are involved in SRDP-22, which show that there are actors who are backing, or at least not opposing, the transition to EVs in all these ST-regimes.

Even actors from the Thermoelectric ST-regime, whose mode of interaction with the electric car niche can be classified as parasitism, are involved in SRDP-22 and helping to consolidate the electric car niche. On the other hand, many actors from ST-regimes that have great synergy with the electric car niche are not supporting it. Therefore, the way each actor from a ST-regime or niche interacts with actors from other ST-regimes and niches cannot be defined by the mode of interaction between these regimes and niches. Many factors, such as politics, regulation, or culture, can cause some actors to ignore the technological aspect, as discussed in Section 6.1

Regarding the niches, the case study data indicate that there is great synergy between the electric car niche and niches from the electricity ST-system, notably the battery, distributed generation, and energy efficiency niches. In fact, there are many actors participating in SRDP-22 that could be considered part of the electric car niche and part of one of the electricity ST-system niches. For example, BYD and Moura are both part of the battery and electric car niches. Therefore, most actors of the electricity ST-system niches are collaborating with the electric car niche and helping to consolidate it.

In addition, the different actors of the Brazilian government that are part of the electricity ST-system, notably ANEEL and MME, are also showing contrasting behaviors in relation to the electric car. While ANEEL is supporting the transition to EVs by creating opportunities for the emergence and consolidation of this technology, MME is promoting biofuels over EVs.

Another relevant finding from the research is that all the actors who are supporting the transition to EVs are doing so by helping to consolidate the electric car niche. None of these actors are willing to help destabilize the private car ST-regime. The reasons for this behavior were discussed in Section 6.2, but the underlying cause seems to be the lack of consensus on which is the best alternative to make urban mobility sustainable in Brazil: electric vehicles, biofuels, or even a mixture of both. In fact, the coexistence of these technologies is a likely outcome of the transition of the private car ST-regime to sustainability in Brazil.

Most actors in the electricity ST-system are not sure which of the multiple visions of sustainable urban mobility will prevail. They do not want to fully commit to EVs before there are clearer indications that the transition to electric mobility will unfold. Therefore, these actors are happy to help consolidate the electric car niche, but not willing to go beyond that.

In summary, relevant actors of the Distribution ST-regime, actors from the electricity ST-system niches, a few relevant actors from other ST-regimes of this ST-system, and ANEEL are influencing the transition to EVs in Brazil by supporting the consolidation of the electric car niche. However, none of these actors are helping to destabilize the private car ST-regime. Besides, most actors of the electricity ST-system are indifferent to the transition to EVs, although they seem more inclined to help the transition than to block it. Finally, there are a few actors in the electricity ST-system, including part of the Brazilian government, who want to block or delay the transition to EVs in Brazil.

7.2 Policy recommendations

The case study results showed that the main factor delaying a transition from ICEVs to EVs in Brazil is the government's lack of a clear strategy for this transition. Most importantly, the government still does not have a clear understanding of the direction it wants this transition to go. There is significant conflict inside the government, with some officials pushing for the transition to EVs, while others support increasing the use of biofuels. These ‘mixed signals’ from the government make the companies from both the urban mobility and electricity ST-systems insecure to invest in electric mobility in Brazil.

Therefore, it is necessary for the Brazilian government to decide which normative orientation it will follow and which path it will choose to make urban mobility sustainable. It should be noted that the government does not need to choose between electric vehicles or biofuels. Investing in these two technologies might be safer than betting on just one of them, at least in the short and medium term. However, not investing in electric mobility will likely be a mistake. As many scholars and experts have already warned, opting to invest only in biofuels will transform Brazil into a ‘technology island’, which will lag behind other countries and will not be able to compete with them in the future.

Moreover, the success of the SRDP-22 showed that it does not take much government investment and incentives for companies to invest in electric mobility. A clear signal from the government that electric mobility will be part of the future of Brazilian urban mobility would be enough for many companies in the electricity ST-system to start investing more in this area, especially given the very clear global trends towards the electrification of urban mobility. This signaling from the government involves a few financial incentives and investments (e.g., tax breaks), and laws, regulations, and norms to regulate electric mobility, especially regarding the electricity ST-system. For example, many interviewees pointed out that Brazil still does not have clear and robust regulation for EV charging, which is necessary to minimize the risks for utility companies to invest in it.

In addition, SRDP-22 achievements also demonstrated that sustainability experiments are a great way for developing countries to access global resources, such as financial resources, technologies, and knowledge networks. The program’s focus on creating new networks of actors also proved to be right, as this is helping to consolidate the electric car niche. Therefore, this is a program that can be replicated in countries that are not on the technological frontier but want to become producers of knowledge and technology and shape the way new technologies will develop.

The present research showed how important the transnational linkages are for the success of the sustainability experiments. In the case of developing countries, these linkages are also significant to strength South-South collaboration and break these countries dependence on technology diffusion from developed countries. However, the transnational linkages present in SRDP-22 were more a consequence of the large presence of transnational actors in the Brazilian electricity ST-system, than something that the program was looking for in the experiments. Thus, more attention should be paid to the transnational linkages when trying to replicate SRDP-22.

7.3 Future work

Many relevant themes on the sustainability transitions field (see Köhler *et al.* 2019) were not explored in the thesis due to the restrictions of time, scope, and financial resources inherent to doctoral research. For example, the role of civil society and social movements in sustainability transitions, ethics and justice in transitions, and behavioral norms, consumption, and everyday life aspects of sustainability transitions. However, these unexplored themes result in opportunities for future research to build on current results and advance further.

Therefore, future work could study the role of the other ST-systems involved in the transition to EVs in Brazil, notably the fossil fuels and the biofuels ST-systems. The research results showed that both these ST-systems are influencing SRDP-22 and the transition to EVs as whole. Studying the influence of the biofuels ST-system in electric mobility might be particularly interesting because ethanol ICEVs, HEVs, and FCEVs are seen by many experts and public officials as a better alternative than EVs to achieve sustainable urban mobility in Brazil.

Another opportunity for future research is to pay more attention to the role of intermediaries in sustainability transitions in Brazil. This is a research topic that has been growing in recent years and there are not many studies on this topic in Brazil. The present research only briefly addressed this topic, analyzing the role of ANEEL in the transition to EVs, but this was not the focus of the research. Therefore, future research may analyze how Brazilian regulatory agencies are influencing sustainability transitions. As one interviewee pointed out, the role of these agencies shifted from command and control to inducing policy, accentuating their role as intermediaries.

In addition, electric mobility is only one of many alternatives to make urban mobility sustainable, as discussed in Section 2.2. Although EVs and biofuels are the two main alternatives considered by policymakers and public officials now, especially giving the hype around EVs, other alternatives could also play an important role. Besides, many of these other alternatives have great synergy with EVs. Thus, future research could address how all these different alternatives are interacting with each other and how they are influencing the Brazilian electric car niche.

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ANNEX A – RESEARCH ETHICS APPROVAL

INSTITUTO DE CIÊNCIAS HUMANAS E SOCIAIS DA UNIVERSIDADE DE BRASÍLIA - UNB

PARECER CONSUBSTANCIADO DO CEP

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: Transição para a sustentabilidade no sistema de mobilidade urbana brasileiro: estudo de caso do carro elétrico

Pesquisador: GABRIEL LEUZINGER COUTINHO

Área Temática:

Versão: 1

CAAE: 56162522.3.0000.5540

Instituição Proponente: Centro de Desenvolvimento Sustentável

Patrocinador Principal: Financiamento Próprio

DADOS DO PARECER

Número do Parecer: 5.311.692

Apresentação do Projeto:

Nível, Área e Instituição: Doutorado, Centro de Desenvolvimento Sustentável, Universidade de Brasília.

Justificativa / Motivação: "A crescente preocupação com as mudanças climáticas, considerada por muitos pesquisadores como a ameaça ambiental mais significativa do século 21, fez com que muitos estudiosos se concentrassem em uma área de pesquisa específica: as transições para a sustentabilidade. Essas mudanças sistêmicas só podem ser alcançadas por meio de profundas modificações estruturais nos sistemas sociotécnicos, ou seja, elementos interconectados (por exemplo, tecnologias, infraestrutura, organizações, políticas) que cumprem uma função social, como transporte, energia e alimentação. [...] O sistema sociotécnico de mobilidade urbana, ou seja, todos os movimentos de pessoas e mercadorias dentro do espaço urbano é particularmente relevante para as mudanças climáticas. [...] No entanto, o sistema sociotécnico de mobilidade urbana não está em um caminho de transição que permitiria atingir a meta do Acordo de Paris de limitar o aquecimento global a 1,5º C. [...] Esse mesmo padrão foi observado no Brasil, onde as emissões anuais deste sistema sociotécnico aumentaram constantemente entre 2000 e 2018. [...] A transição para a sustentabilidade no sistema sociotécnico de mobilidade urbana envolve mudanças amplas na economia, no comportamento do consumidor e na infraestrutura. [...] A transição para carros elétricos pode ser mais fácil de implementar no Brasil do que outras propostas para alcançar a mobilidade urbana sustentável, uma vez que a maioria dos elementos constituintes de um sistema sociotécnico de transporte dependente de carro está presente no país. [...] A hipótese é que o sistema sociotécnico de eletricidade tem interesses econômicos e estratégicos na transição para o carro elétrico no Brasil. Deste modo, este sistema estaria influenciando a dinâmica do sistema sociotécnico de mobilidade urbana de forma a favorecer a transição para os carros elétricos. Além disso, tem-se como parte da hipótese que o sistema sociotécnico de eletricidade está apenas ajudando o nicho do carro elétrico a se consolidar, mas não está tomando ações para desestabilizar o regime sociotécnico atual (carros com motor a combustão interna)".

Metodologia. "A estratégia utilizada [...] será o estudo de caso [...]. O caso selecionado para o estudo é o Projeto Estratégico de Pesquisa e Desenvolvimento - P&D nº 22: 'Desenvolvimento de Soluções em Mobilidade Elétrica Eficiente" (SR&DP-22) da ANEEL. O'. [...] Dois métodos diferentes de coleta de dados são usados: dados secundários e entrevistas semiestruturadas. Dados secundários sobre o caso serão coletados na base de dados da ANEEL relativos ao SR&DP-22. Esses documentos permitirão identificar outras instituições que auxiliaram a ANEEL na concepção do SR&DP-22. Assim, os sites dessas instituições também serão pesquisados em busca de documentos relacionados a RS&DP-22. Outras fontes de dados secundários utilizadas serão os sites, relatórios e comunicados de imprensa de todas as empresas, órgãos públicos, institutos de pesquisa e universidades que participam de qualquer um dos 30 experimentos de sustentabilidade que fazem parte do SR&DP-22. Além disso, serão feitas também entrevistas semiestruturadas. As entrevistas serão virtuais devido à pandemia COVID-19. As entrevistas presenciais serão realizadas em casos excepcionais se solicitadas pelo participante. Os atores serão selecionados para entrevistas por meio de amostragem intencional. Além disso, a amostragem de bola de neve também será usada. Os primeiros atores entrevistados serão selecionados com base em sua relevância para o caso. O primeiro critério utilizado é que os atores tenham participado diretamente do SR&DP-22. Em segundo lugar, serão entrevistados atores de cada um dos estágios de SR&DP-22: conceituação, implementação e desenvolvimento. Portanto, as primeiras entrevistas serão com representantes da Superintendência de Pesquisa e Desenvolvimento e Eficiência Energética (SPE) da ANEEL. A SPE é a área da ANEEL responsável pela concepção e implantação do SR&DP-22 e foi responsável pela seleção dos experimentos de sustentabilidade que fazem parte do SR&DP-22 e. Além disso, a SPE passou a ser responsável por monitorar e controlar o andamento do projeto. Também serão entrevistados atores representantes de outras instituições envolvidas na concepção do projeto, como o Centro de Gestão e Estudos Estratégicos. Além disso, serão entrevistados alguns atores envolvidos nos experimentos de sustentabilidade que fazem parte do SR&DP-22. Por fim, serão avaliados os atores identificados por meio da amostragem da bola de neve". O número previsto de entrevistados é de 15 indivíduos.

Cronograma. O início da coleta de dados está previsto para 02/05/2022 e o término da coleta de dados está previsto para 31/07/2022.

Objetivo da Pesquisa:

De acordo com o projeto apresentado, o objetivo geral que se tem com a pesquisa é "explicar como o sistema sociotécnico de eletricidade influencia a transição para a sustentabilidade para o carro elétrico no Brasil".

Ainda de acordo com o projeto, os objetivos específicos são: "(i) Caracterizar o sistema sociotécnico de mobilidade urbana, o sistema sociotécnico de eletricidade e nicho de carros elétricos no Brasil; (ii) Identificar as principais experiências de sustentabilidade no nicho brasileiro de carros elétricos que envolvem atores dos sistemas sociotécnicos de eletricidade e mobilidade urbana entre 1990 e 2020; (iii) Caracterizar os experimentos de sustentabilidade que fazem parte do Projeto Estratégico de Pesquisa e Desenvolvimento nº 22 da ANEEL; (iv) Avaliar como as experiências de sustentabilidade no nicho de carros elétricos que envolvem atores dos sistemas sociotécnicos de eletricidade e mobilidade urbana influenciam a transição da sustentabilidade para o carro elétrico no Brasil; (v) Fazer recomendações sobre como os atores do sistema sociotécnico de eletricidade podem ajudar a acelerar a transição da sustentabilidade para o carro elétrico no Brasil".

Avaliação dos Riscos e Benefícios:

De acordo com o projeto de pesquisa apresentado, "o principal risco que foi mapeado tem relação com a atual pandemia de COVID-19. Num eventual contato entre pesquisador e entrevistada/o, poderia ocorrer a transmissão do vírus entre as partes, caso uma delas esteja infectada. Para eliminar este risco, optou-se pela realização de entrevistas virtuais apenas, dispondo das diversas ferramentas disponíveis para isso. Ainda que seja possível realizar entrevistas de forma segura seguindo as recomendações das autoridades sanitárias, entende-se que estes procedimentos não são 100% efetivos e, por isso, o melhor é evitar qualquer tipo de contato presencial. Portanto, caso uma pessoa convidada a participar da pesquisa só aceite fazer a entrevista de maneira presencial, esta entrevista será cancelada e a pessoa não participará da pesquisa. [...] Outro risco mapeado é a necessidade de garantir a privacidade das/os entrevistadas/os, bem como assegurar a confidencialidade dos dados e o anonimato. As pessoas participarão da pesquisa de forma anônima e algumas de suas falas durante a entrevista poderiam lhes acarretar problemas em suas instituições caso fossem associadas a elas. Para garantir que isso não aconteça, algumas medidas serão tomadas: - Não haverá qualquer indicação do nome da/o participante ou de sua instituição em qualquer material da pesquisa. Os participantes serão referenciados nos textos da pesquisa de forma genérica apenas. Por exemplo, "pesquisador do setor elétrico" ou "gerente de multinacional do setor automotivo"; - É muito comum que participantes de pesquisas virtuais fiquem receosos de como será o tratamento dos dados e a manutenção do sigilo caso a entrevista seja gravada. Para evitar esse tipo de receio e eliminar o risco de um eventual vazamento da entrevista, optou-se por não as gravar. Serão coletadas apenas notas durante as entrevistas; - As notas coletadas durante a entrevista serão enviadas para as/os entrevistadas/os após a entrevista, para que elas/eles tenham oportunidade de retificá-las e até mesmo solicitar a retirada de algumas informações. Neste segundo caso, qualquer informação que a/o entrevistada/o solicite que seja retirada será apagada de todos os arquivos da pesquisa e jamais será utilizada pelos pesquisadores. - Em toda a documentação do projeto, os participantes serão identificados por um número, e não por seus nomes. A correspondência entre o número e o nome do participante será guardada em um documento protegido por senha, a qual somente o pesquisador principal terá acesso. Logo, ainda que alguém que não faça parte da equipe do projeto consiga acesso a documentos do projeto, como as notas das entrevistas, não saberá quem foi a pessoa entrevistada".

Sobre os benefícios da pesquisa, no projeto, afirma-se que "entende-se que os resultados da pesquisa proposta serão o principal benefício. Visto que todas as pessoas que serão entrevistadas estão envolvidas com o objeto do estudo de caso, entende-se que os resultados da pesquisa serão interessantes e, possivelmente, úteis para elas. Estes resultados poderão ser utilizados, inclusive, para a revisão e aperfeiçoamento de políticas públicas para os setores elétrico e automotivo, o que, espera-se, beneficiaria não apenas as/os participantes da pesquisa, mas toda a sociedade. [...] A pesquisa oferecerá novos insights teóricos sobre questões que ainda precisam de mais desenvolvimento na literatura das transições. Ela fornecerá contribuições teóricas sobre a conceituação do regime sociotécnico e o papel dos incumbentes (atores dos regimes sociotécnicos existentes) nas transições de sustentabilidade. [...] A pesquisa também fornece alguns insights teóricos sobre como diferentes visões de sustentabilidade impactam a governança e o resultado das transições de sustentabilidade".

Comentários e Considerações sobre a Pesquisa:

A análise do projeto indicou que, de fato, os riscos aos participantes foram corretamente avaliados e os procedimentos sugeridos para minimizá-los estão adequados. O TCLE possui as informações necessárias para a compreensão da pesquisa por parte dos participantes. Os outros documentos apresentados esclarecem de forma satisfatória o estudo a ser realizado. De modo geral, o projeto cumpre com as exigências propostas pelas Resoluções CNS 466/2012 e CNS 510/2016.

Considerações sobre os Termos de apresentação obrigatória:

Foram fornecidos todos os termos de apresentação obrigatória.

Conclusões ou Pendências e Lista de Inadequações:

Não foram encontradas pendências.

Considerações Finais a critério do CEP:

Sugere-se, durante e após a realização da pesquisa, o envio dos respectivos Relatórios Parcial e Final.

Este parecer foi elaborado baseado nos documentos abaixo relacionados:

Tipo Documento	Arquivo	Postagem	Autor	Situação
Informações Básicas do Projeto	PB_INFORMAÇÕES_BÁSICAS_DO_PROJETO_1652728.pdf	23/02/2022 09:32:29		Aceito
Outros	Carta_de_encaminhamento.pdf	23/02/2022 09:30:37	GABRIEL LEUZINGER	Aceito
Outros	Curriculo_do_Sistema_de_Curriculos_Lattes_Armando_Pires_orientador.pdf	23/02/2022 09:29:45	GABRIEL LEUZINGER	Aceito
Outros	Justificativa_de_nao_apresentacao_do_Termo_de_Aceite_Institucional.pdf	22/02/2022 09:41:16	GABRIEL LEUZINGER	Aceito
Outros	Instrumento_de_coleta_de_dados.pdf	22/02/2022 09:40:28	GABRIEL LEUZINGER	Aceito
Outros	Curriculo_do_Sistema_de_Curriculos_Lattes_Gabriel_Leuzinger_Coutinho.pdf	22/02/2022 09:38:54	GABRIEL LEUZINGER COUTINHO	Aceito
Outros	Carta_de_revisao_etica.pdf	22/02/2022 09:37:03	GABRIEL LEUZINGER	Aceito
Cronograma	Cronograma.pdf	22/02/2022 09:33:20	GABRIEL LEUZINGER	Aceito

Projeto Detalhado / Brochura Investigador	PhD_Research_Project_Gabriel_Leuzinger.pdf	03/02/2022 07:59:17	GABRIEL LEUZINGER COUTINHO	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	Termo_de_Consentimento_Livre_e_Esclarecido.pdf	03/02/2022 07:56:29	GABRIEL LEUZINGER COUTINHO	Aceito
Folha de Rosto	folhaDeRosto_comite_Etica.pdf	03/02/2022 07:53:49	GABRIEL LEUZINGER	Aceito

Situação do Parecer:
Aprovado

Necessita Apreciação da CONEP:
Não

BRASILIA, 24 de Março de 2022

Assinado por:
MARCIO CAMARGO CUNHA FILHO
(Coordenador(a))

ANNEX B – SRDP-22 PROGRESS INFORMATION PROVIDED BY ANEEL

CONTROLADORIA-GERAL DA UNIÃO

Fala.BR - Plataforma Integrada de Ouvidoria e Acesso à Informação

ALTO CONTRASTE VLIBRAS

Cadastre-se Órgãos Download de Dados LAI Ouvidorias.gov Ajuda

Entrar Cadastrar

Consultar Manifestação

Respostas

19/ 05/ 2022 18:28

Tipo	Responsável	Decisão	Especificação da decisão
Resposta Conclusiva	Coordenador de Pesquisa e Dese	Acesso Concedido	Resposta solicitada inserida no Fala.I

Destinatário Recurso 1ª	Prazo para recorrer	Anexos
Superintendente de Pesquisa e D	30/ 05/ 2022	Situação Chamada 22.xlsx

Prezado(a) cidadão(a),

O Serviço de Informações ao Cidadão (SIC) da Agência Nacional de Energia Elétrica – ANEEL agradece o seu contato e, em atenção à sua solicitação de nº 48003.003882/ 2022- 85, informamos que, em anexo, encaminhamos a relação dos projetos submetidos para avaliação inicial na Chamada de P&D Estratégico nº 22.

Os projetos com situação "Em Execução" encontram-se dentro do cronograma previsto. Os projetos com situação "Carregado" e "Em atraso" estão fora do cronograma, sendo que a proponente tem o direito regulamentar de prorrogar a execução do projeto por até 5 anos.

Os projetos com a situação "Cancelado" tiveram sua execução interrompida a pedido da empresa proponente. A proponente não precisa de justificativa para cancelar projetos, contudo todos os recursos porventura investidos até o cancelamento são automaticamente glosados.

Colocamo-nos à disposição para eventuais dúvidas.

Visite nosso endereço eletrônico para mais informações: www.aneel.gov.br

Informamos ainda que há a possibilidade de interposição, ao Superintendente Pesquisa e Desenvolvimento e Eficiência Energética, de recurso por meio do sistema no prazo de 10 (dez) dias, conforme disposto no art. 15 da Lei nº 12.527/ 2011.

Participe da nossa pesquisa de satisfação para que possamos melhorar nosso atendimento. Sua opinião é importante para o serviço público!

Atenciosamente,

Serviço de Informações ao Cidadão

Superintendente de Pesquisa e Desenvolvimento e Eficiência Energética.

Agência Nacional de Energia Elétrica – ANEEL

www.aneel.gov.br/ acessoainformacao

Teor

Resumo

Informações sobre o andamento do Projeto Estratégico de Pesquisa e Desenvolvimento nº22 - "Desenvolvimento de Soluções em Mobilidade Elétrica"

Fale aqui

Prezados,

Solicito informações sobre o andamento do Projeto Estratégico de Pesquisa e Desenvolvimento nº22 - "Desenvolvimento de Soluções em Mobilidade Elétrica".

Gostaria de saber como está o desenvolvimento dos 30 projetos inicialmente aprovados pela ANEEL. Mais especificamente, gostaria de saber quais destes projetos estão seguindo o cronograma, quais estão atrasados, quais sofreram alterações de escopo e/ ou prazo, e quais foram cancelados pelos proponentes.

Sobre os projetos atrasados, gostaria também de informações sobre quais as razões apresentadas pelas empresas para justificar os atrasos.

Sobre os projetos que sofreram alteração de escopo e/ ou prazo, gostaria também de informações sobre quais foram as mudanças realizadas e quais as razões apresentadas pelas empresas para justificar essas mudanças .

Sobre os projetos cancelados, gostaria também de informações sobre as razões apresentadas pelas empresas para justificar o cancelamento.

Anexos Originais

Não foram encontrados registros.

Manifestação

Tipo de manifestação	Acesso à Informação
Número	48003.003882/ 2022-85
Esfera	Federal
Órgão destinatário	ANEEL – Agência Nacional de Energia Elétrica
Serviço	-
Órgão de interesse	-
Assunto	Acesso à informação
Subassunto	
Tag	-
Data de cadastro	19/ 04/ 2022
Prazo de atendimento	19/ 05/ 2022
Situação	Concluída
Registrado por	Órgão
Modo de resposta	Pelo sistema (com avisos por email)
Canal de entrada	Internet

Anexos

Históricos de ações

Histórico de ações

Data/ Hora	Ação	Responsável	Informações Adicionais
19/ 04/ 2022 08:10	Cadastro	Órgão	Registro dos dados da manifestação
09/ 05/ 2022 17:44	Prorrogação	Órgão	Resposta de manifestação prorrogada de 09/ 05/ 2022 para 19/ 05/ 2022
19/ 05/ 2022 18:28	Registro Resposta	Órgão	Resposta Conclusiva

Encaminhamentos

Não foram encontrados registros.

Prorrogações

Data/ Hora	Prazo Original	Novo Prazo	Responsável	Motivo	Justificativa
09/ 05/ 2022 17:44	09/ 05/ 2022 23:59	19/ 05/ 2022 23:59	Órgão	Indisponibilidade temporária da informação	O servidor responsável pelo tema está impossibilitado, de forma que, será necessário mais prazo para atender à solicitação.

Respostas as pesquisas de satisfação

Não foram encontrados registros.

Voltar à Página Inicial | Responder Pesquisa | Exportar PDF

Voltar ao Topo

Versão 2.21.3

USUÁRIO	AJUDA	INFORMAÇÕES	ÓRGÃOS E ENTIDADES
Entrar	Acessibilidade	Dados Abertos - e-OUV	Manual
Cadastre-se	Mapa do site	Ouvidorias.gov	API Me-OUV
Órgãos	Perguntas frequentes	Painel resolveu?	Documentação API
Download de Dados LAI	Busca de ouvidorias e SICs	Acesso à informação	Adesão aos módulos do Fala.BR
Ouvidorias.gov	Cida	Painel Lei de Acesso à Informação	
Ajuda		Busca de pedidos e respostas	
		Busca de precedentes	

Table A.1 – Progress of SRDP-22 experiments

Project code	Expected duration (months)	Total Expected Cost (R$)	Status
PD-00043-0087	36	11,182,854.44	IN EXECUTION
PD-00047-0087	31	17,524,415.89	IN EXECUTION
PD-00051-0119	36	3,338,168.75	IN EXECUTION
PD-00063-3059	48	17,871,114.32	IN EXECUTION
PD-00063-3060	48	48,251,935.40	IN EXECUTION
PD-00063-3061	36	6,241,952.45	IN EXECUTION
PD-00063-3062	36	27,773,536.82	IN EXECUTION
PD-00064-1058	37	5,358,003.72	IN EXECUTION
PD-00372-9985	36	13,805,254.76	LOADED
PD-00382-0123	48	7,839,669.93	IN EXECUTION
PD-00385-0069	30	14,874,282.45	IN EXECUTION
PD-00387-0022	30	6,257,073.00	IN EXECUTION

Project code	Expected duration (months)	Total Expected Cost (R$)	Status
PD-00391-0039	36	34,687,374.85	IN EXECUTION
PD-00394-1902	24	2,971,123.34	CANCELED
PD-00394-1903	24	2,170,856.90	IN DELAY
PD-00553-0061	48	73,516,174.05	IN EXECUTION
PD-00673-0021	31	4,169,961.28	IN EXECUTION
PD-00678-0001	30	10,905,855.23	CANCELED
PD-02866-0516	24	2,023,143.30	IN DELAY
PD-02866-0517	36	10,364,110.85	IN EXECUTION
PD-02866-0518	36	7,446,261.87	IN EXECUTION
PD-02866-0519	36	5,901,869.84	IN EXECUTION
PD-03052-0004	48	2,077,200.00	CANCELED
PD-04950-0724	36	11,682,255.34	IN EXECUTION
PD-04950-0725	36	4,296,269.07	IN EXECUTION
PD-04951-0726	36	13,115,965.53	IN EXECUTION
PD-05160-1906	36	11,635,550.00	IN EXECUTION
PD-05697-0119	24	6,223,913.73	CANCELED
PD-05697-0219	36	6,416,076.00	IN EXECUTION
PD-05785-2019	48	14,230,360.00	IN EXECUTION
PD-06072-0664	36	33,765,656.00	CANCELED
PD-06585-1912	36	27,655,060.00	IN EXECUTION
PD-06899-6925	48	6,925,859.00	LOADED
PD-06961-0010	36	17,318,555.45	IN EXECUTION
PD-07267-0021	36	9,678,000.01	IN EXECUTION
PD-07427-0319	36	11,553,260.01	IN EXECUTION
PD-07625-0119	32	11,777,840.81	IN EXECUTION
PD-10381-0022	30	8,263,433.00	IN EXECUTION

Source: Provided by ANEEL through the Access to Information Law on May 19th, 2022

APPENDIX A – INFORMED CONSENT FORM

Termo de Consentimento Livre e Esclarecido

Você está sendo convidado/a a participar da pesquisa "Transição para a sustentabilidade no sistema de mobilidade urbano brasileiro: estudo de caso do carro elétrico", de responsabilidade de Gabriel Leuzinger Coutinho, estudante de doutorado da Universidade de Brasília. O objetivo desta pesquisa é explicar como eventos externos ao sistema de mobilidade urbana brasileiro, por exemplo influências do setor elétrico e das montadoras de carro multinacionais e a pandemia de COVID-19, estão influenciando a transição para o carro elétrico no Brasil. Assim, gostaria de consultá-lo/a sobre seu interesse e disponibilidade de cooperar com a pesquisa.

Você receberá todos os esclarecimentos necessários antes, durante e após a finalização da pesquisa, e lhe asseguro que o seu nome não será divulgado, sendo mantido o mais rigoroso sigilo mediante a omissão total de informações que permitam identificá-lo/a. Os dados provenientes de sua participação na pesquisa, tais como questionários e entrevistas, ficarão sob a guarda do pesquisador responsável pela pesquisa.

A coleta de dados será realizada por meio de entrevistas, presenciais ou virtuais ou questionários. É para estes procedimentos que você está sendo convidado a participar. Sua participação na pesquisa não implica em nenhum risco.

Sua participação é voluntária e livre de qualquer remuneração ou benefício. Você é livre para recusar-se a participar, retirar seu consentimento ou interromper sua participação a qualquer momento. A recusa em participar não irá acarretar qualquer penalidade ou perda de benefícios.

Se você tiver qualquer dúvida em relação à pesquisa, você pode me contatar através do telefone 61 99674-1288 ou pelos e-mails leuzinger.gabriel@gmail.com e gabriel.leuzinger@aluno.unb.br.

Este projeto foi revisado e aprovado pelo Comitê de Ética em Pesquisa em Ciências Humanas e Sociais (CEP/CHS) da Universidade de Brasília. As informações com relação à assinatura do TCLE ou aos direitos do participante da pesquisa podem ser obtidas por meio do e-mail do CEP/CHS: cep_chs@unb.br ou pelo telefone: (61) 3107 1592.

Este documento foi elaborado em duas vias, uma ficará com o/a pesquisador/a responsável pela pesquisa e a outra com você.

______________________________ ______________________________

Assinatura do/da participante Assinatura do/da pesquisador/a

____________, ___ de __________de _________

APPENDIX B – ALIGNMENTS OF THE URBAN MOBILITY ST-SYSTEM AND ITS ST-REGIMES

Table B.1 – Alignments of the ST-regimes of the urban mobility ST-system

ST-Regimes	Private car	Bus	Metro/Train	Motorbike	Cycling	Walking
Private car		**Moderate alignment**. Shared infrastructure, but low complementarity.	**Moderate alignment**. Possible interconnected infrastructure and moderate complementarity.	**Moderate alignment**. Shared infrastructure, but low complementarity.	**Weak alignment**. No shared infrastructure and limited complementarity.	**Weak alignment**. No shared infrastructure and limited complementarity.
Bus			**Strong alignment**. Good interconnection infrastructure and significant complementarity.	**Moderate alignment**. Shared infrastructure, but low complementarity.	**Weak alignment**. No shared infrastructure and limited complementarity.	**Strong alignment**. Mobility by bus usually involves walking.
Metro/Train				**Moderate alignment**. Possible interconnected infrastructure and moderate complementarity.	**Moderate alignment**. Possible Interconnected infrastructure and potential complementarity	**Strong alignment**. Mobility by metro/train usually involves walking.
Motorbike					**Weak alignment**. No shared infrastructure and limited complementarity	**Weak alignment**. No shared infrastructure and limited complementarity

ST-Regimes	Private car	Bus	Metro/Train	Motorbike	Cycling	Walking
Cycling						**Strong alignment**. Shared infrastructure and some complementarity
Walking						

Source: Developed by the author

Table B.2 – Internal alignment of the Brazilian private car ST-regime

Private car ST-regime dimensions	Technologies and infrastructure	Organizational mode	User requirements	Planning practices and public financing	Societal meaning
Technologies and infrastructure		**Strong alignment**. The public sector is well invested in maintaining the road infrastructure for cars, and there are many viable business models for cars.	**Strong alignment**. Although cars are too expensive to most of the population, they are considered safe, reliable, and convenient.	**Strong alignment**. There are many public incentives to car production and purchase and the development of the necessary infrastructure.	**Moderate alignment**. Although cars are seen as unsustainable by part of the population, it is still seen as a symbol of wealth and status by most people.
Organizational mode			**Moderate alignment**. Congestion is a problem in many cities, and the current organizational mode difficult the access of most people to cars. However, users' still see	**Strong alignment**. Most urban planning practices favor car use, and there is a lot of public financing to maintain the regime.	**Weak alignment**. The current organizational mode reinforces the view that cars are unsustainable (e.g., low occupancy rate).

Private car ST-regime dimensions	Technologies and infrastructure	Organizational mode	User requirements	Planning practices and public financing	Societal meaning
			the private car regime as better than the others.		
User requirements				**Strong alignment**. Public financing and planning are focused on supplying car users' needs.	**Weak alignment**. The requirements of car users are often not aligned with societal values such as equality and sustainability.
Planning practices and public financing					**Weak alignment**. The way cities are planned to benefit cars is detrimental to most of the population, who do not have cars.
Societal meaning					

Source: Developed by the author

Table B.3 – Internal alignment of the Brazilian bus ST-regime

Bus ST-regime dimensions	Technologies and infrastructure	Organizational mode	User requirements	Planning practices and public financing	Societal meaning
Technologies and infrastructure		**Moderate alignment**. The technology is appropriate for the regime organizational mode, but the infrastructure is often insufficient and inefficient.	**Moderate alignment**. There is a lack of infrastructure (e.g., low quality of bus stops) to meet users' needs, But the technology is sufficient.	**Weak alignment**. There is a lack of planning and funding for the necessary infrastructure.	**Moderate alignment**. The technology is seen as less pollutant than the car but more pollutant than other public transport options.
Organizational mode			**Weak alignment**. The bus regime usually does not meet users' demand for safety, reliability, and convenience, although it is considered an affordable option.	**Weak alignment**. There is a lack of planning and funding for the bus regime in most cities.	**Moderate alignment**. Public transport is seen as a good option to achieve sustainability, but other options are better valued than the bus (e.g., metro).
User requirements				**Weak alignment**. Public financing and planning cannot keep up with the demand for more reliable, safe, and convenient public transportation.	**Strong alignment**. Most requirements of bus users are compatible with societal values such as equality and sustainability

Bus ST-regime dimensions	Technologies and infrastructure	Organizational mode	User requirements	Planning practices and public financing	Societal meaning
Planning practices and public financing					**Weak alignment**. The planning and financing of the regime are insufficient and not compatible with most societal values.
Societal meaning					

Source: Developed by the author

Table B.4 – Internal alignment of the Brazilian metro/train ST-regime

Metro/train ST-regime dimensions	Technologies and infrastructure	Organizational mode	User requirements	Planning practices and public financing	Societal meaning
Technologies and infrastructure		**Strong alignment**. The technology and infrastructure are appropriate for the regime organization.	**Strong alignment**. The technology and its infrastructure meet users' demands.	**Moderate alignment**. Although large cities invest a lot in the metro, the train regime often receives fewer resources.	**Strong alignment**. The technology is considered a sustainable and equitable mode of mobility.
Organizational mode			**Strong alignment**. The metro/train regime usually offers a reliable, safe, convenient, and affordable service.	**Moderate alignment**. The regime often does not receive all the necessary funding to reach its full potential.	**Strong alignment**. The metro/rail regime is seen as a sustainable and equitable mode of mobility.

Metro/train ST-regime dimensions	Technologies and infrastructure	Organizational mode	User requirements	Planning practices and public financing	Societal meaning
User requirements				**Weak alignment**. In the cities where it is present, it usually reaches only some parts of the city.	**Strong alignment**. The requirements of metro/train users are compatible with societal values such as equality and sustainability
Planning practices and public financing					**Moderate alignment**. The way the metro/rail regime is planned is compatible with societal expectations in most cases. However, the system is considered expansive by many people.
Societal meaning					

Source: Developed by the author

Table B.5 – Internal alignment of the Brazilian motorbike ST-regime

Motorbike ST-regime dimensions	Technologies and infrastructure	Organizational mode	User requirements	Planning practices and public financing	Societal meaning
Technologies and infrastructure		**Weak alignment**. The existing organizational mode (e.g., traffic configuration) is not appropriate for the technology.	**Moderate alignment**. The technology and its infrastructure meet users' need for reliability and affordability, but not safety.	**Weak alignment**. Cities are not planned to benefit motorbike use, and there is a lack of public funding for this regime.	**Moderate alignment**. The technology is more sustainable and equitable than cars but less sustainable than public transport.
Organizational mode			**Moderate alignment**. The regime does not meet users' safety demands but meets their reliability, convenience, and affordability requirements.	**Weak alignment**. The regime receives limited incentives from the public sector, and the planning of the traffic system does not benefit motorbike use.	**Moderate alignment**. The regime is more sustainable and equitable than cars but less sustainable than public transport.
User requirements				**Weak alignment**. Planning and public financing are not able to meet motorbike users' needs.	**Moderate alignment**. The requirements of motorbikes users are only partly aligned with values of sustainability and equality.
Planning practices and public financing					**Weak alignment**. The planning and financing of the regime are insufficient and not

Motorbike ST-regime dimensions	Technologies and infrastructure	Organizational mode	User requirements	Planning practices and public financing	Societal meaning
					compatible with most societal values.
Societal meaning					

Source: Developed by the author

Table B.6 – Internal alignment of the Brazilian cycling ST-regime

Cycling ST-regime dimensions	Technologies and infrastructure	Organizational mode	User requirements	Planning practices and public financing	Societal meaning
Technologies and infrastructure		**Weak alignment**. The public sector is not invested in maintaining the infrastructure for cycling, and there are few viable business models.	**Moderate alignment**. The infrastructure does not meet most users' demands, although the technology is appropriate for users.	**Weak alignment**. Cities are not planned to allow safe cycling, and there is a lack of public funding for this regime.	**Strong alignment**. The technology is considered compatible with most societal values, such as equality and sustainability.
Organizational mode			**Moderate alignment**. The regime does not meet users' safety demands but meets their reliability, convenience, and affordability requirements.	**Weak alignment**. The regime does not receive almost any support from the public sector, and planning practices usually prioritize motorized modes of	**Strong alignment**. The regime organizational mode is considered compatible with most societal values, such as equality and sustainability.

Cycling ST-regime dimensions	Technologies and infrastructure	Organizational mode	User requirements	Planning practices and public financing	Societal meaning
				transport to the detriment of cycling.	
User requirements				**Weak alignment**. Planning and public financing are not able to meet cyclists' needs.	**Strong alignment**. The cyclists' requirements are aligned with most societal values.
Planning practices and public financing					**Weak alignment**. The planning and financing of the regime are insufficient and not compatible with most societal values.
Societal meaning					

Source: Developed by the author

Table B.7 – Internal alignment of the Brazilian walking ST-regime

Walking ST-regime dimensions	Technologies and infrastructure	Organizational mode	User requirements	Planning practices and public financing	Societal meaning
Technologies and infrastructure		**Weak alignment**. The public sector is not invested in maintaining the infrastructure for walking, and there are few viable business models.	**Moderate alignment**. The infrastructure does not meet most pedestrians' demands, although walking is appropriate for most people.	**Weak alignment**. Cities are not planned to benefit pedestrians, and there is a lack of public funding for this regime.	**Strong alignment**. Walking is considered compatible with most societal values, such as equality and sustainability.
Organizational mode			**Moderate alignment**. The regime often does not meet users' safety and convenience demands but meets their reliability and affordability requirements.	**Weak alignment**. The regime does not receive almost any support from the public sector, and planning practices usually prioritize motorized modes of transport to the detriment of walking.	**Strong alignment**. The regime organizational mode is considered compatible with most societal values, such as equality and sustainability.
User requirements				**Weak alignment**. Planning and public financing are not able to meet pedestrians' needs.	**Strong alignment**. The pedestrians' requirements are aligned with most societal values.
Planning practices and					**Weak alignment**. The planning and financing of the regime are

Walking ST-regime dimensions	Technologies and infrastructure	Organizational mode	User requirements	Planning practices and public financing	Societal meaning
public financing					insufficient and not compatible with most societal values.
Societal meaning					

APPENDIX C – MAIN STARTUPS OF THE ELECTROMOBILITY SECTOR

Table C.1 – Main startups of the electromobility sector

Startup	Main activity
Atlas Power	Battery storage management systems
BeepBeep	EVs sharing
Brilhon	Chargers’ installation and monitoring
e-moving	e-bikes
Egnex	Chargers’ installation and monitoring
eiOn	EVs production and sharing, and charger’s installation and monitoring
Electricity Mobility Brasil	Chargers’ installation and monitoring
Emove	e-bikes and e-scooters
Entech	Solar-powered chargers
EzVolt	Chargers’ installation and monitoring
Gaia Electric Motors	Mini EVs
Hitech-e	EV retailer and rental
Impulse Boards	Electric skateboards
Incharge	Chargers’ installation and monitoring
Infra Solar	Chargers’ installation and monitoring
Landell Tecnologia	EVs components production
Mobilis	Mini EVs
Motiva	Electric motorbikes
movE	Charger’s monitoring
Movi Electric	Mini EVs production and EVs sharing
Netec	EVs components production
Origem	Electric motorbikes
Phuel	Charger’s monitoring
Riba Share	Electric motorbike sharing
Smartcharge	Chargers’ installation and monitoring
Synkar Autonomous	Electric autonomous delivery vehicles
Tupinambá	Chargers’ installation and monitoring
VANMO	E-bikes and e-scooters sharing
Vela Bikes	e-bikes

Startup	Main activity
Volta e-bike	e-bikes
Voltbras	Charger’s monitoring
Voltz Motors	Electric motorbikes
Woie	e-bikes
YAK Tractors	Electric tractors
Zletric	Chargers’ installation and monitoring

Source: Developed by the author based on Liga Ventures’ startup scanner[88].

[88] Available at https://startupscanner.com/. Accessed on May 23rd 2021.

APPENDIX D – COMPANIES THAT MANIFESTED INTEREST IN PARTICIPATING OF SRDP-22

Table D.1 – Companies that manifested interest in participating of SRDP-22

AES Tietê
Afluente Transmissão de Energia Elétrica S.A.
Ampla Energia e Serviços
BAESA - Energética Barra Grande S.A
Baguari Energia S.A.
Baguari I Geração de Energia Elétrica S.A.
Barra Grande Participações
CEB Distribuição S.A
Celesc Distribuição
Celg Distribuição
Celg Geração e Transmissão S/A
CEMIG Distribuição S.A.
CEMIG Geração Camargos S.A.
CEMIG Geração e Transmissão S.A.
CEMIG Geração Itutinga S.A.
CEMIG Geração Leste S.A.
CEMIG Geração Oeste S.A.
CEMIG Geração Salto Grande S.A.
CEMIG Geração Sul S.A.
CEMIG Geração Três Marias S.A.
Centrais Elétricas de Pernambuco S.A. - EPESA
Centrais Elétricas de Rondônia S.A. – CERON
Companhia de Eletricidade do Acre – ELETROACRE
Companhia de Eletricidade do Estado da Bahia
Companhia de Interconexão Energética
Companhia Energética Candeias
Companhia Energética de Pernambuco – Celpe
Companhia Energética de São Paulo - CESP
Companhia Energética do Ceará
Companhia Energética do Rio Grande do Norte – Cosern

Companhia Energética Estreito
Companhia Energética Jaguara
Companhia Energética Manauara
Companhia Energética Miranda
Companhia Energética Potiguar
Companhia Energética Rio das Antas - CERAN
Companhia Estadual de Distribuição de Energia Elétrica – CEEE-D
Companhia Estadual de Geração e Transmissão de Energia Elétrica – CEEE-GT
Companhia Geração de Energia Pilão - CGEP
Companhia Hidrelétrica Teles Pires
Copel Distribuição
CPFL Geração
CPFL Jaguari
CPFL Paulista
CPFL Piratininga
CTEEP – Companhia de Transmissão de Energia Elétrica Paulista
CTG Brasil
Diamante Geração de Energia
DME Distribuição S/A – DMED
DME Energética S/A – DMEE
EDF Norte Fluminense
EDP Espírito Santo Distribuição de Energia S.A
EDP São Paulo Distribuição de Energia S.A
Elektro Redes S.A.
Eletrobras Eletronorte
Eletropaulo Metropolitana Eletricidade de São Paulo
Eletrosul Centrais Elétricas S.A
ENERCAN - Campos Novos Energia
Energética Águas da Pedra S.A.
ENERGISA Borborema Distribuidora de Energia S.A.
ENERGISA Mato Grosso Distribuidora de Energia S.A.
ENERGISA Mato Grosso do Sul Distribuidora de Energia S.A.
ENERGISA Minas Gerais Distribuidora de Energia S.A
ENERGISA Nova Friburgo Distribuidora de Energia S.A.

ENERGISA Paraíba Distribuidora de Energia S.A.
ENERGISA Sergipe Distribuidora de Energia S.A
ENERGISA Sul Sudeste Distribuidora de Energia S.A.
ENERGISA Tocantins Distribuidora de EnergiaS.A.
Engie Brasil Energia
Estreito Energia S.A
Foz do Chapecó Energia
Furnas Centrais Elétricas S.A.,
Geração Céu Azul S.A.
Geração CII S.A.
Guascor do Brasil Ltda
Itapebi Geração de Energia S.A
Itaqui Geração de Energia S.A.
LIGHT SESA
Machadinho Participações
Monel Monjolinho Energética S.A
Narandiba S.A
Norte Energia S.A
Nova Palma Energia
Paranaíba Geração de Energia S.A.
Parnaíba II Geração de Energia
Paulista Lajeado
Pecém II Geração de Energia S.A
PETROBRAS
Petrobras Distribuidora
Potiguar Sul Transmissão de Energia S.A.
RGE Sul
Rosal Energia S.A.
Sá Carvalho S.A.
Serra do Facão Energia
SPIC BRASIL
Termopernambuco S.A.
Transmissão Morro Agudo
Transmissão Piracicaba

Usina Termelétrica Barreiro S.A.
Vale S.A.

Sources: Retrieved from https://sicnet2.aneel.gov.br/sicnetweb/ on 18th June 2021.

APPENDIX E – SRDP-22 SUSTAINABILITY EXPERIMENTS

E.1 PD-00387-0022

This experiment was proposed by Rio Paranapanema Energia, a subsidiary of CTG Brasil, which is owned by the China Three Gorges Corporation (CTG BRASIL, 2020). The project aims to create a cloud platform that can aggregate users and companies involved in the charging of electric vehicles (EVs) and develop a marketplace to offer users access to energy from distributed generation plants or the ACL. The company proposed the development of a point-to-point platform for the insertion of renewable energies to make the model technologically viable. The estimated cost of the experiment is R$ 6,257,073.00 (ANEEL, 2019i).

The scope of the experiment includes: (i) the development of a mobile app, (ii) the creation of an application programming interface to allow other companies to connect their systems to the marketplace, (iii) the implementation of a testing site including an EV charging station, (iv) a study of the necessary regulatory changes to make the system viable, and (v) a detailed description of the business model, including a viability assessment (ANEEL, 2019i).

ANEEL (2019i) considered that this proposal was original, had good applicability and relevance, and its costs were compatible with the scope of the project. According to the evaluation, the experiment has the potential to bolster both the distributed generation and the electric car niches.

Three actors are involved in this experiment besides Rio Paranapanema Energia: Sinapsis Inovação, Way2 Serviços, and EIDEE Design. Rio Paranapanema Energia is an actor of the Large hydroelectric and the Small hydroelectric ST-Regimes (CTG BRASIL, 2020). Sinapsis Inovação em Energia is a R&D company focused on the electricity system. Most of its projects are for actors of the ST-regimes of the electricity ST-system (SINAPSIS INOVAÇÃO EM ENERGIA, 2021). Therefore, Sinapsis Inovação em Energia can be considered an actor of different ST-regimes in this system. Way2 Serviços develops systems to monitor electricity consumption and is an actor from the consumption management niche (WAY2 SERVIÇOS, 2021). EIDEE Design designs several products, including EV charging stations (EIDEE DESIGN, 2021). In this sustainability experiment, this company can be considered an actor of the electric car niche, although it is also part of other ST-systems, ST-regimes, and niches.

There are four interactions in for levels in the experiment: intrasystem niche-regime, intrasystem regime-regime, intersystem niche-regime, and intersystem niche-niche.

Besides, the main mode of interaction is symbiosis. The electric car niche has great synergies with renewable energies (SHAFIEI et al., 2017; CALVILLO et al., 2018), such as Large and Small hydroelectric. Electric cars and consumption management technologies also have a mutual beneficial relationship. Managing an electricity system with a great number of EVs will increase the demand for consumption management technologies. Besides, EV owners will probably require this kind of technology to make the recharging cheaper, for example, by scheduling it for hours when the electricity is cheaper. Finally, we could characterize the interaction between the Large hydroelectric and the Small hydroelectric ST-Regimes and the consumption management niche as competition as this niche technology can result in less electricity consumption. On the other hand, advances on Large hydroelectric and the Small hydroelectric ST-Regimes can make electricity cheaper and reduce the need for consumption management technologies.

The main resources exchanged should be capital (mainly from Rio Paranapanema Energia to the other participants), knowledge, and people. Although Rio Paranapanema Energia is part of a multinational holding, there is no indication that transnational linkages will be relevant to this experiment, as no exchange of resources with international partners is planned.

The experiment focus on a complementary technology to EVs, i.e, a point-to-point platform to integrate renewable energy and EVs. The experiment's impacts will probably be limited to niche consolidation, including articulating expectations and views, building networks of actors, and creating learning process. There is no indication that the experiment will contribute to destabilize the private car ST-regime. The characterization of the experiment is resumed in Table E.1.

Table E.1 – Characterization of experiment PD-00387-0022

Category	Classification
Actors involved	Rio Paranapanema Energia Sinapsis Inovação em Energia Way2 Serviços EIDEE Design

Category	Classification
Start and end date	20/12/2019 – 20/12/2021
Level of interaction	Intrasystem niche-regime Intrasystem regime-regime Intersystem niche-regime Intersystem niche-niche
Mode of interaction	Competition Symbiosis
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions Niche consolidation - build new networks of actors Niche consolidation - create learning process at multiple dimensions
Value-chain level of interaction	Focus on complementary technologies
Resources exchanged in the experiment	Capital Knowledge People
Impact of transnational linkages on the experiment	Transnational linkages are present but do not influence de experiment

Source: Developed by the author based on ANEEL (2019i)

E.2 PD-00391-0039

This experiment was proposed by EDP São Paulo, a subsidiary of EDP Brasil, which is owned by the Portuguese energy company Energias de Portugal (EDP) (EDP BRASIL, 2021). The experiment’s objective is to develop an operational model for electric mobility. This experiment includes the installation of 30 DC fast chargers from different suppliers to be used in real tests of the operational model. The estimated cost of the experiment is R$ 32,938,655.07 (ANEEL, 2019j).

The scope of the experiment includes: (i) installing an EV fast charging infrastructure, (ii) developing software application to monitor the system, (iii) acquiring the EVs for the tests, (iv) a study of the necessary regulatory changes to make the system viable, and (v) a detailed description of the business model, including a viability assessment (ANEEL, 2019j).

ANEEL (2019j) considered that this proposal was original, had good applicability and relevance. ANEEL praised the high number of companies participating in the experiment, which can develop into an interesting innovation network. The agency also highlighted the relevant scientific contributions that the experiment will provide. Although ANEEL approved the cost of the experiment, the agency questioned the necessity of using expensive imported EVs instead of cheaper options (ANEEL, 2019j).

There are thirteen actors involved in this experiment. Five of them are subsidiaries of EDP Brasil: EDP São Paulo and EDP Espírito Santo (Distribution ST-regime), Lageado Energia (Large hydroelectric ST-regime), Porto de Pecém Geração de Energia (Thermoelectric ST-regime), EDP Grid (Trader ST-regime) (EDP BRASIL, 2021).

ABB and Siemens supply electrical equipment and participate in several ST-regimes of the ST-electricity system (ABB, 2021b; SIEMENS, 2021). Nonetheless, these two companies have considerably increased their investments in electric mobility in the last few years (SCHUETZE; HIRT, 2021; LIENERT, 2022). Therefore, they can be considered actors of the Distribution and Transmission ST-regimes and the electric car niche in the context of SRDP-22.

The Grupo de Estudos do Setor Elétrico (GESEL) is a research group from UFRJ and COPPETEC is a foundation that manages projects from GESEL and other research groups from UFRJ (COPPETEC, 2021; GESEL, 2021). GESEL is part of several different ST-regimes and niches of the electricity ST-system. In the context of this experiment, GESEL can be considered part of the electric car niche because their participation is related to the EV charging system. COPPETEC is not directly involved in any ST-regime and is only involved in the experiment to manage the resources that would be transferred to GESEL. Therefore, it should not be considered as an actor of any ST-regime or niche of the electricity or urban mobility ST-systems.

Electric Mobility Brasil is part of the electric car niche and supplies EV chargers (ELECTRIC MOBILITY BRASIL, 2021). The last three companies participating in the experiments are all subsidiaries of the Volkswagen Group: Volkswagen, Audi, and Porsche (VOLKSWAGEN AG, 2021). Therefore, they are all actors of the Private car ST-regime.

The high and diverse number of participants means that there are interactions between regimes and niches in almost all levels in this experiment. The only exception is intrasystem niche-niche because there is only one niche actor of each ST-system involved.

In this experiment, there are many different modes of interaction. First, the interaction between the electric car niche and the Large hydroelectric ST-regime can be characterized as symbiosis, as detailed in the previous experiment. On the other hand, the interaction of the electric car niche with the Thermoelectric ST-regime can be considered parasitism. The use of the electric car will probably increase the demand for renewable energy, as they are part of the energy transition (STOKES; BREETZ, 2018; VAN DER KAM et al., 2018; ARCOS-VARGAS, 2021; TORABI; GOMES; MORGADO-DIAS, 2021; YUAN et al., 2021), inhibiting the thermoelectric plants. But the use of the thermoelectric plants can be necessary to provide the electricity necessary to charge EVs in case there is not enough renewable energy available, thus is benefits the EVs.

Moreover, there is also symbiosis between the Distribution, Transmission and the Trader ST-regime and the electric car niche. These regimes will benefit from the increase in electricity sales due to the use of electric cars, and the electric car niche benefits from stable and robust Distribution, Transmission, and the Trader ST-regimes, which make EVs usage more reliable. Moreover, there is competition between the Private car ST-regime, strongly based on ICEVs, and the electric car niche.

The interaction between the Large hydroelectric and the Thermoelectric ST-regimes is competition, as they compete to provide electricity to society. The interaction between all the other ST-regimes from the electricity sector involved in this experiment with each other can be characterized as symbiosis, as they all benefit from each other. Finally, the interaction of all these regimes with the Private car ST-regime can be characterized as neutralism, as none of them benefits or inhibits the other.

The main resources exchanged should be capital, knowledge, and people. It is also expected some level of technology exchange. However, it is clearly stated in the proposal that EDP Brasil will have the industrial property of all the results related to the software developed and the Volkswagen Group will have the industrial property of any innovations related to the EVs and their charging (ANEEL, 2019j).

Although many of the actors are part of multinational holdings, transnational linkages will have only a limited impact in the experiment: the electric cars used will be imported by the companies of the Volkswagen Group. The experiment focuses on a complementary technology to EVs, i.e., the operational model for electric mobility.

However, the main technology is also relevant to the experiment because the Volkswagen Group expects to develop innovations in the electric car.

The experiment's impacts will probably be limited to niche consolidation, including articulating expectations and views, building networks of actors, and creating learning process. There is no indication that the experiment will contribute to destabilize the private car ST-regime. The characterization of the experiment is resumed in Table E.2.

Table E.2 – Characterization of experiment PD-00391-0039

Category	Classification
Actors involved	EDP São Paulo EDP Espírito Santo Porto do Pecém Geração de Energia Lageado Energia EDP Grid ABB Siemens GESEL COPPETEC Electric Mobility Brasil Volkswagen do Brasil Audi do Brasil Porsche Brasil
Start and end date	01/01/2020 – 31/01/2023
Level of interaction	Intrasystem niche-regime Intrasystem regime-regime Intersystem niche-regime Intersystem regime-regime Intersystem niche-niche
Mode of interaction	Competition Symbiosis

Category	Classification
	Neutralism Parasitism
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions Niche consolidation - build new networks of actors Niche consolidation - create learning process at multiple dimensions
Value-chain level of interaction	Focus on complementary technologies Focus on the main technology
Resources exchanged in the experiment	Capital Knowledge Technology People
Impact of transnational linkages on the experiment	Transnational linkages are present and influence the experiment

Source: Developed by the author based on ANEEL (2019j)

E.3 PD-02866-0516

This experiment was proposed by COPEL Distribuição, a subsidiary of the public company Companhia Paranaense de Energia (COPEL), which is owned by the Paraná state government (COPEL, 2021). The experiment's main goal is to create a communication and integration system to connect electricity distributors with energy consumption management platforms. The experiment will involve tests of this systems in laboratory and on the field. The estimated cost of the experiment is R$ 2,203,143.30 (ANEEL, 2019k).

ANEEL (2019k) considered that this proposal was original, had good applicability and relevance, and its costs were compatible with the scope of the project. According to ANEEL (2019k), the main aspect of the experiment's relevance is that having a better energy consumption management would allow the government to postpone investments in electricity generation because the available energy resources would be better used. Nonetheless, the proposal was criticized for not including members from academia or research centers.

Three actor are participating in the experiment: COPEL Distribuição, Motiva Motocicletas, and Serviço Nacional de Aprendizagem Industrial (SENAI). COPEL is an actor of the Distribution ST-regime (COPEL, 2021). Motiva produces electric motorcycles and should be considered an actor of the electric motorcycle niche (MOTIVA MOTOCICLETAS, 2021). SENAI is a non-profit organization that provides professional training for workers from the industrial sector (SENAI, 2019). It can be classified as an actor of many ST-regimes from both the electricity and the urban mobility ST-system.

There are four levels of interaction in this experiment if SENAI is considered as an actor of two ST-systems: intrasystem regime-regime, intrasystem niche-regime, intersystem niche-regime, and intersystem regime-regime. The main mode of interaction is symbiosis, as the Distribution ST-regime and the electric motorcycle niche should benefit from each other just as is the case of the electric car niche (see Section E.2).

The main resources exchanged should be capital, knowledge, and people. COPEL Distribuição will be the main source of all these resources. Besides, there are no transnational linkages present in the experiment. The communication and integration system that is the focus of the experiment is a complementary technology to EVs

The experiment's impacts will probably be limited to niche consolidation, including articulating expectations and views, building networks of actors, and creating learning process. There is no indication that the experiment will contribute to destabilize the private car ST-regime. The characterization of the experiment is resumed in Table E.3.

Table E.3 – Characterization of experiment PD-02866-0516

Category	Classification
Actors involved	COPEL Distribuição Motiva Motocicletas SENAI
Start and end date	Not informed
Level of interaction	Intrasystem niche-regime Intrasystem regime-regime Intersystem niche-regime Intersystem niche-niche
Mode of interaction	Symbiosis

Category	Classification
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions Niche consolidation - build new networks of actors Niche consolidation - create learning process at multiple dimensions
Value-chain level of interaction	Focus on complementary technologies
Resources exchanged in the experiment	Capital Knowledge People
Impact of transnational linkages on the experiment	Transnational linkages are not present

Source: Developed by the author based on ANEEL (2019k)

E.4 PD-02866-0519

This experiment was also proposed by COPEL Distribuição. The experiment aims to develop a managing system for 'electric highways', i.e., EV charging stations distributed along a highway. This system will be able to integrate different distributors, users, vehicles, and charging stations in a single platform. The estimated cost of the experiment is R$ 6,147,649.04 (ANEEL, 2019l).

The scope of the experiment also includes the adjustment of the system to be used in urban areas and simulations to determine the best disposition of the charging stations along the highways. Besides, the existing EV charging stations at the BR-277 highway, which were installed by COPEL Distribuição and Itaipu Binacional, will be used to test the system developed in the experiment (ANEEL, 2019l). The experiment also includes the installation of two new charging stations in the highway.

ANEEL (2019l) considered that this proposal was original, had good applicability and relevance, and its costs were compatible with the scope of the project. However, no particular characteristic of the experiment was highlighted by the agency (ANEEL, 2019l).

The experiment has the involvement of three actors from the electricity ST-system: COPEL Distribuição, Universidade Federal de Santa Maria (UFSM), and Centro Internacional de Energias Renováveis e Biogás (CIBiogás). As defined in the previous section, COPEL is an actor of the Distribution ST-regime. The research group from UFSM that is participating on the experiment, Centro de Excelência em Energia e Sistemas de Potência (CEESP), develop innovations for the Distribution, Transmission ST-regimes (CEESP, 2021). CIBiogás is a research center focused on biogas and biomass applications (CIBIOGÁS, 2019). It can be considered an actor of the biomass ST-Regime.

All actors in this experiment are from the electricity ST-system. Therefore, only intrasystem interactions are present in the experiment. The main mode of interaction is symbiosis, between the Distribution, Transmission, and Biomass ST-regimes.

The main resources exchanged should be capital, knowledge, and people. COPEL Distribuição will be the main source of all these resources, especially capital. Besides, there are no transnational linkages present in the experiment. The electric highway management system that is the focus of the experiment is a complementary technology to EVs

The experiment's impacts will probably be limited to niche consolidation, including articulating expectations and views, building networks of actors, and creating learning process. There is no indication that the experiment will contribute to destabilize the private car ST-regime. The characterization of the experiment is resumed in Table E.4.

Table E.4 – Characterization of experiment PD-02866-0519

Category	Classification
Actors involved	COPEL Distribuição CEESP - UFSM CIBiogas
Start and end date	08/10/2019 – 30/12/2023
Level of interaction	Intrasystem niche-regime Intersystem niche-niche
Mode of interaction	Symbiosis
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions Niche consolidation - build new networks of actors Niche consolidation - create learning process at multiple dimensions
Value-chain level of interaction	Focus on complementary technologies

Category	Classification
Resources exchanged in the experiment	Capital Knowledge People
Impact of transnational linkages on the experiment	Transnational linkages are not present

Source: Developed by the author based on ANEEL (2019l)

E.5 PD-07625-0119

This experiment proposal was submitted by Paranaíba I Geração de Energia (PARNA I), a subsidiary of the Brazilian oil and gas company Eneva (ENEVA, 2021). The objective is to develop a digital platform to integrate electricity generators and distributors and final users to enable EV charging. The main feature of this platform will be an automatic payment system. The experiment also includes the installation of three fast charging and four charging stations to do a field test of the platform. The estimated cost of the experiment is R$ 11,777,840.79 (ANEEL, 2019m).

ANEEL (2019m) considered that this proposal was original, had good applicability and relevance, and its costs were compatible with the scope of the project. However, the agency criticized the experiment's study of economic viability, indicating that it makes a few assumptions that are not realistic (ANEEL, 2019m).

Four of the seven organizations involved in the experiment are subsidiaries of Eneva: PARNA I, Paranaíba II Geração de Energia (PARNA II), Pecém II Geração de Enegia (PECÉM II), and Itaqui Geração de Energia (ITAQUI) (ENEVA, 2021). These are all actors from the Thermoelectric ST-regime. Sunrise Engenharia e Consultoria provides solutions in solar energy, energy efficiency and EV charging (SUNRISE ENGENHARIA E CONSULTORIA, 2021). It can be considered an actor of both the electric car and energy efficiency niches. Mirow&Co do Brasil is a management consulting firm that is not part of any ST-regime or niche of the electricity and urban mobility ST-systems (MIROW&CO DO BRASIL, 2021). Venturus is a R&D company that operates in many sectors, including agriculture, heavy industry, health, and the automotive industry (VENTURUS, 2021). In the context of this experiment, Venturus can be considered an actor of the electric car niche.

There are many are interactions in several different levels in this experiment: intrasystem niche-regime, intrasystem regime-regime, intersystem niche-regime, and intersystem niche-niche.

As detailed before (see Section E.2), there is parasitism between the electric car niche and the Thermoelectric ST-regime. Besides, the interaction between the electric car and the energy efficiency niches can be considered symbiosis. The increased use of EVs should increase the demand for energy efficiency. On the other hand, having better energy efficiency technologies may reduce electricity prices and promote the adoption of electric cars.

Finally, there is amensalism between the energy efficiency niche and the Thermoelectric ST-regime. An increase in energy efficiency can lead to the reduction of the consumption of electricity, inhibiting the Thermoelectric ST-regime, but any advances in thermoelectric electricity generation should not impact, positively or negatively, the energy efficiency niche. In fact, amensalism is the mode of interaction between the whole electricity ST-system and the energy efficiency niches. They represent two opposing paradigms (GUNN, 1997). Nonetheless, energy efficiency regulation has been captured by the electricity ST-system companies, transforming it in something beneficial to them (CROUCHER, 2011). This capture is why the electricity ST-system is so willing to invest in energy efficiency. Nonetheless, this is an anomaly and, in terms of the core technology, the mode of interaction between most of the ST-regimes of the electricity ST-system and the energy efficiency niche is amensalism.

The main resources exchanged should be capital, knowledge, and people. Besides, there are no evident transnational linkages present in the experiment. The experiment focuses on a complementary technology to electric cars.

The experiment's impacts will probably be limited to niche consolidation, including articulating expectations and views, building networks of actors, and creating learning process. There is no indication that the experiment will contribute to destabilize the private car ST-regime. The characterization of the experiment is resumed in Table E.5.

Table E.5 – Characterization of experiment PD-07625-0119

Category	Classification
Actors involved	PARNA I PARNA II

Category	Classification
	PECÉM I ITAQUI Sunrise Engenharia e Consultoria Mirow&Co do Brasil Venturus
Start and end date	01/11/2019 – 01/11/2021
Level of interaction	Intrasystem niche-regime Intrasystem regime-regime Intersystem niche-regime Intersystem niche-niche
Mode of interaction	Symbiosis Parasitism Amensalism
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions Niche consolidation - build new networks of actors Niche consolidation - create learning process at multiple dimensions
Value-chain level of interaction	Focus on complementary technologies
Resources exchanged in the experiment	Capital Knowledge People
Impact of transnational linkages on the experiment	Transnational linkages are not present

Source: Developed by the author based on ANEEL (2019m)

E.6 PD-00043-0087

This experiment was proposed by Companhia Energética de Pernambuco (Celpe), a subsidiary of the electricity company Neoenergia, which is owned by Iberdrola, a multinational company incorporated in Spain (NEOENERGIA, 2021). The experiment's goal is to implement an electromobility system in the Fernando de Noronha Island. This system will integrate smart grid, solar energy, distributed generation, internet of things (IoT), and electric car technologies. The estimated cost of the experiment is R$ 20,746,274.78 (ANEEL, 2019n).

The experiment also encompasses (ANEEL, 2019n): (i) the creation of a roadmap for the development of similar experiments in other touristic areas, (ii) an analysis of the socioenvironmental impacts of the experiment, (iii) the analysis and optimization of the EVs charging to maximize the use of renewable energy, (iv) installation of 21 EV chargers, and (v) a study of the necessary regulatory changes to make the system viable, especially in touristic areas with environmental restrictions, such as Fernando de Noronha Island. Besides, the system will use many different EVs, including six electric cars, four electric ‘buggies’, two electric car specifically to V2G applications, and one micro-bus for 25 passengers (ANEEL, 2019n).

ANEEL (2019n) considered that this proposal was original, had good applicability and relevance, and its costs were compatible with the scope of the project. The agency highlighted the complexity of implanting this kind of experiment in a protected area and the many different technologies that are part of the experiment. ANEEL (2019n) also emphasized that the experiment will bring relevant contributions to the local community, such as better public services and capacitation of local workers to operate the electromobility system, and important scientific productions both in the technological and environmental fields.

Eleven organizations are participating in the experiment. Six of them are subsidiaries of Neoenergia: Celpe, Elektro Redes, Companhia Energética do Rio Grande do Norte (Cosern), Companhia de Eletricidade do Estado da Bahia (Coelba), Termopernambuco, and Itapebi Geração de Energia Elétrica (Itapebi Geração) (NEOENERGIA, 2021). The first four are actors of the Distribution ST-regime, Termopernambuco is part the Thermoelectric ST-regime, and Itapebi is part of the Large hydroelectric ST-regime.

Three research institutions are involved in the experiment: Fundação CPqD, Instituto Avançado de Tecnologia e Inovação (IATI) and Federal University of Pernambuco (UFPE). Fundação CPqD is a R&D company focused on IoT, blockchain, and AI solutions from several sector, including the electricity ST-system (FUNDAÇÃO CPQD, 2021). It can be considered an actor of the consumption management niche. IATI is private research center that do research in several fields, including smart grids, batteries, renewable energy and electromobility (IATI, 2021). Thus, it is an actor of the battery and electric car niches and the solar, wind, and biomass ST-regimes. UFPE has several research groups and laboratories (UFPE, 2021). However, the experiment description in ANEEL's system does not specify which one of them is taking part in the experiment. Therefore, it is difficult to classify UFPE role in this experiment.

Finally, two companies of the electric car niche are also participating in the experiment: BYD Energy do Brasil (BYD Brasil) and eiON. BYD Brasil is a subsidiary of the Chinese corporation BYD co. Besides the electric car niche, BYD Brasil is also part of the solar ST-regime and the battery niche in Brazil (BYD BRASIL, 2021). eiON is a startup that produces mini electric cars, has an EV sharing system, and installs EVs chargers (EION, 2021). Thus, eiON is an actor of the electric car niche.

Therefore, there are many are interactions in several different levels in this experiment: intrasystem niche-niche, intrasystem niche-regime, intrasystem regime-regime, intersystem niche-regime, and intersystem niche-niche.

Many of the interactions between ST-regimes and niches in this experiment have been characterized in previous sections (see Sections E.1 and E.2). There is symbiosis between renewable energy (Solar, Wind, Biomass, and Large hydroelectric ST-regimes) and the electric car and consumption management niches. The interaction between Thermoelectric ST-regime the electric car niche is parasitism. There is also competition between the different ST-regimes that produce electricity, as they all supply the same resource. And the interaction between these same ST-regimes and the Distribution ST-regime is symbiosis. Besides there is symbiosis between the consumption management and the electric car niches and competition between the consumption management niche and the different ST-regimes of the electricity ST-system.

Moreover, there is symbiosis between the battery and the electric car niches and renewable energy technologies. Batteries area an essential part of electric cars and are also useful to mitigate the intermittency that is inherent to renewable energies. On the other hand, the demand for batteries will only increase as the demand for EVs and renewable energy increases. There is amensalism between the battery niche and the Thermoelectric ST-regime because advances in battery technology will lead to the increase in renewable energy usage and reduce the demand for thermoelectric energy. But any advance in thermoelectric should not significantly inhibit batteries.

The main resources exchanged should be capital, knowledge, and people. Transnational linkages will have a small relevance to the experiment, as the EVs that will be used will be imported from China. The focus of the experiment is on complementary technologies of EVs, notably the charging system. Although BYD and eiON are part of the experiment, there is no clear indication that they will use it to improve their products. Therefore, there does not seem to be a focus on the development of EVs in this experiment.

The experiment's impacts will probably be limited to niche consolidation, including articulating expectations and views, building networks of actors, and creating learning process. There is no indication that the experiment will contribute to destabilize the private car ST-regime. The characterization of the experiment is resumed in Table E.6.

Table E.6 – Characterization of experiment PD-00043-0087

Category	Classification
Actors involved	Celpe Cosern Coelba Elektro Redes Termopernambuco Itapebi Geração Fundação CPqD IATI UFPE BYD Brasil eiON
Start and end date	Not informed – Duration of 36 months
Level of interaction	Intrasystem niche-regime Intrasystem regime-regime Intrasystem niche-niche Intersystem niche-regime Intersystem niche-niche
Mode of interaction	Competition

Category	Classification
	Symbiosis Parasitism Amensalism
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions Niche consolidation - build new networks of actors Niche consolidation - create learning process at multiple dimensions
Value-chain level of interaction	Focus on complementary technologies
Resources exchanged in the experiment	Capital Knowledge People
Impact of transnational linkages on the experiment	Transnational linkages are present and influence the experiment

Source: Developed by the author based on ANEEL (2019n)

E.7 PD-00047-0087

This experiment was also proposed by a subsidiary of Neoenergia: Coelba (NEOENERGIA, 2021). The experiment will create a ‘green corridor’ between the states of Bahia and Rio Grande do Norte, with the installation of eleven EV charging stations along the highway and another six in shopping centers in the major cities in the corridor (Salvador, Aracaju, Maceió, Recife, João Pessoa, and Natal). The experiment’s objective is to develop a new business model in electromobility for companies of the electricity ST-system. The estimated cost of the experiment is R$ 20,528,780.76 (ANEEL, 2019o).

The scope of the experiment also includes: (i) the development of a software to monitor the charging stations and an app for users to check the availability and book a time to use these stations, (ii) studies to evaluate the impact of the charging stations in the electricity grid, (iii) study of the necessary regulatory changes to create a ‘dynamic tariff’ to be used in the system, and (iv) evaluate and compare the performance of BEV and PHEVs within the system (ANEEL, 2019o).

ANEEL (2019o) evaluated that this proposal was original, had good applicability and relevance, and its costs were acceptable given the scope of the project. The agency highlighted the importance of creating an EV charging infrastructure in the Northeast region, which might stimulate the use of EVs in the region. ANEEL (2019o) also pointed out that the car manufacturer CAOA Chery withdrawal from the experiment was a significant loss and a downside in the proposal.

There are twelve actors involved in this experiment. Six of them are also participating in PD-00043-0087 and are all subsidiaries of Neoenergia: Coelba, Celpe, Elektro, Cosern, Termopernambuco, and Itapebi Geração. As detailed in the previous section, Coelba, Celpe, Elektro Redes, Cosern are actors of the Distribution ST-regime, Termopernambuco is part of the Thermoelectric ST-regime and Itapebi Geração is an actor of the Large hydroelectric ST-regime. Besides, another subsidiary of Neoenergia is taking part in the experiment: NC Energia. This company operates as a trader in the Brazilian electricity system and, therefore, is part of the Trader ST-regime (NC ENERGIA, 2021; NEOENERGIA, 2021).

Besides, three organizations involved in other experiments are also taking part: Sinapsis Inovação em Energia (different ST-regimes of the electricity ST-system), ABB (Distribution and Transmission ST-regimes, and electric car niche), and GESEL (electric car niche). The other two actors in the experiment, SENAI's Campus Integrado de Manufatura e Tecnologia (CIMATEC) and the Universidade Federal do ABC (UFABC), are both education and research institutions CIMATEC conducts research on biotechnology, automation and robotics, mobility, renewable energy, among others (CIMATEC, 2021). This institution is part of many niches and ST-regimes in different ST-systems. In the context of this experiment, it can be considered part of the electric car niche. UFABC also conducts research in different areas (UFABC, 2021) and the experiment description in ANEEL's system does not specify which one of them is taking part in the experiment. Therefore, it is difficult to classify UFABC role in this experiment.

It is possible to identify interactions in four levels in this experiment: intrasystem niche-regime, intrasystem regime-regime, intersystem niche-regime, and intersystem niche-niche.

The interactions between ST-regimes and niches in this experiment have been characterized in previous sections (see Sections E.1 and E.2). The interaction between Thermoelectric ST-regime the electric car niche is parasitism. The interaction between the Thermoelectric, Distribution, Transmission, and Trader ST-regimes is symbiosis. Besides, there is also symbiosis between the electric car niche and the Distribution, Transmission, and Trader ST-regimes.

Although Coelba is part of a multinational holding, there is no indication that transnational linkages will be relevant to this experiment, as no exchange of resources with international partners is planned. The focus of the experiment is on complementary technologies of EVs, notably the charging system that will be implemented.

The experiment's impacts will probably be limited to niche consolidation, including articulating expectations and views, building networks of actors, and creating learning process. There is no indication that the experiment will contribute to destabilize the private car ST-regime. The characterization of the experiment is resumed in Table E.7.

Table E.7 – Characterization of experiment PD-00047-0087

Category	Classification
Actors involved	Coelba Cosern Celpe Termopernambuco Itapebi Geração Elektro NC Energia ABB Sinapsis Inovação em Energia GESEL CIMATEC UFABC
Start and end date	Not informed – Duration of 36 months
Level of interaction	Intrasystem niche-regime Intrasystem regime-regime Intersystem niche-regime Intersystem niche-niche
Mode of interaction	Competition Parasitism

Category	Classification
	Symbiosis
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions Niche consolidation - build new networks of actors Niche consolidation - create learning process at multiple dimensions
Value-chain level of interaction	Focus on complementary technologies
Resources exchanged in the experiment	Capital Knowledge People
Impact of transnational linkages on the experiment	Transnational linkages are not present

Source: Developed by the author based on ANEEL (2019o)

E.8 PD-00051-0119

This experiment was proposed by DME Distribuição (DMED), a subsidiary of the public holding DME Poços de Caldas Participações (DME), which is owned by the municipality of Poços de Caldas (DME POÇOS DE CALDAS, 2020). The experiment aims to develop methods to calculate the price that should be charged of users of EV charging stations, considering both public and residential stations (ANEEL, 2019p).

The scope of the experiment includes (ANEEL, 2019p): (i) installing six charging stations, three for electric bicycles and three for electric cars, in different locations of Poço de Caldas (one of these stations will be powered by solar energy and have an energy storage system.), (ii) creating an energy consumption monitoring device to be installed in the electric bicycles and cars, and (iii) developing a mobile application platform to enable users to book a time to use these stations and give them the option to include the charging cost in their electricity bill. The estimated cost of the experiment is R$ 3,067,429.84 (ANEEL, 2019p).

ANEEL (2019p) considered that this proposal was original, had reasonable applicability and relevance, and its costs were compatible with the scope of the project. The agency indicated that the inclusion of a station powered by distributed and renewable energy is interesting because this model has a good potential for replicability in other cities.

Five actors are involved in this experiment besides DMED: DME Energética (DMEE), Sociedade Mineira de Cultura (SMC), Instituto Federal do Sul de Minas Gerais (IFSULDEMINAS), Alba Tecnologia Industrial, and ABB. DMED is an actor of the Distribution ST-regime (DME POÇOS DE CALDAS, 2020). DMEE is also a subsidiary of DME. It is responsible for the large and small hydroelectric of the DME (DME POÇOS DE CALDAS, 2020). Therefore, DMEE is an actor of the Large hydroelectric and Small hydroelectric ST-regimes.

SMC is the entity that *Pontifícia Universidade Católica de Minas Gerais* (PUC Minas) (PUC MINAS, 2021a), which is the organization involved in the experiment. PUC Minas and IFSULDEMINAS are both education and research institutions. Researchers from the electrical engineering, computer engineering, architecture and urbanism, law, and marketing fields from PUC Minas and IFSULDEMINAS are involved in the experiment (IFSULDEMINAS, 2021). They will be responsible for creating the monitoring device and the mobile application that will be used in the experiment (PUC MINAS, 2021b). Therefore, PUC Minas and IFSULDEMINAS can be considered actors of the electric car niche in this experiment.

Alba Tecnologia Industrial provides solar energy solutions, including the system's dimensioning and installation of the infrastructure. This company is part of the Solar ST-regime. As detailed in section E.2, ABB is an actor of the Distribution and Transmission ST-regimes, and the electric car niche.

Despite the relevant number of actors involved in this experiment, there are only two levels of interaction: intrasystem regime-regime and intersystem niche-regime.

The interactions between ST-regimes and niches in this experiment have been characterized in previous sections (see Sections E.1 and E.2). The interaction between Large hydroelectric, Small hydroelectric and Solar ST-regimes is competition. The interaction of these ST-regimes with the Distribution and Transmission ST-regimes can be characterized as symbiosis. Besides, the interaction of all these ST-regimes with the electric car niche is also symbiosis.

The main resources exchanged should be capital (mainly from DMED and DMEE to the other participants), knowledge, and people. The only multi-national organization participating in the experiment is ABB. Nonetheless, transnational linkages probably will not influence the experiment. The experiment focus on a complementary technology to

EVs, i.e., methods to charge users of EVs charging stations. However, as an energy consumption monitoring device for EVs will be developed and a patent will be registered for it (ANEEL, 2019p), it can be considered that the experiment also focus on EVs.

The experiment's impacts will probably be limited to niche consolidation, including articulating expectations and views, building networks of actors, and creating learning process. There is no indication that the experiment will contribute to destabilize the private car ST-regime. The characterization of the experiment is resumed in Table E.8.

Table E.8 – Characterization of experiment PD-00051-0119

Category	Classification
Actors involved	DMED DMEE PUC Minas IFSULDEMINAS Alba Tecnologia Industrial ABB
Start and end date	12/2019 – 11/2022
Level of interaction	Intrasystem regime-regime Intersystem niche-niche
Mode of interaction	Symbiosis Competition
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions Niche consolidation - build new networks of actors Niche consolidation - create learning process at multiple dimensions
Value-chain level of interaction	Focus on complementary technologies Focus on the main technology
Resources exchanged in the experiment	Capital Knowledge People

Category	Classification
Impact of transnational linkages on the experiment	Transnational linkages are present but do not influence de experiment

Source: Developed by the author based on ANEEL (2019p)

E.9 PD-00063-3059

This experiment was proposed by Companhia Paulista de Força e Luz (CPFL Paulista), a subsidiary of the group CPFL Energia, whose majority shareholder is the Chinese energy company State Grid Corporation of China (CPFL ENERGIA, 2021). The experiment's goal is to integrate EV charging stations with solar energy and energy storage technologies (ANEEL, 2019q). The energy storage system will be built with low-cost modular lead-carbon batteries, using Brazilian technology with a high recycling rate (95%). Moreover, two different systems will be developed using these batteries: one for use in highways and one for urban areas. A third energy storage system will also be developed, using second-life lithium-ion EV batteries (ANEEL, 2019q).

According to ANEEL (2019q), this experiment is original, has reasonable applicability and good relevance. The agency praised the fact that the proposed solar-powered EV charging station could be implemented in rural and remote areas with little or no access to electricity services but questioned its applicability (ANEEL, 2019q). ANEEL (2019q) indicated that the area required for the photovoltaic panels is too large.

The agency indicated that the planned costs of the experiment are not in accordance with SR&DP rules. CPFL Paulista intended to hire a company (Chine Eletric Power Research Institute) without an office in Brazil to be part of the experiment, what is not allowed (ANEEL, 2019q). In addition, ANEEL (2019q) required CPFL to better detail the costs related to the acquisition of second-life batteries and human resources. The estimated cost of the experiment is R$ 19,712,209.98 (ANEEL, 2019q).

Eight organizations are participating in the experiment. Four of them are subsidiaries of CPFL Energia: CPFL Paulista, Companhia Piratininga de Força e Luz (CPFL Piratininga), Companhia Luz e Força Santa Cruz (CPFL Santa Cruz), and RGE Sul Distribuidora de Energia (RGE Sul) (CPFL ENERGIA, 2021). These are all actors from the Distribution ST-regime.

The other four actors are: Acumuladores Moura (Moura), IATI, Instituto Edson Mororó Moura (ITEMM), and UFPE. Moura is a Brazilian company that produces battery for ICEVs. Recently, Moura has been developing ion-lithium batteries for EVs and energy storage applications (MOURA, 2021). Therefore, Moura can be considered part of both the Private car ST-regime and the battery and electric car niches.

IATI is an actor of the battery and electric car niches and the solar, wind, and biomass ST-regimes, as detailed in Section E.6. ITEMM is a research institute focused on solar energy and energy storage. It develops batteries for both EV and stationary applications (ITEMM, 2021). Thus, ITEMM can be considered part of the solar energy ST-regime and the battery and electric car niches. Regarding UFPE, it was not possible to identify what is its role in the experiment or which of its departments or research groups are involved. Therefore, it is difficult to classify UFPE role in this experiment.

Therefore, there are many are interactions in several different levels in this experiment: intrasystem niche-regime, intrasystem regime-regime, intersystem niche-regime, intersystem regime-regime, and intersystem niche-niche.

The interactions between ST-regimes and niches in this experiment have been characterized in previous sections (see Sections E.1 and E.2). The interaction between Solar, Wind, and Biomass ST-regimes is competition. The interaction of these ST-regimes with the Distribution ST-regime can be characterized as symbiosis. Besides, the interaction of the Solar, Wind, and Biomass ST-regimes with the electric car and battery niches is also symbiosis.

There is also symbiosis between the battery niche and the Distribution ST-regime. As detailed in previously (see Section E.6), battery can help mitigate renewable energies intermittency, which would improve the reliability and quality of the electricity distribution system reliability with high penetration of renewable energy, notably solar and wind (SARKAR et al., 2018; HEINE et al., 2019; DE SIQUEIRA; PENG, 2021). On the other hand, improvements in the electricity distribution system, will not benefit or inhibit the battery niche. Therefore, the mode of interaction between the Distribution ST-regime and the battery niche can be characterized as commensalism.

The interaction of all these regimes of the electricity ST-system with the Private car ST-regime can be characterized as neutralism. And the interaction between the Private car ST-regime and the electric car niche is competition.

The interaction between the battery niche and the Private car ST-regime could be considered ambiguous. Batteries are an important part of ICEV, and the Private car ST-regime can benefit from advances in this technology. On the other hand, the battery niche has as strong synergy with the electric car niche. Thus, advances in battery technology can either benefit or inhibit ICEV. This also happens on the other way. Battery technology can be both benefited by ICEVs or inhibited by them if they suppress the increase of EVs. Given this ambiguous relationship between this ST-regime and this niche, their interaction will be characterized as neutralism.

The main resources exchanged should be capital, knowledge, and people. Transnational linkages are present in the experiment, as CPFL Paulista is part of the State Grid Corporation of China holding. However, there is no indication that transnational linkages will be relevant in the experiment. The focus of the experiment is on complementary technologies of EVs, notably the charging system.

The experiment's impacts will probably be limited to niche consolidation, including articulating expectations and views, building networks of actors, and creating learning process. There is no indication that the experiment will contribute to destabilize the private car ST-regime. The characterization of the experiment is resumed in Table E.9.

Table E.9 – Characterization of experiment PD-00063-3059

Category	Classification
Actors involved	CPFL Paulista CPFL Piratininga CPFL Santa Cruz RGE Sul Moura IATI ITEMM UFPE
Start and end date	20/12/2019 – 19/12/2023
Level of interaction	Intrasystem niche-regime Intrasystem regime-regime Intersystem niche-regime Intersystem regime-regime Intersystem niche-niche
Mode of interaction	Competition Symbiosis

Category	Classification
	Neutralism Commensalism
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions Niche consolidation - build new networks of actors Niche consolidation - create learning process at multiple dimensions
Value-chain level of interaction	Focus on complementary technologies
Resources exchanged in the experiment	Capital Knowledge People
Impact of transnational linkages on the experiment	Transnational linkages are present but do not influence the experiment

Source: Developed by the author based on ANEEL (2019q)

E.10 PD-00063-3061

This experiment was also proposed by CPFL Paulista. The experiment objective is to evaluate the performance of EV batteries in second-life applications (ANEEL, 2019r). The experiment's scope includes: (i) developing different products based on second-life EV batteries, (ii) do laboratory tests in these products, (iii) propose viable business models to use second-life EV batteries, (iv) study of the necessary regulatory changes to enable the use of second-life EV batteries in the products developed during the experiment, and (v) create a methodology to evaluate the conditions of EV batteries.

ANEEL (2019r) evaluated that this proposal was original, had excellent applicability and reasonable relevance. The agency highlighted that the technologies, methods, and business models that will be developed in the experiment can be used in many different applications by several actors of the electricity ST-system, such as distributors and independent generators (ANEEL, 2019r). However, ANEEL (2019r) also acknowledged that these applications may take a long time to become viable because they depend on the dissemination of EVs. The electricity agency concluded that the experiments costs, R$ 7,241,954.37, were acceptable given the scope of the project (ANEEL, 2019r).

There are five actors involved in this experiment. Most of them are subsidiaries of CPFL Energia: CPFL Paulista, CPFL Piratininga, CPFL Santa Cruz (CPFL ENERGIA, 2021). As detailed in the previous section, all these companies are part of the Distribution ST-regime. The other two actors participating in the experiment are Fundação CPqD and BYD. The first is an actor of the consumption management niches and the second is part of the battery and electric car niches and the solar ST-regime (see Section E.6).

It is possible to identify interactions in five levels in this experiment: intrasystem niche-regime, intrasystem regime-regime, intrasystem niche-niche, intersystem niche-regime, and intersystem niche-niche.

The interactions between ST-regimes and niches in this experiment have been characterized in previous sections (see Sections E.1, E.2, E.6, and E.9). The interaction of the Solar ST-regimes with the Distribution ST-regime can be characterized as symbiosis. Besides, the interaction of these ST-regimes with the electric car niche is also symbiosis. There is symbiosis between the consumption management and the electric car niches too. The interaction of consumption management niche and the different ST-regimes of the electricity ST-system is characterized as competition. There is neutralism between the battery and consumption management niches. Finally, the mode of interaction of the between the battery niche and the Solar and Distribution ST-regimes is characterized as symbiosis and commensalism, respectively.

The main resources exchanged should be capital, knowledge, and people. Besides, there is no indication that transnational linkages will be relevant in the experiment, although they are present (see Section E.9). The focus of the experiment is on complementary technologies of EVs, in this case, applications for second-life EV batteries.

The experiment's impacts will probably be limited to niche consolidation, including articulating expectations and views, building networks of actors, and creating learning process. There is no indication that the experiment will contribute to destabilize the private car ST-regime. The characterization of the experiment is resumed in Table E.10.

Table E.10 – Characterization of experiment PD-00063-3061

Category	Classification
Actors involved	CPFL Paulista CPFL Piratininga

Category	Classification
	CPFL Santa Cruz Fundação CPqD BYD Brasil
Start and end date	20/12/2019 – 19/12/2022
Level of interaction	Intrasystem niche-regime Intrasystem regime-regime Intrasystem niche-niche Intersystem niche-regime Intersystem niche-niche
Mode of interaction	Competition Symbiosis Neutralism Commensalism
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions Niche consolidation - build new networks of actors Niche consolidation - create learning process at multiple dimensions
Value-chain level of interaction	Focus on complementary technologies
Resources exchanged in the experiment	Capital Knowledge People
Impact of transnational linkages on the experiment	Transnational linkages are present but do not influence the experiment

Source: Developed by the author based on ANEEL (2019r)

E.11 PD-00063-3062

This is another experiment proposed by CPFL Paulista. The experiment is a pilot study of the substation of 100% of CPFL Paulista ICEV fleet in Indaiatuba – São Paulo by EVs, including trucks and heavy duty vehicles (ANEEL, 2019s). The experiment also includes the installation of charging stations, implementation of an electromobility laboratory, and the local production of electric trucks. The aim of this experiment is to reduce the operational costs of CPFL Paulista vehicle fleet and develop a business model to manage electric fleets that can be replicated by other companies (ANEEL, 2019s).

ANEEL (2019s) evaluated that this proposal was original, had reasonable applicability and good relevance. The agency considered the participation of the bus and truck manufacturer Man Latin América Indústria e Comércio de Veículos (MAN) a positive point of the experiment (ANEEL, 2019s). According to ANEEL (2019s), this partnership may contribute to reduce the cost of EVs in Brazil.

The estimated cost of the experiment is R$ 34,025,601.74. Almost half of this cost is related to the purchase of six electric trucks, six small electric trucks, twelve heavy duty electric cars, seven electric cars and the installation of twenty-five charging stations (ANEEL, 2019s). ANEEL (2019s) evaluated that this cost is too high and recommended substituting only half of CPFL ICEV fleet in Indaiatuba to reduce the cost of the experiment. According to the electricity agency, substituting only half the fleet would be enough to achieve the experiment objective (ANEEL, 2019s).

Many of the organizations involved in PD-00063-3059 and PD-00063-3061 are also participating in this experiment: CPFL Paulista, CPFL Piratininga, CPFL Santa Cruz, and RGE Sul (CPFL ENERGIA, 2021). The other organizations are GESEL, Siemens, MAN, CIMATEC, and Fundação José Bonifácio (FUJB-UFRJ). As detailed in previous sections, CPFL Paulista, CPFL Piratininga, CPFL Santa Cruz, and RGE Sul are actors of the Distribution ST-regime, GESEL can be considered an actor of the electric car niche, Siemens is part of the Distribution and Transmission ST-regimes, and the electric car niche, and CIMATEC can be considered part of the electric car niche.

MAN is owned by the Traton group, whose majority shareholder is the Volkswagen Group (TRATON GROUP, 2021). MAN produces buses and trucks in Brazil. Therefore, it can be considered part of the bus ST-regime in the urban mobility ST-system. FUJB-UFRJ manages projects from GESEL and other research groups from UFRJ (FUJB-UFRJ, 2021), similarly to COPPETEC (see Section E.2). Therefore, it should not be considered as an actor of any ST-regime or niche of the electricity or urban mobility ST-systems.

The following levels of interaction are present in the experiment: intrasystem niche-regime, intrasystem regime-regime, intersystem niche-regime, and intersystem regime-regime.

As is the case in PD-00063-3059 and PD-00063-3061, the principal mode of interaction is symbiosis. The interaction of the Distribution and Transmission ST-regimes with each other and with the electric car niche can be characterized as symbiosis. Besides, there is a neutral interaction of these ST-regimes with the bus ST-regime. However, there is competition between the bus ST-regime and the electric car niche. Just as there is a competition between the Private car ST-regime with the bus ST-regime for the supply of mobility to society, there is this same competition between the bus ST-regime and the electric car niche.

The main resources exchanged should be capital, knowledge, and people. Besides, there is no indication that transnational linkages will be relevant in the experiment, although they are present (see Section E.9).

The value-chain level of interaction of this experiment is the main technology, i.e., the EVs. The experiment's impacts will probably be limited to niche consolidation, including articulating expectations and views, building networks of actors, and creating learning process. There is no indication that the experiment will contribute to destabilize the private car ST-regime. The characterization of the experiment is resumed in Table E.11.

Table E.11 – Characterization of experiment PD-00063-3062

Category	Classification
Actors involved	CPFL Paulista CPFL Piratininga CPFL Santa Cruz RGE Sul Siemens MAN CIMATEC FUJB-UFRJ
Start and end date	20/12/2019 – 19/12/2022
Level of interaction	Intrasystem niche-regime Intrasystem regime-regime Intersystem niche-regime

Category	Classification
	Intersystem niche-niche
Mode of interaction	Competition Symbiosis Neutralism
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions Niche consolidation - build new networks of actors Niche consolidation - create learning process at multiple dimensions
Value-chain level of interaction	Focus on the main technology
Resources exchanged in the experiment	Capital Knowledge People
Impact of transnational linkages on the experiment	Transnational linkages are present but do not influence the experiment

Source: Developed by the author based on ANEEL (2019s)

E.12 PD-00372-9985

This experiment was proposed by Centrais Elétricas do Norte do Brasil (Eletronorte), a subsidiary of the public company Centrais Elétricas Brasileiras (Eletrobras), whose majority owner is the Brazilian Federal Union (ELETRONORTE, 2020; ELETROBRAS, 2021). The experiment's main goal is to develop an EV-based virtual power plant (VPP)[89] (ANEEL, 2019t). The scope of the experiment comprises the installation of a 45-kW bi-directional EV charging station, a 20-kW photovoltaic energy generation unit, and a 10-kW hydrogen energy storage unit. Pickup trucks with larger battery packs than usual electric cars will be used in the experiment to study the economic viability of large storge units (ANEEL, 2019t). The estimated cost of the experiment is R$ 13,805,254.75 (ANEEL, 2019t).

[89] "A virtual power plant is a cluster of dispersed generator units, controllable loads and storages systems, aggregated in order to operate as a unique power plant" (LOMBARDI; POWALKO; RUDION, 2009, p. 1). An EV-based VPP employ V2G applications to integrate EVs as decentralized energy storage units in the VPP (WANG et al., 2020).

ANEEL (2019t) considered that this proposal was original, had good applicability and relevance. According to ANEEL (2019t), this experiment has the potential to positively impact all the stages of electricity chain (generation, transmission, distribution, and consumption). The experiment can transform the role of EVs in the electricity grid from mere consumers into a stabilizing element of the grid. Besides, it will create many new business models for companies of the electricity ST-system (ANEEL, 2019t).

However, ANEEL (2019t) has not approved the experiment's cost. Although the cost of R$ 13,805,254.75 was considered compatible with the scope of the project, the agency considered that the premises used in the economic viability study were not well detailed and justified. One of the main problems is the scenario considered for the expansion of the EV fleet in the next 10 years (ANEEL, 2019t).

Three actors are participating in the experiment: Eletronorte, Tracel, and the Pontifícia Universidade Católica do Rio de Janeiro (PUC Rio). Eletronorte is part of the Large hydroelectric, Thermoelectric, and Transmission ST-regimes (ELETRONORTE, 2020). Tracel is a company that develops solutions in solar energy, energy efficiency, micro hydroelectric generation, energy management, and electromobility (TRACEL, 2021). In the context of the experiment, it can be considered an actor of the distributed generation, energy efficiency, and electric car niches. PUC-Rio has several research groups and laboratories (PUC-RIO, 2021). However, it was not possible to identify what is its role in the experiment or which of its departments or research groups are involved. Therefore, it is difficult to classify PUC-Rio role in this experiment.

There are at least two levels of interaction in this experiment if Tracel is considered an actor of two ST-systems: intrasystem niche-regime and intersystem niche-regime.

Most interactions between ST-regimes and niches in this experiment have been characterized in previous sections (see Sections E.1, E.2, E.5 and E.6). The interaction of between Large hydroelectric and Thermoelectric ST-regimes is competition, and the interaction of these ST-regimes with the Transmission ST-regime is symbiosis. The interaction of the electric car niche with the Large hydroelectric and Transmission ST-regimes and with the Thermoelectric ST-regime is characterized as symbiosis and parasitism, respectively. The mode of interaction between the different ST-regimes of the electricity ST-system involved in this experiment and the energy efficiency niche is amensalism.

Finally, there is competition between the different ST-regimes of the electricity ST-system involved in this experiment and the distributed generation niche. This niche technology is in direct competition with centralized electricity generation to fulfill society need for electricity (FERREIRA et al., 2019). There is great synergy between the distributed generation and electric cars, as detailed by Singh and Dubey (2022). Thus, the interaction between these two niches can be characterized as symbiosis. Besides there are also clear synergies between distributed generation and energy efficiency (OLIVA, 2017).

The main resources exchanged should be capital, knowledge, and people. Eletronorte will be the main source of all these resources. Besides, there are no transnational linkages present in the experiment. The VPP that is the focus of the experiment is a complementary technology to EVs.

The experiment's impacts will probably be limited to niche consolidation, including articulating expectations and views, building networks of actors, and creating learning process. There is no indication that the experiment will contribute to destabilize the private car ST-regime. The characterization of the experiment is resumed in Table E.12.

Table E.12 – Characterization of experiment PD-00372-9985

Category	Classification
Actors involved	Eletronorte Tracel PUC-Rio
Start and end date	Not informed
Level of interaction	Intrasystem niche-regime Intersystem niche-regime
Mode of interaction	Competition Symbiosis Parasitism
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions Niche consolidation - build new networks of actors Niche consolidation - create learning process at multiple dimensions
Value-chain level of interaction	Focus on complementary technologies

Category	Classification
Resources exchanged in the experiment	Capital Knowledge People
Impact of transnational linkages on the experiment	Transnational linkages are not present

Source: Developed by the author based on ANEEL (2019t)

E.13 PD-00382-0123

This experiment was proposed by Light, a holding that owns several companies of the electricity ST-system, such as Light Energia, Light Conecta, and Light Com (LIGHT, 2021). The experiment's objective is to develop business models and technologies for EV sharing schemes and to evaluate the technical and economic impacts of the electrification of Lights' car fleet (ANEEL, 2019u). This experiment includes: (i) the installation of 10 EV charging stations in Rio de Janeiro, (ii) study the viability of implementing EV fast charging stations in electrical substations, and (iii) do a pilot test of an EV sharing system with 8 electric mini cars[90] and 8 electric cars. The estimated cost of the experiment is R$ 8,934,094.78 (ANEEL, 2019u).

ANEEL (2019u) considered that this proposal was original, and had good applicability and relevance. The agency affirmed that although carsharing schemes are not innovative, the implementation of an 'e-carsharing' can be considered an innovative solution (ANEEL, 2019u). Moreover, ANEEL (2019u) considered that this system has a great potential to be implemented in many Brazilian cities because carsharing is a global tendency[91]. However, the agency considered that the projection that the experiment will induce the growth of Rio de Janeiro EV fleet by 5,000 units in a short period is overly optimistic and should be reviewed(ANEEL, 2019u).

There are six actors involved in this experiment: Light, Guascor do Brasil, GESEL, Movida, CIMATEC, and COPPETEC. Light is an actor of several ST-regimes of the electricity ST-system: Distribution, Transmission, Trader, Large hydroelectric, and Small hydroelectric (LIGHT, 2021). As described in previous sections, GESEL can be considered part of the electric car niche, COPPETEC is not directly involved in any ST-

[90] Vehicles classified in EU category L.

[91] Note that this evaluation was made before the COVID-19 pandemic outbreak, which has considerably impacted carsharing.

regime and is only involved in the experiments to manage the resources that would be transferred to GESEL, and CIMATEC can be considered part of the electric car niche. Guascor, a subsidiary of Siemens, provides distributed generation solutions (SIEMENS, 2019). Therefore, it is an actor of the distributed generation niche. Movida is a car rental company (MOVIDA, 2021). It is an actor of the Private car ST-regime.

Therefore, there are interactions in four different levels in this experiment: intrasystem niche-regime, intersystem niche-regime, intersystem regime-regime, and intersystem niche-niche.

The interactions between ST-regimes and niches in this experiment have been characterized in previous sections (see Sections E.1, E.2, E.5, E.6, and E.12). The interaction of between Large hydroelectric and Small hydroelectric ST-regimes is competition. The interaction of these ST-regimes with the Distribution, Transmission, Trader ST-regimes is symbiosis. The interaction of the electric car niche with all the ST-regimes of the electricity ST-system involved in this experiment is also symbiosis. There is competition between these ST-regimes and the distributed generation niche, and symbiosis between this niche and the electric car niche. There is neutralism in the interaction of the Private car ST-regime with all the ST-regimes and niche of the electricity ST-system that are part of this experiment. Finally, the mode of interaction of the electric car niche with the Private car ST-regime is competition.

The main resources exchanged should be capital, knowledge, and people. There are no transnational linkages present in the experiment and The EV sharing schemes that is the focus of the experiment is a complementary technology to EVs.

The experiment’s impacts will probably be limited to niche consolidation, including articulating expectations and views, building networks of actors, and creating learning process. There is no indication that the experiment will contribute to destabilize the private car ST-regime. The characterization of the experiment is resumed in Table E.13.

Table E.13 – Characterization of experiment PD-00382-0123

Category	Classification
Actors involved	Light Guascor do Brasil GESEL Movida

Category	Classification
	CIMATEC COPPETEC
Start and end date	01/01/2020 – 31/01/2023
Level of interaction	Intrasystem niche-regime Intersystem niche-regime Intersystem regime-regime Intersystem niche-niche
Mode of interaction	Competition Symbiosis Neutralism
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions Niche consolidation - build new networks of actors Niche consolidation - create learning process at multiple dimensions
Value-chain level of interaction	Focus on complementary technologies
Resources exchanged in the experiment	Capital Knowledge People
Impact of transnational linkages on the experiment	Transnational linkages are not present

Source: Developed by the author based on ANEEL (2019u)

E.14 PD-00385-0069

This is another experiment proposed by a subsidiary of Neoenergia: Elektro (NEOENERGIA, 2021). The experiment aims to develop an electric truck to be used by Elektro in the maintenance of the electricity grid infrastructure (ANEEL, 2019v). This truck will be prepared for V2G applications and opportunity charging[92] in Elektro's

[92] Opportunity charging means to charge the EV at every opportunity. For example, it allows fast-charging a bus at a bus-stop while boarding the passengers. It significantly reduces the battery size requirements of the vehicle (GORMEZ; HAQUE; SOZER, 2021).

electricity grid infrastructure. This experiment includes the construction of two trucks and one charging station (ANEEL, 2019v).

ANEEL (2019v) considered that this proposal was original, and had good applicability and relevance. The agency highlighted the many challenges of this experiment, specially developing a system to allow the trucks to couple to the electricity grid for the opportunity charging. The agency also emphasized the relevant impact this vehicle can have on improving the maintenance of the electricity grid (ANEEL, 2019v). Moreover, ANEEL (2019v) indicated that this experiment should contribute to leverage technological advances within industries and research centers in Brazil. The estimate cost of the experiment is R$ 14,845,505.45. ANEEL (2019v) criticized many aspects of the estimated costs presented and requested many adjustments. For example, the agency considered that the spending on human resources was excessively high, as they represent almost 80% of the total cost.

There are six actors involved in this experiment. Most of them are subsidiaries of Neoenergia: Elektro, Coelba, Celpe, and Cosern (NEOENERGIA, 2021). All these companies are actors of the Distribution ST-regime (NEOENERGIA, 2021). The other two actors participating in the experiment are Lactec and BYD Brasil. Lactec is a research center that does several types of laboratory experiments in several different areas, including, electric equipment, water quality, high voltage, and GHG emissions. Regarding the electricity and the urban mobility ST-systems, they have participated experiments in electromobility, distributed generation, energy efficiency, smart grids, and energy storage (LACTEC, 2021). Therefore, Lactec can be considered part of the electric car, battery, energy efficiency, and distributed generation niches. As detailed in previous sections, BYD Brasil is an actor of the solar ST-regime and the battery and electric car niches.

It is possible to identify interactions in all levels, expect intersystem regime-regime.

Most interactions between ST-regimes and niches in this experiment have been characterized in previous sections (see Sections E.1, E.2, E.5, E.6, E.9, and E.12). The interaction between the Distribution and Solar ST-regimes, and the electric car niche is symbiosis. The mode of interaction of Distribution ST-regime with the energy efficiency and distributed generation niches is competition. This ST-regime interaction with the battery niche is characterized as commensalism. Besides, there is symbiosis between the Solar ST-regime, these niches (OLIVA, 2017), and the electric car niche.

The main resources exchanged should be capital, knowledge, and people. Transnational linkages are not directly present and do not influence the experiment, as all organizations participating in the experiment are Brazilian. The focus of the experiment is on the main technology, the electric trucks in this case. The experiment's impacts will probably be limited to niche consolidation, including articulating expectations and views, building networks of actors, and creating learning process. There is no indication that the experiment will contribute to destabilize the private car ST-regime. The characterization of the experiment is resumed in Table E.14.

Table E.14 – Characterization of experiment PD-00385-0069

Category	Classification
Actors involved	Elektro Cosern Celpe Coelba Lactec BYD Brasil
Start and end date	Not informed – Duration of 30 months
Level of interaction	Intrasystem niche-regime Intrasystem regime-regime Intrasystem niche-niche Intersystem niche-regime Intersystem niche-niche
Mode of interaction	Competition Symbiosis Commensalism
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions Niche consolidation - build new networks of actors Niche consolidation - create learning process at multiple dimensions

Category	Classification
Value-chain level of interaction	Focus on complementary technologies
Resources exchanged in the experiment	Capital Knowledge People
Impact of transnational linkages on the experiment	Transnational linkages are not present

Source: Developed by the author based on ANEEL (2019v)

E.15 PD-00553-0061

This experiment was proposed by Petróleo Brasileiro S.A. (Petrobras), a state-owned Brazilian oil and gas company (PETROBRAS, 2021). The experiment's objective is to do laboratory and field tests on batteries, EVs, and charging stations that have not been tested in Brazil. This experiment will allow the researchers to gather data on the use of EVs by Brazilian consumers (ANEEL, 2019w).

This is one of the most comprehensive and expensive experiments in SRDP-22, with an estimated cost of R$ 84,004,641.64 (ANEEL, 2019w). The scope of the experiment includes (ANEEL, 2019w): (i) building laboratories designed to test EV's batteries and charging stations, (ii) do tests of EV car-sharing schemes, (iii) develop a method do define the optimum place to install EV charging stations, (iv) test EV's efficiency and life cycle impacts in Brazil, and (v) develop a wireless mobile EV fast charger.

ANEEL (2019w) considered that this proposal was original, had good applicability and relevance. The agency praised several aspects of the experiment, notably the participation of many research institutions and car companies in the experiment, which can develop into an interesting innovation network (ANEEL, 2019w). Despite the praise, ANEEL questioned several points of the cost estimated presented by Petrobras. The agency found that many of the personnel expenses were above what would be reasonable given the scope of the project (ANEEL, 2019w).

There are seventeen actors involved in this experiment (see Table E.15). Petrobras is the 4th largest company in Brazil (REDAÇÃO, 2021) and the 17th largest energy company in the world (S&P GLOBAL, 2021). It is the main actor of the fossil fuels ST-system. In the electricity ST-system, Petrobras is the main actor of the Thermoelectric ST-regime, as it owns approximately 20% of the Brazilian thermoelectric generation capacity, which is three times more than the second largest thermoelectric generator agent (ANEEL, 2021). BR Distribuidora is Brazil's largest fossil fuels distributor and is partly owned (37.5%) by Petrobras (BR DISTRIBUIDORA, 2020). It is an important actor of the fossil fuels ST-system and Private car ST-regime, given the relevance of the gas stations to the functioning of this regime.

Engie Brasil Energia (Engie Brasil), the largest private electricity producer of Brazil, is a subsidiary of the French company Engie (ENGIE BRASIL, 2021), which is one of the world largest electric utilities companies (MURPHY et al., 2021). Engie Brasil is part of many ST-regimes of the electricity ST-system: Wind, Large hydroelectric, Thermoelectric, Solar, Biomass, and Transmission (ENGIE BRASIL, 2021). Companhia Energética Estreito is a subsidiary of Engie Brasil and owns 40% of the Consórcio Estreito Energia (CESTE), which operates the hydroelectric Estreito, one of the largest in Brazil. Therefore, Companhia Energética Estreito is an actor of the Large hydroelectric ST-regime. Cofely do Brasil Serviços de Energia (Cofely) is also a subsidiary of Engie Brasil. Cofely provides energy efficiency solutions (ENGIE BRASIL, 2021). Cofely can be considered part of the energy efficiency niche.

Several research institutions are part of the experiment: Fundação CPqD, Lactec, Universidade Tecnológica Federal do Paraná (UTFPR), Unicamp, and Universidade Federal de Santa Catarina (UFSC). As detailed in previous sections, Fundação CPqD can be considered an actor of the consumption management niche, and Lactec is part of the electric car, battery, energy efficiency, and distributed generation niches. It was not possible to identify the role of the universities in this experiment.

Three companies of the private car ST-regime are participating in the experiment: the Brazilian subsidiaries of Toyota Motor Corp, Nissan Motor Corp, and Groupe Renault. Besides, Mobilis, an actor of the electric car niche (see Table C.1), is also part of the experiment.

Finally, there are three other companies involved in the experiment: ABB, iDevices Tecnologia, and Sollus Indústria Eletrônica (Sollus). As detailed in section E.2, ABB is an actor of the Distribution and Transmission ST-regimes, and the electric car niche. iDevices Tecnologia is part of the battery niche (IDEVICES TECNOLOGIA, 2021). Sollus a company that produces LED lamps, but has started investing in EV charging stations through the company Incharge (SOLLUS, 2021). Therefore, it can be considered part of the electric car niche.

The high and diverse number of participants means that there are interactions between regimes and niches in all levels in this experiment.

Besides, all possible modes of interactions between ST-regimes and niches are present in this experiment. Many of these modes have been characterized in previous sections (see Sections E.1, E.2, E.5, E.6, E.9, and E.12). The mode of interaction between the Wind, Large hydroelectric, Thermoelectric, Solar, Biomass ST-regimes is competition. The interaction between these ST-regimes and the Distribution and Transmission ST-regimes is characterized as symbiosis. Besides, these ST-regimes interaction with the energy efficiency niche can be considered amensalism.

The mode of interaction between the different ST-regimes of the electricity ST-system and the consumption management and distributed generation niches is competition. However, there are great synergy between the distributed generation and the Solar ST-regime, as this niche is mostly based on photovoltaic electricity generation. Thus, in this case, the mode of interaction is symbiosis. Besides, there is commensalism between the Distribution and Transmission ST-regimes and the battery niche.

There is neutralism in the interaction of the Private car ST-regime with all the ST-regimes and niche of the electricity ST-system that are part of this experiment. Regarding the electric car, there is symbiosis with most of the ST-regimes of the electricity ST-system. The exception, in this case, is the Thermoelectric ST-regime, as the mode of interaction between this ST-regime and the electric car niche is parasitism. And there also is symbiosis with the distributed generation, energy efficiency, and consumption management niches. There is a competition between the electric car niche and Private car ST-regime. Moreover, there is also clear competition between the electric car niche and the whole fossil fuels ST-system.

Finally, there is symbiosis between the energy efficiency, distributed generation, and battery niches. The mode of interaction between the consumption management and the battery niches is neutralism. Besides, many studies show that there is great synergy between consumption management and energy efficiency technologies (ALONSO et al., 2013; OPREA; BÂRA; REVEIU, 2018; HASAN; TRIANNI, 2020), thus the mode of interaction between these two niches can be considered symbiosis. Moreover, consumption management technologies are important for distributed generation to work properly (PAVIČIĆ; ŽUPAN; CAZIN, 2018), so the interaction between these two niche can also be considered symbiosis.

The main resources exchanged should be capital, knowledge, and people. It is also expected some level of technology exchange. Although many of the actors are part of multinational holdings, transnational linkages will have only a limited impact in the experiment: the electric cars used will be imported. Given the experiment's broad scope, it focuses on technologies in all levels of the value-chain: component (batteries), complement (EV charging stations) and focal (EVs).

The experiment's impacts will probably be limited to niche consolidation, including articulating expectations and views, building networks of actors, and creating learning process. There is no indication that the experiment will contribute to destabilize the private car ST-regime. The characterization of the experiment is resumed in Table E.15.

Table E.15 – Characterization of experiment PD-00553-0061

Category	Classification
Actors involved	Petrobras BR Distribuidora Engie Brasil Companhia Energética Estreito Cofely Fundação CPqD Lactec UTFPR Unicamp UFPR Toyota do Brasil Nissan do Brasil Renault do Brasil Mobilis ABB Sollus iDevices Tecnologia

Category	Classification
Start and end date	19/12/2019 – 19/12/2023
Level of interaction	Intrasystem niche-regime Intrasystem regime-regime Intrasystem niche-niche Intersystem niche-regime Intersystem regime-regime Intersystem niche-niche
Mode of interaction	Competition Symbiosis Neutralism Parasitism Commensalism Amensalism
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions Niche consolidation - build new networks of actors Niche consolidation - create learning process at multiple dimensions
Value-chain level of interaction	Focus on complementary technologies Focus on component technologies Focus on the main technology
Resources exchanged in the experiment	Capital Knowledge Technology People
Impact of transnational linkages on the experiment	Transnational linkages are present and influence the experiment

Source: Developed by the author based on ANEEL (2019w)

E.16 PD-00673-0021

This is another experiment proposed by a subsidiary of EDP Brasil: Lageado Energia. The experiment's objective is to develop a scalable system of smart infrastructure to the charge of electric buses (ANEEL, 2019x). The idea of the experiment's proponents is to design a system that can be adopted by local, intercity, and interstate bus companies, and possibly also by companies that have fleets of trucks. The experiment includes the installation of at least four electric bus charging stations. The estimated cost of the experiment is R$ 6,596,625.27 (ANEEL, 2019x).

ANEEL (2019x) considered that this proposal was original, had good applicability and relevance, and its costs were compatible with the scope of the project. According to the agency', the experiment has great potential because the bus fleet in operation in Brazil exceeds 500 thousand units (ANEEL, 2019x).

There are eight actors involved in this experiment. Five of them are subsidiaries of EDP Brasil: Lageado Energia (Large hydroelectric ST-regime), EDP São Paulo and EDP Espírito Santo (Distribution ST-regime), Porto de Pecém Geração de Energia (Thermoelectric ST-regime), and EDP Grid (Trade ST-regime) (EDP BRASIL, 2021).

WEG is also participating. It is a company that produces equipment to several different applications including, electricity generation, transmission, and distribution, solar energy, electromobility (electric motors, powertrains, EV chargers, and electric traction systems), energy efficiency, and smart grids (WEG, 2021). In the context of the SRDP-22, WEG has a role like that of ABB and Siemens. Thus, WEG can be considered an actor of the Distribution and Transmission ST-regimes, and the electric car niche.

The other two organizations taking part in the experiment are Fundação Centros de Referência em Tecnologias Inovadoras (CERTI) and VIX. CERTI is an R&D institution that does research in artificial intelligence, microelectronics, bioeconomy, smart grid, electric mobility, among others (CERTI, 2021). Thus, CERTI can be considered part of the electric car niche. VIX Logística is a logistic company that is part of the Grupo Águia Branca, which is one of the largest transport and logistics business conglomerates in Brazil (GRUPO ÁGUIA BRANCA, 2021; VIX LOGÍSTICA, 2022). In this experiment, it can be considered an actor of the bus ST-regime, as it will be the company responsible for the purchase and operation of the electric buses.

There are interactions in four different levels in this experiment: intrasystem niche-regime, intrasystem regime-regime, intersystem niche-regime, and intersystem regime-regime.

All the modes of interactions between ST-regimes and niches in this experiment have been characterized in previous sections (see Sections E.1, E.2, E.5, E.6, E.12, and E.15). The mode of interaction between the Large hydroelectric and Thermoelectric ST-regimes is competition. The interaction between these ST-regimes and the Distribution, Transmission, and Trader ST-regimes is characterized as symbiosis. The interaction of these ST-regimes with the electric car niche is characterized as symbiosis, except for the Thermoelectric ST-regime. In this case the mode of interaction with the electric car niche is parasitism. There is neutralism between the ST-regimes and niches of the electricity ST-system and the bus ST-regime and competition between this ST-regime and the electric car niche.

The main resources exchanged should be capital, knowledge, and people. Besides, there is no indication that transnational linkages will be relevant in the experiment, although they are present (see Section E.2). The focus of the experiment is on complementary technologies of EVs, in this case, a system for the charging electric buses.

The experiment's impacts will probably be limited to niche consolidation, including articulating expectations and views, building networks of actors, and creating learning process. There is no indication that the experiment will contribute to destabilize the private car ST-regime. The characterization of the experiment is resumed in Table E.16.

Table E.16 – Characterization of experiment PD-00673-0021

Category	Classification
Actors involved	Lajeado Energia EDP Espírito Santo Porto do Pecém Geração de Energia EDP São paulo EDP Grid Siemens CERTI Viação Águia Branca

Category	Classification
Start and end date	01/01/2020 – 31/01/2023
Level of interaction	Intrasystem niche-regime Intrasystem regime-regime Intersystem niche-regime Intersystem regime-regime
Mode of interaction	Competition Symbiosis Neutralism
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions Niche consolidation - build new networks of actors Niche consolidation - create learning process at multiple dimensions
Value-chain level of interaction	Focus on complementary technologies
Resources exchanged in the experiment	Capital Knowledge People
Impact of transnational linkages on the experiment	Transnational linkages are present but do not influence the experiment

Source: Developed by the author based on ANEEL (2019x)

E.17 PD-00678-0001

This experiment was proposed by EDF Norte Fluminense, a subsidiary of EDF, a multinational company incorporated in France (EDF NORTE FLUMINENSE, 2020). The experiment's goal is to improve the MagLev Cobra, a superconducting magnetic levitation urban train prototype, currently being developed at the Laboratório de Aplicações de Supercondutores (Superconductor Applications Laboratory - LASUP) from UFRJ (ANEEL, 2019y). The estimated cost of the experiment is R$ 20,335,605.23 (ANEEL, 2019y).

The experiment includes (ANEEL, 2019y): (i) improving the wagons used in the MagLev, (ii) developing a new electric motor to the prototype, (iii) evaluating the impact of the MagLev in the electricity grid, (iv) studying the environmental impacts caused by the MagLev and how they can be reduced. The focus of the improvements in the prototype is overcoming its current restrictions to allow the scalability of this mode of transportation.

ANEEL (2019y) considered that this proposal was original, had good applicability and relevance, and its costs were compatible with the scope of the project. The agency highlighted that the experiment can provide a new option for public transportation in Brazil (ANEEL, 2019y). Nonetheless, ANEEL (2019y) also stated that there is a non-negligible risk that unforeseen events make this solution economically unfeasible. Moreover, ANEEL (2019y) requested a better detailing of the economic feasibility study because of all the uncertainties involved. The agency also suggested that it is necessary the participation of industrial actors in the experiment. Only energy companies and research institutions are involved in the experiment (ANEEL, 2019y).

Eleven organizations are participating in the experiment. Only one of them, COPPETEC, cannot be considered part of the electricity ST-system. As was the case in the experiment PD-00391-0039, COPPETEC is only involved in the experiment to allow the participation of LASUP. This laboratory research is focused on superconductors, which include the MagLev (LASUP, 2021). LASUP can be considered part of its own niche, i.e., the MagLev niche in the urban mobility ST-system because this technology could, in the future, challenge many of the existing ST-regimes in this system (e.g., metro and bus ST-regime).

Considering the other organizations in the experiment, the main proponent, EDF Norte Fluminense, can be considered an actor of the Thermoelectric and Large hydroelectric ST-regimes. The company owns a thermoelectric power plant in Rio de Janeiro and a large hydroelectric[93] in Mato Grosso (EDF NORTE FLUMINENSE, 2020).

Five of the companies are actors of the Large hydroelectric ST-regime: Rio Verde Energia, Foz do Chapecó Energia, Energética Barra Grande (Baesa), Serra do Facão Energia, and Companhia Energética de São Paulo (CESP). Rio Verde Energia operates the Salto hydroelectric power plant and is a subsidiary of CTG Brasil (CTG BRASIL, 2020). Foz do Chapecó Energia operates the Foz do Chapecó hydroelectric power plant and is owned by CPFL Energia, Furnas, and CEEE (FOZ DO CHAPECÓ ENERGIA,

[93] EDF Norte Fluminense owns 51% of the Sinop Energia, which operates the Sinop hydroelectric power plant. Eletronorte (24.5%) and Chesf (24.5%) are the other owners of Sinop Energia (EDF NORTE FLUMINENSE, 2020).

2021). Baesa operates the Barra Grande hydroelectric power plant and is owned by Alcoa Alumínio, CPFL Energia, CBA Energia, Barra Grande Participações, and DMEE (BAESA, 2021). Serra do Facão Energia operates the Serra do Falcão hydroelectric power plant and is owned by Alcoa Alumínio, Furnas, DMEE, and Camargo Corrêa Energia (FURNAS, 2021). CESP operates three hydroelectric power plants in the state of São Paulo and is owned by joint venture between Grupo Votorantim and Canada Pension Plan Investment Board (CPPIB) (CESP, 2021).

Three of the companies involved in the experiment are subsidiaries of the Brazilian energy group Global Participações em Energia (GPE): Companhia Energética Candeias (CEC), Companhia Energética Manauara (CEM), and Companhia Energética Potiguar (CEP) (GPE, 2020). CEC operates the thermoelectric power plants Global I and Global II, CEM operates the thermoelectric power plants Potiguar and Potiguar III, and CEM operates the thermoelectric power plant Manauara. Therefore, all these companies are actors of the Thermoelectric ST-regime.

Finally, Jordão Consultoria e Projetos is a consulting firm specialized in managing R&D projects for companies of the electricity ST-system. In this experiment, the company has the role of managing the experiment and being the link between all the actors involved. Therefore, Jordão Consultoria e Projetos should not be considered part of any specific ST-regime or niche, only part of the electricity ST-system.

Therefore, there are only two levels of interaction in the experiment, intrasystem regime-regime, intersystem niche-regime, because most of the organizations participating are ST-regime actors from the electricity ST-system.

Despite the great number of actors in this experiment, there are only two modes of interaction, as most of the actors are from the same ST-regime or niche. Most of these modes of interactions between have been characterized in previous sections (see Sections E.1, E.2, E.5, E.6, E.12, and E.15). There is competition between the Large hydroelectric and Thermoelectric ST-regimes. Besides, there is neutralism between the MagLev niche and these ST-regimes. Neither of them is benefited or inhibited by their interaction with each other.

The main resources exchanged should be capital, knowledge, and people. Transnational linkages are present, but they will not be relevant in the experiment. Besides, the focus of the experiment is on EVs, in this case the MagLev.

The experiment's impacts will probably be limited to niche consolidation, including articulating expectations and views, building networks of actors, and creating learning process. There is no indication that the experiment will contribute to destabilize the private car ST-regime. The characterization of the experiment is resumed in Table E.17.

Table E.17 – Characterization of experiment PD-00678-0001

Category	Classification
Actors involved	EDF Norte Fluminense Rio Verde Energia Foz do Chapecó Energia Baesa Serra do Facão Energia CESP CEC CEM CEP COPPETEC / LASUP Jordão Consultoria e Projetos
Start and end date	Not informed – Duration of 36 months
Level of interaction	Intrasystem regime-regime Intersystem niche-regime
Mode of interaction	Competition Neutralism
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions Niche consolidation - build new networks of actors Niche consolidation - create learning process at multiple dimensions
Value-chain level of interaction	Focus on the main technology
Resources exchanged in the experiment	Capital Knowledge People

Category	Classification
Impact of transnational linkages on the experiment	Transnational linkages are present but do not influence the experiment

Source: Developed by the author based on ANEEL (2019y)

E.18 PD-02866-0518

This is another experiment proposed by COPEL Distribuição. The experiment main goal is to develop a system to manage payments of EV charging operations (ANEEL, 2019z). The experiment also involves studying how different types of payment systems for charging EV can impact user’s behavior when charging and, consequently, the electricity grid. The system will be implemented and test in the existing EV charging stations at the BR-277 highway, which were installed by COPEL Distribuição and Itaipu Binacional (BOMBIERI, 2021). The estimated cost of the experiment is R$ 7,446,261.87 (ANEEL, 2019z).

ANEEL (2019z) considered that this proposal was original, had good applicability and relevance, and its costs were compatible with the scope of the project. The agency did not highlight any particular characteristic of the experiment (ANEEL, 2019z).

The experiment has the involvement of four actors from the electricity ST-system: COPEL Distribuição, Lactec, XPERT Empreendimentos Eletrônicos, and EIDEE. As defined in the previous section, COPEL is an actor of the Distribution ST-regime, Lactec can be considered part of the electric car, battery, energy efficiency, and distributed generation niches, and EIDEE can be considered an actor of the electric car niche. XPERT develops managing systems for gas stations and fuel transport fleets (XPERT, 2021). This company is part of the fossil fuel ST-system but can also be considered part of the Private car ST-regime, due to its focus on gas stations.

There are niche and ST-regime actors from both the electricity and the urban mobility ST-systems involved in the experiment. Therefore, there are interactions in four levels: all the kinds of intersystem interaction plus niche-regime intrasystem.

All of the modes of interactions in this experiment have been characterized in previous sections (see Sections E.1, E.2, E.5, E.6, E.12, and E.15). There is symbiosis between the electric car niche and Distribution ST-regime. The mode of interaction of Distribution ST-regime with the energy efficiency and distributed generation niches is competition. And the interaction between this ST-regime and the battery niche can be characterized as commensalism. There is symbiosis between the energy efficiency, distributed generation niches and battery niches. Finally, there is competition between the Private car ST-regime and the electric car niche and neutralism between this ST-regime and the niches of the electricity ST-system.

The experiment's impacts will probably be limited to niche consolidation, including articulating expectations and views, building networks of actors, and creating learning process. There is no indication that the experiment will contribute to destabilize the private car ST-regime. The characterization of the experiment is resumed in Table E.18.

Table E.18 – Characterization of experiment PD-02866-0518

Category	Classification
Actors involved	COPEL Distribuição Lactec XPERT EIDEE
Start and end date	01/11/2019 – 01/11/2022
Level of interaction	Intrasystem niche-regime Intersystem niche-niche Intersystem regime-niche Intersystem regime-regime
Mode of interaction	Competition Symbiosis Neutralism Commensalism
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions Niche consolidation - build new networks of actors Niche consolidation - create learning process at multiple dimensions
Value-chain level of interaction	Focus on complementary technologies
Resources exchanged in the experiment	Capital Knowledge

Category	Classification
	People
Impact of transnational linkages on the experiment	Transnational linkages are not present

Source: Developed by the author based on ANEEL (2019z)

E.19 PD-04950-0724

This experiment was proposed by CEMIG Distribuição (CEMIG D), a subsidiary of the public company Companhia Energética de Minas Gerais (CEMIG), whose majority shareholder is the Minas Gerais state government (CEMIG, 2021). The experiment's goal is to develop a system of opportunity charging for BRT (ANEEL, 2019aa). A prototype of the system will be developed and tested using smaller vehicles, i.e., electric minibuses[94]. The vehicles will have an energy storage system that combines batteries and ultracapacitors and will be capable of opportunity charging and DC fast charging (ANEEL, 2019aa).

The scope of the experiment also includes (ANEEL, 2019aa): (i) building three prototypes of the electric minibus by adapting IVECO's internal combustion engine minibus, (ii) developing an EV DC fast charging station optimized for opportunity charging, (iii) optimizing the hybrid battery-ultracapacitor storage system based on the national technology available, and (iv) studying the impact of the introduction of this technology in Belo Horizonte's public transport system. Besides, the experiment encompasses the installation of a 'pilot bus line', with five DC fast charging stations, on the University of Minas Gerais (UFMG) campus in Belo Horizonte, where the EV will be tested (ANEEL, 2019aa). The estimated cost of the experiment is R$ 12,432,255.33 (ANEEL, 2019aa).

According to ANEEL (2019aa), this experiment is original, has reasonable applicability and good relevance. The agency highlighted that the use of national technology increases the possibilities of developing innovations that can be patented. Nonetheless, ANEEL (2019aa) asked CEMIG Distribuição to carry out a comprehensive economic evaluation of the electric minibus, comparing it with existing technologies, especially the BRT.

Six organizations are participating in the experiment. Two of them are subsidiaries of CEMIG: CEMIG D and CEMIG Geração e Transmissão (CEMIG GT) (CEMIG,

[94] Vehicle classified in EU category M2.

2021). CEMIG D is an actor of the Distribution ST-regime and CEMIG GT is part of the Transmission, Large hydroelectric and Small hydroelectric ST-regimes.

The other four are: CNH Industrial Brasil, Nansen, Concert Technologies, and UFMG. CNH Industrial Brasil is a subsidiary of the Dutch multinational corporation CNH Industrial. CNH Industrial Brasil is the owner of IVECO Brasil, which produces medium and heavy commercial vehicles, buses, and trucks (CNH INDUSTRIAL, 2021). Thus, CNH Industrial Brasil can be considered part or the bus ST-regime. Nansen produces electricity meters and EV charging stations (NANSEN, 2021). In 2019, Nansen became part of the Chinese group Sanxing Electric Co. (NANSEN, 2019). Nansen can be considered part of both the Distribution ST-regime and the electric car niche. Concert Technologies develops technologies for the operation of the electricity grid, mainly to electricity distribution companies (CONCERT TECHNOLOGIES, 2021). Thus, Concert Technologies can be considered an actor to the Distribution ST-regime.

UFMG will provide the location for testing the opportunity charging system and vehicle prototypes used in the experiment. Besides, UFMG Tesla Laboratory will also participate of the project (UFMG, 2019). This laboratory belongs to UFMG’s Department of Electrical Engineering and does research in many areas, including electromobility (UFMG, 2021). Thus, UFMG can be considered an actor of the electric car niche in this experiment.

Therefore, there are interactions in several different levels in this experiment: intrasystem niche-regime, intrasystem regime-regime, intersystem niche-regime, and intersystem regime-regime.

All of the modes of interactions in this experiment have been characterized in previous sections (see Sections E.1, E.2, E.5, E.6, E.12, E.15, and E.16). The mode of interaction between the Large hydroelectric and Small hydroelectric ST-regimes is competition. There is symbiosis between these ST-regimes and the Distribution and Transmission ST-regimes. There is symbiosis between the electric car niche all the ST-regime of the electricity ST-system involved in this experiment. Finally, there is neutralism between the ST-regimes of the electricity ST-system and the bus ST-regime and competition between this ST-regime and the electric car niche.

The main resources exchanged should be capital, knowledge, technology, and people. Transnational linkages are present in the experiment, as some actors are part of multinational groups. However, there is no indication that transnational linkages will be relevant in the experiment. The focus of the experiment is on the EV, in this case buses.

The experiment's impacts will probably be limited to niche consolidation, including articulating expectations and views, building networks of actors, and creating learning process. There is no indication that the experiment will contribute to destabilize the private car ST-regime. The characterization of the experiment is resumed in Table E.19.

Table E.19 – Characterization of experiment PD-04950-0724

Category	Classification
Actors involved	CEMIG D CEMIG GT CNH Industrial Brasil Nansen Concert Technologies UFMG
Start and end date	Not informed
Level of interaction	Intrasystem niche-regime Intrasystem regime-regime Intersystem niche-regime Intersystem regime-regime
Mode of interaction	Competition Symbiosis Neutralism
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions Niche consolidation - build new networks of actors Niche consolidation - create learning process at multiple dimensions
Value-chain level of interaction	Focus on the main technology
Resources exchanged in the experiment	Capital Knowledge Technology People

Category	Classification
Impact of transnational linkages on the experiment	Transnational linkages are present but do not influence the experiment

Source: Developed by the author based on ANEEL (2019aa)

E.20 PD-04950-0725

This experiment was also proposed by CEMIG D. The experiment's objective is to implement and monitor an EV charging system. The scope of the experiment also includes the installation of photovoltaic energy generation systems in some of the charging stations, development of software to manage the communication between the charging station and the utility company and between the charging station and the users and study of the impact of the EV charging system in the electricity grid (ANEEL, 2019ab). The estimated cost of the experiment is R$ 4,296,269.07 (ANEEL, 2019ab).

ANEEL (2019ab) considered that this proposal was original, had good applicability and relevance. The agency praised the software that will allow users to access their electricity consumption history, find the nearest charging station and buy electricity at reduced prices. (ANEEL, 2019ab). However, ANEEL (2019ab) criticized the business plan and the economic feasibility study presented. The agency asked CEMIG to present more detailed versions of these documents, clearly indicating the benefits of the system that will be developed and the premise used in the feasibility study (ANEEL, 2019ab).

The experiment has the involvement of four organizations: CEMIG D, CEMIG GT, Fundação de Apoio à Cultura, Ensino, Pesquisa e Extensão de Alfenas (FACEPE), and Universidade Federal de Alfenas (UNIFAL). As detailed in the previous section, CEMIG D is an actor of the Distribution ST-regime and CEMIG GT is part of the Transmission, Large hydroelectric and Small hydroelectric ST-regimes.

FACEPE is a public institution that helps UNIFAL develop its activities, notably research and social projects. Thus, FACEPE is only involved in the experiment to manage the resources that would be transferred to UNIFAL. Besides, FACEPE is not directly involved in any ST-regime. Regarding UNIFAL, it is the Laboratório Aplicado de Pesquisas em Eficiência Energética (Applied Laboratory for Research in Energy Efficiency - LAPEE) of the university that is participating in the experiment (BELISSA, 2019). LAPEE research focus is energy efficiency, but it also research EV's charging systems (UNIFAL, 2021). Thus, UNIFAL can be considered part of the energy efficiency and electric car niches.

There are interactions in only two levels: regime-regime intrasystem and niche-regime intersystem.

All of the modes of interactions in this experiment have been characterized in previous sections (see Sections E.1, E.2, E.5, E.6, E.12, E.15, and E.16). The mode of interaction between the Large hydroelectric and Small hydroelectric ST-regimes is competition. There is symbiosis between these ST-regimes and the Distribution and Transmission ST-regimes. There is symbiosis between the electric car niche all the ST-regime of the electricity ST-system involved in this experiment. Finally, these ST-regimes interaction with the energy efficiency niche can be considered amensalism.

The main resources exchanged should be capital, knowledge, and people. Besides, there are no transnational linkages present in the experiment. The EV charging system that is the focus of the experiment is a complementary technology to EVs

The experiment's impacts will probably be limited to niche consolidation, including articulating expectations and views, building networks of actors, and creating learning process. There is no indication that the experiment will contribute to destabilize the private car ST-regime. The characterization of the experiment is resumed in Table E.20.

Table E.20 – Characterization of experiment PD-04950-0725

Category	Classification
Actors involved	CEMIG D CEMIG GT FACEPE UNIFAL
Start and end date	Not informed
Level of interaction	Intrasystem regime-regime Intersystem niche-regime
Mode of interaction	Competition Symbiosis Amensalism
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions Niche consolidation - build new networks of actors

Category	Classification
	Niche consolidation - create learning process at multiple dimensions
Value-chain level of interaction	Focus on complementary technologies
Resources exchanged in the experiment	Capital Knowledge People
Impact of transnational linkages on the experiment	Transnational linkages are not present

Source: Developed by the author based on ANEEL (2019ab)

E.21 PD-04951-0726

This experiment was also proposed by a subsidiary of CEMIG: CEMIG GT (CEMIG, 2021). The experiment aims to develop a prototype of hybrid propulsion system that combines an electric powertrain with an internal combustion engine that can be fueled with LPG, ethanol, biomethane, and petrol (ANEEL, 2019ac; CEMIG, 2020). The scope of the experiment also includes (ANEEL, 2019ac): (i) developing a photovoltaic electric power generation system to be installed on the roof of the car, (ii) studying the viability of using Li-S batteries in the car's energy storage system, (iii) developing a model to predict the car performance, energy consumption, and energy efficiency with any of the possible fuel configurations, and (iv) developing in-wheel motors to be installed in the car's wheels. The estimated cost of the experiment is R$ 13,115,965.53 (ANEEL, 2019ac).

ANEEL (2019ac) evaluated that this proposal was original, had good applicability and was reasonably relevant. The agency understands that there is demand in the Brazilian market for a hybrid EV, combining plug-in technology with biofuels (ANEEL, 2019ac). Besides, ANEEL (2019ac) understands that this experiment has a high potential for the developing innovations that can give origin to patents and scientific publications. Nonetheless, the agency affirmed that the limited infrastructure of the experiment, only one vehicle and three charging stations, may limit the experiment's results (ANEEL, 2019ac). Besides, ANEEL (2019ac) criticized the estimated costs presented by CEMIG GT, specially the high expected consumption of fossil fuels during the experiment (37.500 liters).

There are seven actors involved in this experiment. Four of them are subsidiaries of CEMIG: CEMIG D, CEMIG GT, Efficientia, and Companhia de Gás de Minas Gerais (GASMIG) (CEMIG, 2020, 2021). As detailed in Section E.19, CEMIG D is an actor of the Distribution ST-regime and CEMIG GT is part of the Transmission, Large hydroelectric and Small hydroelectric ST-regimes. Efficientia was merged with CEMIG Geração Distribuída (CEMIG GD) to create CEMIG Soluções Inteligentes em Energia (CEMIG SIM) in 2019. CEMIG SIM offers distributed solar energy and energy efficiency solutions (CEMIG, 2020). It can be considered an actor of the energy efficiency and distributed generation niches. GASMIG is the exclusive distributor of piped natural gas throughout the state of Minas Gerais (CEMIG, 2021). It will provide the LPG and biomethane that will be used in the experiment (UFMG, 2019). It is an actor of the fossil fuel ST-system, but could also be considered part of the thermoelectric ST-regime, as it supplies natural gas to some thermoelectric power plants in Minas Gerais (CEMIG, 2021).

The other organizations involved in the experiment are: UFMG, SMC, and Fiat Chrysler Automóveis Brasil (FCA Brasil). Tesla Laboratory and the Laboratório de Análise da Combustão e Motores (Laboratory of Combustion and Engine Analysis) are the sections of UFMG participating in the experiment (UFMG, 2019). Tesla Laboratory is an actor of the electric car niche (this laboratory research has been detailed in Section E.19). The Laboratório de Análise da Combustão e Motores will develop the 'tetrafuel' internal combustion engine that will be used in the experiment. This laboratory can be considered part of the Private car ST-regime, due to its research focus on internal combustion engines. Therefore, in this experiment, UFMG can be considered part of the electric car niche and the Private car ST-regime.

As detailed in Section E.8, SMC is the entity that manages PUC Minas, which is the organization involved in the experiment. Three laboratories of PUC Minas are participating in the experiment. These laboratories conduct research on dynamic testing, GHG emissions and solar energy (UFMG, 2019). Thus, in this experiment, PUC Minas can be considered an actor of the private car and Solar ST-regimes. Finally, FCA Brasil is a subsidiary of the multinational Stellantis (STELLANTIS, 2021). It is one of the main actors of the Private car ST-regime.

It is possible to identify interactions in four levels in this experiment: intrasystem niche-regime, intrasystem regime-regime, intersystem niche-regime, and intersystem regime-regime.

Moreover, there are many modes of interactions in this experiment, which have been characterized in previous sections (see Sections E.1, E.2, E.5, E.6, E.12, E.15, and E.16). The mode of interaction between the Large hydroelectric, Small hydroelectric, Thermoelectric, and Solar ST-regimes is competition. There is symbiosis between these ST-regimes and the Distribution and Transmission ST-regimes. The mode of interaction of these ST-regimes with the electric car niche is characterized as symbiosis, except for the Thermoelectric ST-regime. In this case the mode of interaction with the electric car niche is parasitism.

There is amensalism between the energy efficiency niche and the ST-regimes of the electricity ST-system involved in this experiment. The mode of interaction of these ST-regimes with the distributed generation niche is competition, except for the Solar ST-regime. In this case, the mode of interaction is symbiosis. Besides there is symbiosis between these niches of the electricity ST-system and the electric car niche.

Finally, there is neutralism in the interaction of the Private car ST-regime with all the ST-regimes and niche of the electricity ST-system that are part of this experiment. And there is competition between this ST-regime and the electric car niche.

The main resources exchanged should be capital, technology, knowledge, and people. Besides, transnational linkages are present, but they will not be relevant in the experiment. The focus of the experiment is EVs, but it will also study a component technology, i.e., a new kind of battery.

The experiment's impacts will probably be limited to niche consolidation, including articulating expectations and views, building networks of actors, and creating learning process. There is no indication that the experiment will contribute to destabilize the private car ST-regime. The characterization of the experiment is resumed in Table E.21.

Table E.21 – Characterization of experiment PD-04951-0726

Category	Classification
Actors involved	CEMIG D CEMIG GT CEMIG SIM GASMIG UFMG SMC

Category	Classification
	FCA Brasil
Start and end date	Not informed
Level of interaction	Intrasystem niche-regime Intrasystem regime-regime Intersystem niche-regime Intersystem regime-regime
Mode of interaction	Competition Symbiosis Neutralism Parasitism Amensalism
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions Niche consolidation - build new networks of actors Niche consolidation - create learning process at multiple dimensions
Value-chain level of interaction	Focus on the main technology Focus on component technologies
Resources exchanged in the experiment	Capital Technology Knowledge People
Impact of transnational linkages on the experiment	Transnational linkages are present but do not influence the experiment

Source: Developed by the author based on ANEEL (2019ac)(2019ab)

E.22 PD-05160-1906

This experiment was proposed by CEB Distribuição (CEB-D), another subsidiary of Neoenergia[95] (NEOENERGIA, 2021). The experiment's objective is to implement, in the Federal District, a system the sale of electricity for electric mobility with an intelligent recharge management platform, integrating renewable sources, interoperable electric stations and electronic billing for the consumer (ANEEL, 2019ad; AGÊNCIA BRASÍLIA, 2020). This experiment's scope includes (ANEEL, 2019ad): (i) implementing a system to optimize the electricity grid by integrating EV charging and distribute photovoltaic energy generation, (ii) developing a payment system with dynamic tariffs based on the electricity system energy demand and the time of the charging, (iii) installing two EV charging stations, and (iv) acquiring 10 electric minibuses[96] and 10 electric minitrucks[97] to be used in the experiment. The estimated cost of the experiment is R$ 11,635,550.00 (ANEEL, 2019ad)

ANEEL (2019ad) considered that this proposal was original, and had reasonable applicability and relevance. The agency understood that this experiment can be replicated in other cities if successful, and praised the participation of car manufacturers (ANEEL, 2019ad). Nonetheless, ANEEL (2019ad) also criticized many points of the experiment, including: (i) the car-sharing system is not sufficiently detailed in the proposal (e.g., the rationale for the selection of the location of the two charging stations is not presented), (ii) it is not clear if the vehicles that will be used have all the necessary certifications, as they were not commercially sold at time of the proposal, (iii) the estimated costs are not sufficiently detailed and justified, and (iv) it is not clear how the experiment will be managed.

There are six actors involved in this experiment: CEB-D, Instituição Científica e de Inovação Tecnológica Brasil (ICT Inova Brasil), Federal University of Mato Grosso do Sul (UFMS), Brave Brasil, Anod-Arc, and M. Fap Consultoria Elétrica e Comércio. CEB-D is an actor of the Distribution ST-regime. ICT Inova Brasil is a research center focused on the electricity system. It has projects in many areas, including distributed generation,

[95] When this experiment was proposed in 2019, CEB-D was a subsidiary of the Companhia Energética de Brasília (CEB), a public company whose majority shareholder is the Federal District government (CEB, 2020). However, CEB sold CEB-D to Neoenergia in December 2020 (NEOENERGIA, 2021).

[96] Vehicle classified in EU category M2.

[97] Vehicles classified in EU category L.

smart grid, and electromobility[98]. Thus, ICT Inova Brasil can be considered part of the distributed generation and electric car niches. Brave Brasil is an electric car manufacture that will provide the vehicles that will be used in the experiment. Therefore, it is an actor of the electric car niche. The role of UFMS, Anod-Arc, and MFAP in the experiment is not clear.

There are at least three levels of interaction this experiment: intrasystem niche-regime, intersystem niche-regime, and intersystem niche-niche. Besides, there is at least two modes of interaction in this experiment, which have been characterized in previous sections (see Sections E.1, E.2, E.5, E.6, E.12, E.15, and E.16). The mode of interaction between the Distribution ST-regime and the electric car niche is symbiosis. There is also symbiosis between distributed generation and electric car niches. Finally, the interaction of the Distribution ST-regime with the distributed generation niche is characterized as competition.

The main resources exchanged should be capital, knowledge, and people. Although CEB-D is now part of a multinational holding, there is no indication that transnational linkages will be relevant to this experiment, as no exchange of resources with international partners is planned. The EV sharing schemes that is the focus of the experiment is a complementary technology to EVs.

The experiment's impacts will probably be limited to niche consolidation, including articulating expectations and views, building networks of actors, and creating learning process. There is no indication that the experiment will contribute to destabilize the private car ST-regime. The characterization of the experiment is resumed in Table E.22.

Table E.22 – Characterization of experiment PD-05160-1906

Category	Classification
Actors involved	CEB-D ICT Inova Brasil UFMS Anod-Arc M. Fap Consultoria Elétrica e Comércio Brave Brasil
Start and end date	01/04/2020 – 01/04/2023

[98] ICT Inova Brasil develops both EV charging stations and EVs.

Category	Classification
Level of interaction	Intrasystem niche-regime Intersystem regime-regime Intersystem niche-niche
Mode of interaction	Competition Symbiosis
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions Niche consolidation - build new networks of actors Niche consolidation - create learning process at multiple dimensions
Value-chain level of interaction	Focus on complementary technologies
Resources exchanged in the experiment	Capital Knowledge People
Impact of transnational linkages on the experiment	Transnational linkages are present but do not influence the experiment

Source: Developed by the author based on ANEEL (2019ad)

E.23 PD-05697-0219

This experiment was proposed by Celesc Distribuição (Celesc D), a subsidiary of the public company Centrais Elétricas de Santa Catarina (Celesc), whose majority owner is the Santa Catarina state government (CELESC, 2020). The experiment's main goal is to convert ICEV from public fleets to EVs (ANEEL, 2019ae). The experiment also includes (ANEEL, 2019ae): (i) testing two different systems to convert ICEV into EVs, (ii) optimize the powertrain used to reduce its weight and, consequently, be able to reduce the size of the battery pack, and (iii) invest in the development of the electromobility courses of the Instituto Federal de Santa Catarina (IFSC), and (iv) equip IFSC laboratories with all the necessary equipment to conduct the experiment.

ANEEL (2019ae) considered that this proposal was original, had good applicability and relevance, and its costs were compatible with the scope of the project. The agency only questioned the necessity of buying a large size 3D printer (ANEEL, 2019ae). The estimated cost of the experiment is R$ 6,416,076.00 (ANEEL, 2019ae).

Only Celesc D and IFSC are participating in the experiment. Celesc D is an actor of the Distribution ST-regime. IFSC is an education and research institution (IFSC, 2021). The Electromobility Lab (Emol), which is part of the Grupo de Pesquisas em Eletrônica de Potência e Acionamentos Industriais (Power Electronics and Industrial Drives Research Group - GEPAI), is the IFSC's section that will be involved in the expertiment (IFSC, 2020). Emol-GEPAI have great experience in converting ICEVs to EVs (GEPAI, 2021). Therefore, IFSC can be considered part of the electric car niche in this experiment.

As there are only two actors in the experiment, there is only one level of interaction, intersystem niche-regime. There is also only one mode of interaction: symbiosis. The main resources exchanged should be capital, knowledge, and people. Celesc D will be the main source of capital, while IFSC will be the main provider of knowledge. Besides, there are no transnational linkages present in the experiment. The EVs are the main focus of the experiment.

The experiment's impacts will probably be limited to niche consolidation, including articulating expectations and views, building networks of actors, and creating learning process. There is no indication that the experiment will contribute to destabilize the private car ST-regime. The characterization of the experiment is resumed in Table E.23.

Table E.23 – Characterization of experiment PD-05697-0219

Category	Classification
Actors involved	Celesc D IFSC
Start and end date	10/2020 a 10/2023
Level of interaction	Interystem niche-regime
Mode of interaction	Symbiosis
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions Niche consolidation - build new networks of actors Niche consolidation - create learning process at multiple dimensions
Value-chain level of interaction	Focus on complementary technologies
Resources exchanged in the experiment	Capital Knowledge

Category	Classification
	People
Impact of transnational linkages on the experiment	Transnational linkages are not present

Source: Developed by the author based on ANEEL (2019ae)

E.24 PD-05785-2019

This experiment was proposed by Companhia Estadual de Distribuição de Energia Elétrica (CEEE-D), a subsidiary of Equatorial Energia[99] (EQUATORIAL ENERGIA, 2021). The experiment's objective is to implement the first electric highway of Rio Grande do Sul, with the installation of 10 EV charging stations between the cities of Chuí and Torres (ANEEL, 2019af). This electric highway will be part of the Rota Elétrica Mercosul , i.e., a 900 km electric highway connecting the states of Paraná, Santa Catarina, and Rio Grande do Sul with Paraguay and Uruguay (ANEEL, 2019af; UFSM, 2020).

The experiment's scope also includes: (i) developing a monitoring and payment system based on blockchain technology for the charging infrastructure that will be installed along the highway, (ii) identifying the driving and charging patterns of drivers using the electric highway to optimize the system, (iii) installing renewable energy sources (e.g. solar and wind) and energy storage systems in the EV charging stations (ANEEL, 2019af; UFSM, 2020). The estimated cost of the experiment is R$ 4,296,269.07 (ANEEL, 2019af).

ANEEL (2019af) considered that this proposal was original, and had reasonable applicability and relevance. The agency praised the interconnection of the proposed electric highway with the existing ones in Paraná and Uruguay. However, ANEEL (2019af) highlighted that to achieve the full integration of these highways CEEE-D needs to negotiate with the companies that own the EV charging infrastructure in these other highways. According to the agency, these negotiations can delay or even make the integration unfeasible (ANEEL, 2019af). Another risk in the experiment is that the use of the blockchain technology in payment systems had not been regulated in Brazil at the

[99] When this experiment was proposed in 2019, CEEE-D was part of the Companhia Estadual de Energia Elétrica Participações (CEEE-PAR), a public company whose majority shareholder is the Rio Grande do Sul state government (CEEE-D, 2021). However, CEEE-PAR sold CEEE-D to Equatorial Energia in March 2021 (JUNIOR, 2021).

time of the proposal[100]. This fact could also delay or make the system unfeasible (ANEEL, 2019af). Finally, ANEEL (2019af) questioned the need of purchasing 15 EVs to be used in the experiment.

There are ten actors involved in this experiment. CEEE-D operates the electricity gird of part of the Rio do Grande do Sul state (CEEE-D, 2021) and is an actor of the Distribution ST-regime. Companhia Estadual de Geração e Transmissão de Energia Elétrica (CEEE-GT) is a subsidiary of CEEE-PAR. CEEE-GT operates several transmission lines and large and small hydroelectric power plants in Rio do Grande do Sul. Thus, this company can be considered part of the Transmission, Large hydroelectric, and Small hydroelectric ST-regimes. The section of UFSM that is participating in the project is the Centro de Excelência em Energia e Sistemas de Potência (Center of Excellence in Energy and Power Systems – CEESP). CEESP conducts research on distributed generation, electromobility, waste-to-energy, and energy storage. In this experiment, it will work both on the distributed generation and EV charging stations solutions. Thus, UFSM can be considered part of the electric car and distributed generation niches.

Three of the companies involved are from the electricity ST-system: ABB, WEG, and DMS Engenharia. ABB and WEG are actors of the Distribution and Transmission ST-regimes, and the electric car niche (see Sections E.2 and Section E.16). DMS Engenharia is an engineering company that provides services in renewable energy (mainly solar energy), automation, and power substations (DMS ENGENHARIA, 2021). In this experiment, DMS Engenharia is involved with the renewable energy systems, and can be considered part of the Solar ST-regime.

General Motors, Electric Mobility Brasil, and SIM Rede de Postos (SIM) are all part of the urban mobility ST-system. General Motors is the second largest car manufacturer in Brazil and one of the main actors of the Private car ST-regime (see 4.2.1). Electric Mobility Brasil is part of the electric car niche, as detailed in Section E.2. SIM is the largest gas station chain in Brazil, with more than 140 units in the South of Brazil (SIM, 2021). Thus, SIM can be considered part of the private car ST-regime. Finally, Hotel Laghetto Viverone Moinhos is a hotel in Porto Alegre and is not part of any ST-regime or niche of the electricity and urban mobility ST-systems.

[100] The use of blockchain had not been regulated until July 2021, although the president of the House of Representatives indicated in May that he wanted to vote a law regulating blockchains still in 2021 (BERTONCELLO, 2021; ALVES, 2021).

There are four levels of interaction in this experiment: intrasystem niche-regime, intrasystem regime-regime, intersystem niche-regime, and intersystem niche-regime.

All the modes of interaction in this experiment have been characterized in previous sections (see Sections E.1, E.2, E.5, E.6, E.12, E.15, and E.16). The mode of interaction between the Large hydroelectric, Small hydroelectric, and Solar ST-regimes is competition. There is symbiosis between these ST-regimes, the Distribution and Transmission ST-regimes and the electric car niche. Finally, there is neutralism in the interaction of the Private car ST-regime with all the ST-regimes and niche of the electricity ST-system that are part of this experiment. And there is competition between this ST-regime and the electric car niche.

The main resources exchanged should be capital, knowledge, and people. Transnational links will be relevant to this experiment, as the cars that will be used in the tests will be imported and provided by General Motors. The electric way that is the focus of the experiment is a complementary technology to EVs.

The experiment's impacts will probably be limited to niche consolidation, including articulating expectations and views, building networks of actors, and creating learning process. There is no indication that the experiment will contribute to destabilize the private car ST-regime. The characterization of the experiment is resumed in Table E.24.

Table E.24 – Characterization of experiment PD-05785-2019

Category	Classification
Actors involved	CEEE-D CEEE-GT UFSM ABB WEG DMS Engenharia General Motors Electric Mobility Brasil SIM Hotel Laghetto Viverone Moinhos
Start and end date	24/09/2020 – 24/09/2024

Category	Classification
Level of interaction	Intrasystem niche-regime Intrasystem regime-regime Intersystem niche-regime Intersystem regime-regime
Mode of interaction	Competition Symbiosis Neutralism
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions Niche consolidation - build new networks of actors Niche consolidation - create learning process at multiple dimensions
Value-chain level of interaction	Focus on complementary technologies
Resources exchanged in the experiment	Capital Knowledge People
Impact of transnational linkages on the experiment	Transnational linkages are present and influence the experiment

Source: Developed by the author based on ANEEL (2019af)

E.25 PD-06585-1912

This experiment was proposed by Energisa Minas Gerais Distribuidora de Energia (EMG), a subsidiary of the Brazilian electricity company Energisa (ENERGISA, 2021). The experiment's goal is to integrate solar energy with electromobility through the installation of EV charging stations next to solar energy power plants in urban areas. This would guarantee that the energy used to charge the vehicles is 100% from renewable sources (ANEEL, 2019ag). The experiment also includes the use of mobile energy storage systems (ESS) with at least 300 kWh, which will be loaded at the solar plant and then moved during peak demand times to locations where there is a high concentration of EVs (ANEEL, 2019ag; UFPB, 2021). Besides, EMG will develop a system to identify in real time the locations with high concentration of EVs. This system will also inform drivers of the current and future location of the mobile ESS, so that they can plan when to charge their EVs. (ANEEL, 2019ag). The estimated cost of the experiment is R$ 30,005,500.00 (ANEEL, 2019ag).

ANEEL (2019ag) considered that this proposal was original, had reasonable applicability and relevance, and its costs were compatible with the scope of the project. The agency praised the monitoring and information system because it optimizes the use of the EV charging stations (ANEEL, 2019ag). However, ANEEL (2019ag) understands that this business model it more applicable to companies that offer Mobility-as-a-Service (MaaS), such as uber. The use by regular EV owners may be limited. Therefore, the agency indicated that the study of economic feasibility of the business model that was presented with the porposal needs to be improved.

Fourteen organizations are participating in the experiment. Twelve of them are subsidiaries of Energisa (ENERGISA, 2021): Energisa Tocantins Distribuidora de Energia (ETO), Energisa Mato Grosso do Sul Distribuidora de Energia (EMS), Energisa Mato Grosso Distribuidora de Energia (EMT), Energisa Sul-Sudeste Distribuidora de Energia (ESS), Energisa Sergipe Distribuidora de Energia (ESE), Energisa Paraíba Distribuidora de Energia (EPB), Energisa Borborema Distribuidora de Energia (EBO), Energisa Nova Friburgo Distribuidora de Energia (ENF), Energisa Acre Distribuidora de Energia (EAC), Energisa Rondônia Distribuidora de Energia (ERO), and Alsol Energias Renováveis. Except for Alsol, all these companies are part of the Distribution ST-regime. Alsol produces electricity through solar and biogas power plants. The company also develops solar distributed generation projects (ENERGISA, 2021). Therefore, Alsol can be considered part of the solar and biomass ST-regimes and the distributed generation niche.

The other two organizations participating in the experiment are BYD Brasil and the *Universidade Federal da Paraíba* (UFPB). BYD Brasil is part of the solar ST-regime and the battery and electric car niches in Brazil (see Section E.6). The section of UFPB involved in this experiment is the Smart Grid Group, which conducts research on smart grid, distributed generation, energy systems, and energy storage (UFPB, 2021). Thus, UFPB can be considered part of the distributed generation niche.

There are interactions in several different levels in this experiment: intrasystem niche-niche, intrasystem niche-regime, intrasystem regime-regime, intersystem niche-regime, and intersystem niche-niche.

Despite the great number of actors, there are only two modes of interactions because most of the actors are from the same ST-regime. All the modes of interaction in this experiment have been characterized in previous sections (see Sections E.1, E.2, E.5, E.6, E.9, E.12, E.15, and E.16). The mode of interaction between the Biomass and Solar ST-regimes is competition. There is symbiosis between these ST-regimes, the Distribution ST-regime, and the electric car niche. Besides, the mode of interaction of these ST-regimes with the distributed generation niche is competition, except for the Solar ST-regime. In this case, the mode of interaction is symbiosis, which is also the mode of interaction between this niche and the electric car niche. There is also symbiosis between the Biomass and Solar ST-regimes and the battery niche. The mode of interaction of the battery niche with the Distribution ST-regime and the distributed generation niche is commensalism and symbiosis, respectively.

The main resources exchanged should be capital, knowledge, and people. Transnational linkages will have a small relevance to the experiment, as the EVs that will be used will be imported from China. The focus of the experiment is on complementary technologies of EVs, notably the charging system. Although BYD is participating in the experiment, there is no clear indication that it will use it to improve its products. Therefore, there does not seem to be a focus on the development of EVs in this experiment.

The experiment's impacts will probably be limited to niche consolidation, including articulating expectations and views, building networks of actors, and creating learning process. There is no indication that the experiment will contribute to destabilize the private car ST-regime. The characterization of the experiment is resumed in Table E.25.

Table E.25 – Characterization of experiment PD-06585-1912

Category	Classification
Actors involved	EMG
	ETO
	EMS
	EMT
	ESS
	ESE

Category	Classification
	EPB EBO ENF EAC ERO Alsol BYD Brasil UFPB
Start and end date	Not informed – Duration of 36 months
Level of interaction	Intrasystem niche-regime Intrasystem regime-regime Intrasystem niche-niche Intersystem niche-regime Intersystem niche-niche
Mode of interaction	Competition Symbiosis Commensalism
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions Niche consolidation - build new networks of actors Niche consolidation - create learning process at multiple dimensions
Value-chain level of interaction	Focus on complementary technologies
Resources exchanged in the experiment	Capital Knowledge People
Impact of transnational linkages on the experiment	Transnational linkages are present and influence the experiment

Source: Developed by the author based on ANEEL (2019ag)

E.26 PD-06899-6925

This experiment was proposed by Serra do Facão Energia, which is owned by Alcoa Alumínio, Furnas, DMEE, and Camargo Corrêa Energia (FURNAS, 2021). The project aims to develop a hybrid EV powered by ethanol and prepared for V2G applications (ANEEL, 2019ah). The experiment includes the construction of two prototypes and a laboratory for the development of the batteries that will be used (ANEEL, 2019ah). The estimated cost of the experiment is R$ 6,925,859.00 (ANEEL, 2019ah).

ANEEL (2019ah) considered that this proposal was original, had reasonable applicability and relevance, and its costs were compatible with the scope of the project. According to ANEEL's (2019ah) evaluation, a hybrid EV powered by ethanol could boost the use of EVs in Brazil.

Only three actors are involved in this experiment: Serra do Facão Energia, Instituto Tecnológico de Aeronáutica (ITA), and AVL South America. Serra do Facão Energia is an actor of the Large hydroelectric ST-regime, as detailed in Section E.17. ITA is an education and research institution managed by the Brazilian Air Force (ITA, 2021). ITA's Laboratório de Combustão, Propulsão e Energia (Combustion, Propulsion and Energy Laboratory - LCPE) is the entity involved in the experiment. LCPE conducts research on combustion engines for rockets and, gas turbines, internal combustion engines for cars, among others. The laboratory will work in the development of the hybrid motor. It can be considered part of the private car ST-regime, due to its focus on combustion engines. AVL South America is the Brazilian subsidiary of AVL, is the world's largest independent company for development, simulation, and testing in the automotive industry (AVL, 2021). Therefore, it is an actor of the private car ST-regime.

There are interactions in only one level of interaction in the experiment: intersystem regime-regime. Besides, there is also only one mode of interaction: Neutralism between the Large hydroelectric and Private car ST-regimes.

The main resources exchanged should be capital (mainly from Serra do Facão to the other participants), knowledge, and people. Although AVL is part of a multinational holding, there is no indication that transnational linkages will be relevant to this experiment, as no exchange of resources with international partners is planned. Finally, the experiment focus on EVs.

The experiment's impacts will probably be limited to niche consolidation, including articulating expectations and views, building networks of actors, and creating learning process. There is no indication that the experiment will contribute to destabilize the private car ST-regime. The characterization of the experiment is resumed in Table E.26.

Table E.26 – Characterization of experiment PD-06899-6925

Category	Classification
Actors involved	Serra do Facão Energia AVL ITA
Start and end date	Not informed
Level of interaction	Intersystem regime-regime
Mode of interaction	Neutralism
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions Niche consolidation - build new networks of actors Niche consolidation - create learning process at multiple dimensions
Value-chain level of interaction	Focus on the main technology
Resources exchanged in the experiment	Capital Knowledge People
Impact of transnational linkages on the experiment	Transnational linkages are present but do not influence de experiment

Source: Developed by the author based on ANEEL (2019ah)

E.27 PD-06961-0010

This experiment was proposed by CEC, a subsidiary of GPE (see Section E.17). The objective of the experiment is to develop a fast charger, with national technology, that can be used both by bicycles and electric cars and also in V2G applications (ANEEL, 2019ai). The experiment includes (ANEEL, 2019ai): (i) developing an electric bicycle with wireless charging and geolocation system, (ii) creating a system for the purchase of electricity online, (iii) developing an algorithm to optimize the charging system, and (iv) implement a three pilot projects with 8 charging stations, 80 bicycles, and 9 cars, divided between six Brazilian states. Moreover, the pilot projects have different focus: (i) small cities, (ii) big cities, and (iii) universities campus (UFMS, 2020).

ANEEL (2019ai) considered that this proposal was original, had good applicability and relevance, and its costs were compatible with the scope of the project. The agency praised the focus on using national technology or developing it for all hardware and software, except electric cars, which will be used in the experiment. (ANEEL, 2019ai). ANEEL (2019ai) also praised the effort of doing pilot projects in six different Brazilian states, increasing the diversity of the information that will be gathered during the experiment. The agency's only criticism was the high personnel expenses, which exceed 50% of the total cost of the experiment (R$ 16,212,875.82). According to ANEEL (2019ai), these expansions are not well justified in the proposal.

Twenty-four organizations are participating in the experiment. Three of them are subsidiaries of GPE and actors of the thermoelectric ST-regime (see Section E.17): CEC, CEM, and CEP. Four subsidiaries of Equatorial Energia are also involved: Equatorial Energia Maranhão (EQTL Maranhão), Equatorial Energia Piauí (EQTL Piauí), Equatorial Energia Pará (EQTL Pará), and Equatorial Energia Alagoas (EQTL Alagoas). These are all actors of the Distribution ST-regime (EQUATORIAL ENERGIA, 2021). Besides, five of the companies are actors of the Large hydroelectric ST-regime: BAESA and Serra do Facão Energia (see Section E.17), Itiquira Energia[101] (QUEBEC ENGENHARIA, 2021), Rio Paraná Energia[102] (CTG BRASIL, 2021), and Enel Cachoeira Dourada[103] (ENEL BRASIL, 2020). Finally, AES Brasil[104] operates several large and small hydroelectric power plants, wind farms, and solar power plants (AES BRASIL, 2021). Thus, AES Brasil is part of the Large hydroelectric, Small hydroelectric, Wind, and Solar ST-regimes.

From the other eleven organizations involved in the experiment, six are municipalities, and are not part of any specific ST-regime or niche. The remaining five organizations are: Nexsolar Soluções em Energia Solar, Nastek Industria e Tecnologia, Lactec, Associação Brasileira dos Produtores Independentes de Energia Elétrica (Brazilian Association of Independent Electric Energy Producers – APINE), and UFMS. Nexsolar provides solutions in solar energy (NEXSOLAR, 2021). In the experiment, Nexsolar will provide the photovoltaic generation and the charging station infrastructure.

[101] Itiquira Energia is owned by Quebec Engenharia (QUEBEC ENGENHARIA, 2021).

[102] Rio Paraná Energia is owned by CTG Brasil (CTG BRASIL, 2020).

[103] Enel Cachoeira Dourada is a subsidiary of Enel Brasil, which is owned by the Italian holding Enel SpA (ENEL BRASIL, 2020).

[104] When the experiment was proposed, AES Brasil was named AES Tietê. However, the company underwent a restructuring process in 2020 and a new holding was created, which was named AES Brasil (AES BRASIL, 2021).

Therefore, it can be considered an actor of the both the Solar ST-regime and the electric car niche.

Nastek offers smart grid products and applications (NASTEK, 2021). It can be considered part of the Distribution ST-regime. As detailed in previous sections, Lactec can be considered part of the electric car, battery, energy efficiency, and distributed generation niches. APINE is an association that represents independent electricity procurers[105]. APINE has more than 60 members from all ST-regimes of the electricity ST-system, except the Nuclear ST-regime (APINE, 2021). In this experiment, APINE can be considered an actor of the same ST-regimes of the electricity ST-system as the other actors involved.

Finally, the Laboratório de Inteligência Artificial, Eletrônica de Potência e Sistemas Digitais (Laboratory of Artificial Intelligence, Power Electronics and Digital Systems – BATLAB) is the section of UFMS that is participating in the experiment (UFMS, 2021). BATLAB will work with Nexsolar in the development of the EV charging stations hardware that will be used in the experiment (UFMS, 2020). Therefore, UFMS can be considered part of the electric car niche in this experiment.

Therefore, there are four levels of interaction in the experiment: intrasystem niche-regime, intrasystem regime-regime, intersystem niche-regime, and intersystem niche-niche.

All the modes of interaction in this experiment have been characterized in previous sections (see Sections E.1, E.2, E.5, E.6, E.9, E.12, E.15, and E.16). The mode of interaction between Large hydroelectric, Small hydroelectric, Wind, and Solar ST-regimes is competition. There is symbiosis between these ST-regimes, the Distribution ST-regime, and the electric car niche. Besides, the mode of interaction of these ST-regimes with the distributed generation niche is competition, except for the Solar ST-regime. In this case, the mode of interaction is symbiosis, which is also the mode of interaction between this niche and the electric car niche.

There is also symbiosis between the Large hydroelectric, Small hydroelectric, Wind, and Solar ST and the battery niche. The mode of interaction of the battery niche with the Distribution ST-regime and the energy efficiency niche is commensalism and symbiosis, respectively. Besides, there is amensalism between the energy efficiency niche and the ST-regimes of the electricity ST-system involved in this experiment. Finally,

[105] Companies authorized to produce and sell electricity in the ACL.

there is symbiosis between the niches of the electricity ST-system and the electric car niche.

The main resources exchanged should be capital, technology, knowledge, and people. Transnational linkages are present, as many of the organizations involved are part of multinational groups. However, they will not be relevant in the experiment. Besides, the focus of the experiment is on complementary technologies to EVs.

The experiment's impacts will probably be limited to niche consolidation, including articulating expectations and views, building networks of actors, and creating learning process. There is no indication that the experiment will contribute to destabilize the private car ST-regime. The characterization of the experiment is resumed in Table E.27.

Table E.27 – Characterization of experiment PD-06961-0010

Category	Classification
Actors involved	CEC CEM CEP Rio Paraná Energia Baesa AES Brasil EQTL Maranhão EQTL Pará EQTL Piauí EQTL Alagoas Serra do Facão Energia Enel Cachoeira Dourada Itiquira Energia Nexsolar Soluções em Energia Solar UFMS Nastek Indústria e Tecnologia Lactec

Category	Classification
	Morrinhos Municipality Itumbiara Municipality São Luís Municipality Belém Municipality Teresina Municipality Maceió Municipality APINE
Start and end date	13/07/2020 – 13/01/2024
Level of interaction	Intrasystem regime-regime Intrasystem niche-regime Intersystem niche-niche Intersystem niche-regime
Mode of interaction	Competition Symbiosis Commensalism Amensalism
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions Niche consolidation - build new networks of actors Niche consolidation - create learning process at multiple dimensions
Value-chain level of interaction	Focus on the main technology
Resources exchanged in the experiment	Capital Technology Knowledge People
Impact of transnational linkages on the experiment	Transnational linkages are present but do not influence the experiment

Source: Developed by the author based on ANEEL (2019ai)

E.28 PD-07267-0021

This is another experiment proposed by a subsidiary of EDP Brasil: Porto do Pecém Geração de Energia. The experiment's objective is to develop electric mobility solutions for the taxi and ride-hailing apps market based on a charging infrastructure for light vehicles with low impact on the electricity grid (ANEEL, 2019aj). The experiment includes (ANEEL, 2019aj): (i) the installation of two EV charging stations, one of them with energy storage and photovoltaic energy generation systems, in places that provide convenience for the drivers (ii) two mobile charging systems to recharge EV in case it run out of energy before reaching a charging station, and (iii) develop a business model for EV charging that is compatible with the exiting private passenger transport market. The estimated cost of the experiment is R$ 12,934,540.38 (ANEEL, 2019x).

ANEEL (2019aj) considered that this proposal was original, had good applicability and relevance. According to the agency', the experiment has great potential because the private passenger ride-hailing apps market has been growing consistently in Brazil[106] (ANEEL, 2019aj). However, ANEEL (2019aj) criticized that there are no participants who can explore the infrastructure that will be built during the experiment, after its conclusion. Given the characteristic of the space to be developed for the charging stations, with a considerable portion of the experiment costs destined to the construction of these spaces, and considering their potential for generating business, the agency understands that it is necessary to add as many commercial partners as possible to the experiment. to minimize its payback time (ANEEL, 2019aj).

There are eight organizations involved in this experiment. Five of them are subsidiaries of EDP Brasil: Porto de Pecém Geração de Energia (Thermoelectric ST-regime), Lageado Energia (Large hydroelectric ST-regime), EDP São Paulo and EDP Espírito Santo (Distribution ST-regime), and EDP Grid (Trader ST-regime) (EDP BRASIL, 2021).

The other three organizations are: Moura, IATI and ITEMM. As detailed in previous sections, Moura can be considered part of both the private car ST-regime and the battery and electric car niches, IATI is an actor of the battery and electric car niches and the solar, wind, and biomass ST-regimes, and ITEMM can be considered part of the solar ST-regime and the battery and electric car niches.

[106] Note that this evaluation was made before the COVID-19 pandemic outbreak, which has considerably impacted the taxi and ride-hailing apps market.

There are interactions in four different levels in this experiment: intrasystem niche-regime, intrasystem regime-regime, intersystem niche-niche, intersystem niche-regime.

All possible modes of interaction are present in this experiment. They have been characterized in previous sections (see Sections E.1, E.2, E.5, E.6, E.9, E.12, E.15, and E.16). The mode of interaction between Large hydroelectric, Thermoelectric, Biomass, Wind, and Solar ST-regimes is competition. There is symbiosis between these ST-regimes, the Distribution and Trader ST-regimes. The mode of interaction of all these ST-regimes of the electricity ST-system with the electric car niche is characterized as symbiosis, except for the Thermoelectric ST-regime. In this case the mode of interaction with the electric car niche is parasitism.

The is symbiosis in the interaction between the Large hydroelectric, Small hydroelectric, Biomass, Wind, and Solar ST and the battery niche. The mode of interaction of the battery niche with the Thermoelectric, Distribution, and Trader ST-regimes is amensalism, commensalism and neutralism, respectively. Besides, there is symbiosis between the battery and electric car niches.

Finally, there is neutralism in the interaction of the Private car ST-regime with all the ST-regimes and niche of the electricity ST-system that are part of this experiment. And there is competition between this ST-regime and the electric car niche.

The main resources exchanged should be capital, knowledge, and people. Besides, there is no indication that transnational linkages will be relevant in the experiment, although they are present (see Section E.2). The focus of the experiment is on complementary technologies of EVs, in this case, electric mobility solutions for the taxi and ride-hailing apps market.

The experiment's impacts will probably be limited to niche consolidation, including articulating expectations and views, building networks of actors, and creating learning process. There is no indication that the experiment will contribute to destabilize the private car ST-regime. The characterization of the experiment is resumed in Table E.28.

Table E.28 – Characterization of experiment PD-07267-0021

Category	Classification
Actors involved	Porto do Pecém Geração de Energia EDP Espírito Santo Lajeado Energia

Category	Classification
	EDP São paulo EDP Grid Moura IATI ITEMM
Start and end date	Not informed – Duration of 36 months
Level of interaction	Intrasystem niche-regime Intrasystem regime-regime Intersystem niche-niche Intersystem niche-regime
Mode of interaction	Competition Symbiosis Neutralism Parasitism Commensalism Amensalism
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions Niche consolidation - build new networks of actors Niche consolidation - create learning process at multiple dimensions
Value-chain level of interaction	Focus on complementary technologies
Resources exchanged in the experiment	Capital Knowledge People
Impact of transnational linkages on the experiment	Transnational linkages are present but do not influence the experiment

Source: Developed by the author based on ANEEL (2019aj)

E.29 PD-07427-0319

This experiment was proposed by Norte Energia[107]. The experiment's main goal is to develop an electric mobility system to serve the population of the Guamá campus from the *Universidade Ferderal do Pará* (UFPA) (ANEEL, 2019ak). This system will integrate electric buses, electric boats, photovoltaic electricity generation, energy storage, charging infrastructure, cloud-based data storage and processing, and a managing system. The experiment includes the development and construction of the electric boat (ANEEL, 2019ak). The estimated cost of the experiment is R$ 11,868,260.00.

ANEEL (2019ak) considered that this proposal was original, had good applicability and relevance, and its costs were compatible with the scope of the project. The agency praised the development of the electric boat because waterway is the main means of transport in the region of the experiment. ANEEL (2019ak) also praised the upgrades that will be made in many of UFPA's laboratories for the experiment.

Five actors are participating in the experiment: Norte Energia, UFPA, Fundação CPQD, BYD Brasil, and ABB. Norte Energia operates one of Brazil's largest hydroelectric power plants: Belo Monte. Thus, it is part of the Large hydroelectric ST-regime. As detailed in previous sections, Fundação CPQD can be considered an actor of the consumption management niche, ABB is an actor of the Distribution and Transmission ST-regimes, and the electric car niche. BYD Brasil is an actor of the solar ST-regime and the battery and electric car niches.

Four laboratories and research groups of UFPA are involved in the experiment (ANEEL, 2019ak): Centro de Excelência em Eficiência Energética da Amazônia (CEAMAZON), Laboratório de Computação e Telecomunicações (LCT), Núcleo de Pesquisa e Desenvolvimento em Telecomunicações, Automação e Eletrônica (LASSE) e Laboratório de Engenharia Naval (LABNAV). CEAMAZON conducts research in the fields of electricity distribution and transmission (CEAMAZON, 2021). LCT's focus is on telecommunications applications (UFPA, 2021a). LASSE also conducts research in the field of telecommunications, in addition to electronics and automation (LASSE, 2021). Finally, LABNAV researches solutions and applications for water transport (UFPA, 2021b). Therefore, UFPA can be considered part of the Distribution and

[107] Norte Energia was founded in 2010 to build and operate the Belo Monte hydroelectric power plant. It has several shareholders including many organizations of the electricity ST-system: Eletrobras (main shareholder), Neoenergia, CEMIG, Light, J Malucelli Energia, and Aliança Norte Energia (NORTE ENERGIA, 2021).

Transmission ST-regimes, the telecommunications ST-system, and the urban water transport ST-regime[108].

There are five levels of interaction in this experiment: intrasystem niche-regime, intrasystem regime-regime, intersystem niche-niche, intersystem niche-regime, and intersystem regime-regime.

Most modes of interaction present in this experiment have been characterized in previous sections (see Sections E.1, E.2, E.5, E.6, E.9, E.12, E.15, and E.16). The mode of interaction between Large hydroelectric and Solar ST-regimes is competition. There is symbiosis between these ST-regimes, the Distribution and Transmission ST-regimes, and the electric car niche.

The is symbiosis in the interaction between the Large hydroelectric and Solar ST and the electric car niche with the battery niche. Besides, this niche interaction with the Distribution and Transmission ST-regimes is characterized as commensalism. The mode of interaction between the different ST-regimes of the electricity ST-system and the consumption management niche is competition. The mode of interaction between the consumption management niche with the electric car and battery niches is symbiosis and neutralism, respectively.

The interaction electric car niche with the water transport ST-regime can be characterized as neutralism, as none of them benefits or inhibits the other. Besides, the interaction of this ST-regime with the ST-regimes and niches of the electricity ST-system can be characterized as neutralism, as none of them positively or negatively impact the other, like the interaction of these ST-regimes and niche with the Private car ST-regime (see Section E.9).

One exception could be the interaction between Large hydroelectric and Water transport ST-regimes. The construction of hydroelectric can difficult navigation or even make it impossible if it blocks the passage of vessels or if disrupt the natural flow of the river (MARTINS et al., 2011; VON SPERLING, 2012). On the other hand, hydroelectric can be used no regulate the river flow in order to improve its navigability throughout the year, and locks can be used to allow the passage of vessels (SOITO; FREITAS, 2011). Therefore, taking a similar approach to the characterization of the mode of interaction between the Private car St-regime and the battery niche (see Section E.9), the mode of

[108] As detailed in Section 4.2, urban water transport was not considered in the characterization of the Brazilian urban mobility system because this type of mobility is only present in a small percentage of Brazilian cities. However, Belém-PA, where this experiment is taking place, is one of these cities.

interaction between Large hydroelectric and Water transport ST-regimes is characterized as neutralism.

Finally, is difficult to characterize the mode of interaction of the different ST-regimes and niches of the electricity and urban mobility ST-systems with the whole telecommunications ST-system. Therefore, it would be necessary to identify which ST-regime or niche of this ST-system LCT is part and then characterize the interactions. However, this will not be done because the focus of the thesis is the interaction between the electricity and urban mobility ST-systems.

The main resources exchanged should be capital, knowledge, and people. Norte Energia will be the main source of all capital. Besides, there are no transnational linkages present in the experiment. The system that is the focus of the experiment is a complementary technology to EVs.

The experiment's impacts will probably be limited to niche consolidation, including articulating expectations and views, building networks of actors, and creating learning process. There is no indication that the experiment will contribute to destabilize the private car ST-regime. The characterization of the experiment is resumed in Table E.29.

Table E.29 – Characterization of experiment PD-07427-0319

Category	Classification
Actors involved	Norte Energia UFPA Fundação CPQD BYD Brasil ABB
Start and end date	11/2019 a 11/2022
Level of interaction	Intrasystem niche-regime Intrasystem regime-regime Intersystem niche-niche Intersystem niche-regime Intersystem regime-regime
Mode of interaction	Competition Symbiosis

Category	Classification
	Neutralism Commensalism
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions Niche consolidation - build new networks of actors Niche consolidation - create learning process at multiple dimensions
Value-chain level of interaction	Focus on complementary technologies
Resources exchanged in the experiment	Capital Knowledge People
Impact of transnational linkages on the experiment	Transnational linkages are not present

Source: Developed by the author based on ANEEL (2019ak)

E.30 PD-10381-0022

This experiment was proposed by Rio Paraná Energia, a subsidiary of CTG Brasil (CTG BRASIL, 2020). The project aims to develop a business model that allow electricity producers to sell electricity directly to EV users (ANEEL, 2019al). This system would allow consumers to buy electricity only from renewable sources or even from a specific power plant. The experiment will include a pilot-project to sell electricity from the Rio Paraná hydroelectric power plant to some EV charging stations (ANEEL, 2019al). The estimated cost of the experiment is R$ 8,263,433.00 (ANEEL, 2019i).

ANEEL (2019al) considered that this proposal was original, had good applicability and relevance, and its costs were compatible with the scope of the project. The agency commented very few points of the experiment. ANEEL (2019al) criticized the low number of participants involved but praised the experiment's initiative to visit schools close to the experiment location to teach the students about electromobility.

Only three organizations are involved in this experiment: Rio Paraná Energia, Lactec, and Incharge. All are part of other experiments and have been described in previous sections. Thus, Rio Paraná Energia is an actor of the Large hydroelectric ST-regime, Lactec is part of the electric car, battery, and distributed generation niches, and Incharge is an actor of the electric car niche.

In this experiment, there are interactions in only three levels: intrasystem niche-regime, intersystem niche-regime, and intersystem niche-niche. Besides, there are only two modes of interaction. These modes have been detailed in previous sections (see Sections E.1, E.2, E.5, E.6, E.9, E.12, E.15, and E.16). The mode of interaction between Large hydroelectric ST-regime and electric car and battery niches is symbiosis. Besides, there is competition between this ST-regime and the distributed generation niche. Finally, there is symbiosis between the three niches in this experiment.

The main resources exchanged should be capital (mainly from Rio Paraná Energia to the other participants), knowledge, and people. Although Rio Paraná Energia is part of a multinational holding, there is no indication that transnational linkages will be relevant to this experiment, as no exchange of resources with international partners is planned.

The experiment focuses on a complementary technology to EVs, i.e, the system to sell electricity from producers directly to EV users. The experiment's impacts will probably be limited to niche consolidation, including articulating expectations and views, building networks of actors, and creating learning process. There is no indication that the experiment will contribute to destabilize the private car ST-regime. The characterization of the experiment is resumed in Table E.30.

Table E.30 – Characterization of experiment PD-10381-0022

Category	Classification
Actors involved	Rio Paraná Energia Lactec Incharge
Start and end date	19/12/2019 – 18/06/2022
Level of interaction	Intrasystem niche-regime Intersystem niche-regime Intersystem niche-niche
Mode of interaction	Competition Symbiosis
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions

Category	Classification
	Niche consolidation - build new networks of actors Niche consolidation - create learning process at multiple dimensions
Value-chain level of interaction	Focus on complementary technologies
Resources exchanged in the experiment	Capital Knowledge People
Impact of transnational linkages on the experiment	Transnational linkages are present but do not influence de experiment

Source: Developed by the author based on ANEEL (2019al)

E.31 PD-00063-3060

This is another experiment proposed by CPFL Paulista. The experiment aim is to implement and maintain during 48 months two electromobility Living Labs[109] in two different Brazilian cities to achieve several different goals related to electromobility (ANEEL, 2019am), including: (i) study EV charging stations efficiency, (ii) do a lifecycle analysis of EV's batteries, (iii) evaluate the impacts of scaling up EV use, (iv) train professional to work in electromobility, and (v) develop new services related to EV charging. The estimated cost of the experiment is R$ 70,398,879.07.

ANEEL (2019am) reproved the original proposal of this experiment because of the excessive number (117) of EVs that would be purchased and the inadequate characterization of the counterpart from the organizations involved. In this original version, the estimated cost of the experiment was R$ 88,602,773.83. Nonetheless, the agency evaluated that this proposal was original, had reasonable applicability and good relevance (ANEEL, 2019am). The agency even praised some aspects of the experiment, such as testing several different business models for EV charging stations (ANEEL, 2019am). After a review of the proposal by CPFL Paulista, in which the experiment's estimated cost was significantly reduced and the participants' counterpart increased, ANEEL (2019e) approved the proposal.

[109] Living Labs can be defined as "rigorous campus-based research with operational, academic partners, sustainable data collection/analysis, formal and informal learning activities and measurable outcomes" (MIT, 2021).

Many of the organizations involved in PD-00063-3059, PD-00063-3061, and PD-00063-3062 are also participating in this experiment: CPFL Paulista, CPFL Piratininga, and RGE Sul (CPFL ENERGIA, 2021). The other organizations are Companhia Jaguari de Energia (CPFL Jaguari), Fundação CPQD, MGE Mediçoes Elétricas, CAS Tecnologia, Wax Engenharia, Unicamp, Andrade Analytics, and SENAI.

As detailed in previous sections, CPFL Paulista, CPFL Piratininga, and RGE Sul are actors of the Distribution ST-regime. CPFL Jaguari is also a subsidiary of CPFL Energia (CPFL ENERGIA, 2021), and an actor of the Distribution ST-regime. Besides, Fundação CPQD can be considered an actor of the consumption management niche and SENAI can be classified as an actor of many ST-regimes from both the electricity and the urban mobility ST-system, as detailed in previous sections.

The Laboratório de Estudos do Veículo Elétrico (LEVE) is Unicamp's section that is participating in the experiment. LEVE does research on several themes related to EVs (LEVE, 2021) and can be considered an actor of the electric car niche.

MGE Medições Elétricas develops technology in electricity measurement. It can be considered part of the Distribution ST-regime. CAS Tecnologia develops solutions to several different business using technologies such as IoT, AI, and neural networks. It has done several projects of smart grids for electricity distribution companies (CAS TECNOLOGIA, 2021). Thus, CAS Tecnologia can also be considered part of the Distribution ST-regime. Wax Engenharia offers solutions in several sectors, including for electricity grids operators. In the context of this experiment, it can be considered an actor of the Distribution ST-regime. Finally, it was not possible to identify what Andrade Analytics does.

There are interactions in all the levels, except intrasystem niche-niche. Besides, there are at least two modes of interaction, which have been characterized in previous sections (see Sections E.1, E.2, E.5, E.6, E.9, E.12, E.15, and E.16). The mode of interaction between the Distribution ST-regime and the consumption management and electric car niches is competition and symbiosis, respectively. Besides, there is symbiosis between these two niches.

The main resources exchanged should be capital, knowledge, and people. Besides, there is no indication that transnational linkages will be relevant in the experiment, although they are present (see Section E.9).

The value-chain level of interaction of this experiment is the main technology, i.e., the EVs. The experiment's impacts will probably be limited to niche consolidation, including articulating expectations and views, building networks of actors, and creating learning process. There is no indication that the experiment will contribute to destabilize the private car ST-regime. The characterization of the experiment is resumed in Table E.31.

Table E.31 – Characterization of experiment PD-00063-3060

Category	Classification
Actors involved	CPFL Paulista CPFL Piratininga CPFL Jaguari RGE Sul Fundação CPQD SENAI Unicamp MGE Medições Elétricas CAS Tecnologia WAX Engenharia Andrade Analytics
Start and end date	20/12/2019 – 19/12/2023
Level of interaction	Intrasystem niche-regime Intrasystem regime-regime Intersystem niche-niche Intersystem niche-regime Intersystem regime-regime
Mode of interaction	Competition Symbiosis
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions Niche consolidation - build new networks of actors

Category	Classification
	Niche consolidation - create learning process at multiple dimensions
Value-chain level of interaction	Focus on the main technology
Resources exchanged in the experiment	Capital Knowledge People
Impact of transnational linkages on the experiment	Transnational linkages are present but do not influence the experiment

Source: Developed by the author based on ANEEL (2019e, 2019am)

E.32 PD-00064-1058

This experiment was proposed by AES Brasil, a subsidiary of the North American corporation AES (AES, 2021). The experiment focuses on the development and operation of a digital platform with EV recharge infrastructure (ANEEL, 2019f). It also includes the development of a smart EV home charger. The estimated cost of the experiment is R$ 5,358,003.73.

ANEEL (2019an) considered that this proposal did not meet the requirements of originality, adequacy and applicability of SRDP-22. The experiment's estimated cost was not even evaluated, and the proposal was reproved. The agency reassessed the proposal after it was reviewed by AES Brasil. ANEEL (2019f, 2019ao) considered that this new version of the proposal was original, had reasonable applicability and relevance, and its costs were compatible with the scope of the project. Nonetheless, the agency still requested several adjustments in the proposal (ANEEL, 2019f, 2019ao).

Only four actors are involved in this experiment: AES Brasil, Barassa & Cruz Consulting (BC Consulting), movE, and Electromobility Brasil. As described in Section E.27, AES Brasil is part of the Large hydroelectric, Small hydroelectric, Wind, and Solar ST-regimes. BC Consulting designs technology roadmaps, structures governance platforms, and maps instruments and public policies for Science, Technology, and Innovation (BC CONSULTING, 2021). It has worked for many companies of the electricity ST-systems and can be considered part of this ST-system. However, BC Consulting is not part of any specific ST-regime or niche. The startup movE offers a digital platform for managing and controlling electric vehicle recharges (MOVE, 2021).

It is an actor of the electric car niche. As detailed in Section E.2, Electric Mobility Brasil is part of the electric car niche.

There are interactions in only one level of interaction in this experiment: intersystem niche-regime. Besides, there are only two modes of interaction, which have been characterized in previous sections (see Sections E.1, E.2, E.5, E.6, E.9, E.12, E.15, and E.16). The mode of interaction between the Large hydroelectric, Small hydroelectric, Wind, and Solar ST-regimes is competition. The interaction of these ST-regimes with the electric car niche is symbiosis.

The main resources exchanged should be capital (mainly from AES Brasil to the other participants), knowledge, and people. Although AES Brasil is part of a multinational holding, there is no indication that transnational linkages will be relevant to this experiment, as no exchange of resources with international partners is planned. Finally, the experiment focus on a platform that is complementary to EVs.

The experiment's impacts will probably be limited to niche consolidation, including articulating expectations and views, building networks of actors, and creating learning process. There is no indication that the experiment will contribute to destabilize the private car ST-regime. The characterization of the experiment is resumed in Table E.32.

Table E.32 – Characterization of experiment PD-00064-1058

Category	Classification
Actors involved	AES Brasil BC Consulting movE Electric Mobility Brasil
Start and end date	Not informed – Duration of 30 months
Level of interaction	Intersystem niche-regime
Mode of interaction	Competition Symbiosis
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions Niche consolidation - build new networks of actors Niche consolidation - create learning process at multiple dimensions

Category	Classification
Value-chain level of interaction	Focus on the main technology
Resources exchanged in the experiment	Capital Knowledge People
Impact of transnational linkages on the experiment	Transnational linkages are present but do not influence de experiment

Source: Developed by the author based on ANEEL (2019an, 2019f, 2019ao)

E.33 PD-02866-0517

This is another experiment proposed by COPEL Distribuição. The experiment main goal is to develop an EV charging station integrated with a renewable energy sources and an energy storage system, to ensure comfort and safety for users of EVs and energy security for the electricity grid (ANEEL, 2019ap). The charging station will be managed by a system that is fully integrated to the local electricity distribution company and optimizes each of the station's subsystems (EV charging and energy generation and storage). The estimated cost of the experiment is R$ 10,364,110.85 (ANEEL, 2019ap).

ANEEL (2019ap) considered that this proposal was original, had good applicability and relevance. ANEEL (2019ap) highlighted that, when the system is ready, it will be easy for other electricity distributors to incorporate it. However, the agency reproved this proposal because COPEL Distribuição did not present the Economic Feasibility Study of the experiment (ANEEL, 2019ap). After a review of the proposal by COPEL Distribuição, in which the experiment's Economic Feasibility Study was presented, ANEEL (2019e) approved the proposal. Besides, the experiment's estimated cost was reduced to R$ 7,106,590.59 (ANEEL, 2019g).

The experiment has the involvement of three organizations: COPEL Distribuição, Lactec, and WEG. As detailed in the previous sections, COPEL is an actor of the Distribution ST-regime, Lactec can be considered part of the electric car, battery, and distributed generation niches, and WEG can be considered part of the Distribution and Transmission ST-regimes and the electric car niche.

Although there are only three actors in the experiment, there are interactions in four levels: intrasystem niche-regime, intrasystem niche-niche, intersystem niche-regime, and intersystem niche-niche. Besides, there are three modes of interaction, which have been characterized in previous sections (see Sections E.1, E.2, E.5, E.6, E.9, E.12, E.15, and

E.16). The mode of interaction between the Distribution ST-regime and the electric car, battery, and distributed generation niches is symbiosis, competition, and commensalism, respectively. Besides, there is symbiosis between these three niches.

The main resources exchanged should be capital, knowledge, and people. COPEL Distribuição will be the main source of all these resources, especially capital. Besides, there are no transnational linkages present in the experiment. The EV charging station that is the focus of the experiment is a complementary technology to EVs

The experiment's impacts will probably be limited to niche consolidation, including articulating expectations and views, building networks of actors, and creating learning process. There is no indication that the experiment will contribute to destabilize the private car ST-regime. The characterization of the experiment is resumed in Table E.33.

Table E.33 – Characterization of experiment PD-02866-0517

Category	Classification
Actors involved	COPEL Distribuição Lactec WEG
Start and end date	Not informed – Duration of 36 months
Level of interaction	Intrasystem niche-niche Intrasystem niche-regime Intersystem niche-niche Intersystem niche-regime
Mode of interaction	Competition Symbiosis Commensalism
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions Niche consolidation - build new networks of actors Niche consolidation - create learning process at multiple dimensions
Value-chain level of interaction	Focus on complementary technologies
Resources exchanged in the experiment	Capital

Category	Classification
	Knowledge People
Impact of transnational linkages on the experiment	Transnational linkages are not present

Source: Developed by the author based on ANEEL (2019e, 2019ap)

E.34 PD-03052-0004

This experiment was proposed by Monel Monjolinho Energética, a subsidiary of the Statkraft Energias Renováveis (STATKRAFT ENERGIAS RENOVÁVEIS, 2020), which is part of the Norwegian energy group Statkraft (STATKRAFT, 2021). The experiment's objective is to develop a fast charging station for heavy duty EVs, with solar photovoltaic generation as the primary source and recycled second-life lithium ion batteries as the stationary energy storage system (ANEEL, 2019aq). This system will be installed in UFSC campus and the university's electric bus[110] will be used to tests the system. The estimated cost of the experiment is R$ 2,477,200.00 (ANEEL, 2019aq).

ANEEL (2019aq) considered that this proposal was original and had reasonable applicability and relevance. The agency highlighted that the use of second-life batteries in the energy storage system can create a new market to these batteries. Besides, this energy storage system can mitigate the impact of EV charging on the electricity grid. However, ANEEL (2019aq) reproved this proposal because Monel Monjolinho Energética did not present the Economic Feasibility Study of the experiment and did not specify the role of BYD Brasil in the experiment. Monel Monjolinho Energética submitted a reviewed version of the proposal to ANEEL (ANEEL, 2019h). In this version, the company presented the experiment's Economic Feasibility Study and clarified that BYD will be the supplier of the second-life batteries that will be used in the experiment. This reviewed version of the proposal was approved by ANEEL (2019h).

There are five organizations participating of the experiment: Monel Monjolinho Energética, Statkraft Energias Renováveis, BYD Brasil, UFSC, and Fundação Stemmer para Pesquisa, Desenvolvimento e Inovação (FEESC). Monel Monjolinho Energética operates the hydroelectric power plant Monjolinho (STATKRAFT ENERGIAS RENOVÁVEIS, 2020), and is an actor of the Large hydroelectric ST-regime. Statkraft

[110] Vehicle classified in EU category M3.

Energias Renováveis operates several large and small hydroelectric power plants and wind farms (STATKRAFT ENERGIAS RENOVÁVEIS, 2020). Therefore, it can be considered part of the Large hydroelectric, Small hydroelectric, and Wind ST-regimes. As detailed in previous sections, BYD Brasil is an actor of the Solar ST-regime and the battery and electric car niches.

The other two organizations involved in the experiment are education and research institutions. The section of UFSC participating is the Grupo de Pesquisa Estratégica em Energia Solar (FV-UFSC). FV-UFSC does studies in various areas of application of solar energy in Brazil (FV-UFSC, 2021). Thus, it can be considered part of the Solar ST-regime. FEESC manages teaching, research, extension, and institutional, scientific, and technological development projects for UFSC and some other education and research institutions from Santa Catarina. It is only involved in the experiment to manage the resources that will be transferred to UFSC. Therefore, it should not be considered as an actor of any ST-regime or niche of the electricity or urban mobility ST-systems.

There are interactions in four levels: intrasystem niche-regime, intrasystem regime-regime intrasystem, and niche-regime intersystem. All the modes of interaction in this experiment have been characterized in previous sections (see Sections E.1, E.2, E.5, E.6, E.9, E.12, E.15, and E.16). The mode of interaction between Large hydroelectric, Small hydroelectric, Wind, and Solar ST-regimes is competition. There is symbiosis between these ST-regimes and the electric car and battery niches. Finally, the mode of interaction between the electric car and the battery niche is also symbiosis.

The main resources exchanged should be capital, knowledge, and people. Although Monel Monjolinho Energética, Statkraft Energias Renováveis, and BYD Brasil are part of a multinational holdings, there is no indication that transnational linkages will be relevant to this experiment, as no exchange of resources with international partners is planned. Finally, the experiment focuses on a complementary technology to EVs, i.e., charging stations.

The experiment's impacts will probably be limited to niche consolidation, including articulating expectations and views, building networks of actors, and creating learning process. There is no indication that the experiment will contribute to destabilize the private car ST-regime. The characterization of the experiment is resumed in Table E.34.

Table E.34 – Characterization of experiment PD-03052-0004

Category	Classification
Actors involved	Monel Monjolinho Energética Statkraft Energias Renováveis BYD Brasil UFSC FEESC
Start and end date	Not informed
Level of interaction	Intrasystem niche-regime Intrasystem regime-regime Intersystem niche-regime
Mode of interaction	Competition Symbiosis
Impact of the experiment on the sustainability transition	Niche consolidation - articulate expectations and visions Niche consolidation - build new networks of actors Niche consolidation - create learning process at multiple dimensions
Value-chain level of interaction	Focus on complementary technologies
Resources exchanged in the experiment	Capital Knowledge People
Impact of transnational linkages on the experiment	Transnational linkages are present but do not influence de experiment

Source: Developed by the author based on ANEEL (2019h, 2019aq)

E.35 PD-00394-1902

This experiment was proposed by Furnas Centrais Elétricas (Furnas), a subsidiary of the public company Eletrobras (ELETROBRAS, 2021). The experiment's objective was to develop a business plan that enables the implementation of hybrid and 100% electric buses in the Brazilian urban mobility system (ANEEL, 2019ar). However, ANEEL (2019ar) considered that this proposal did not meet the requirements of SRDP-

22 because the experiment's results would not reach the last stages of ANEEL's innovation chain. Therefore, the agency reproved this proposal (ANEEL, 2019ar).

E.36 PD-00394-1903

This experiment was also proposed by Furnas. The experiment's objective was to study the diffusion of EVs in Brazil and how this process will impact the Brazilian electricity system, especially in the case of companies operating in Brazil (ANEEL, 2019as). However, ANEEL (2019as) considered that this proposal did not meet the requirements of SRDP-22 because the experiment's results would not reach the last stages of ANEEL's innovation chain. Therefore, the agency reproved this proposal (ANEEL, 2019as).

E.37 PD-05697-0119

This experiment was proposed by Celesc D. The main goal was to optimize and implement a new business model for Celesc D's EV charging network. In the new model, the charging stations would be installed in third-party properties, such as malls, supermarkets, and gas stations, instead of public spaces (ANEEL, 2019at). The experiment included the installation of 40 new charging stations. The estimated cost of the experiment was R$ 6,223,913.73 (ANEEL, 2019at)

Although ANEEL (2019at) considered the experiment original and relevant, the agency criticized several points of the proposal. ANEEL (2019at) complained that there was no plan to manage the new charging stations after the experiment conclusion. Besides, it was not clear in the proposal who would manage and own the new charging stations, Celesc D or the properties' owners. Finally, Celesc D did not present the Economic Feasibility Study of the experiment (ANEEL, 2019at, 2019au). Therefore, ANEEL (2019at) reproved the proposal. Celesc D presented a reviewed version of the proposal but ANEEL (2019au) concluded that this version still did not meet the requirements of SRDP-22 and should not be approved.

E.38 PD-06072-0664

This experiment was proposed by Celg Distribuição, a subsidiary of Enel Brasil, which is owned by the Italian holding Enel SpA (ENEL BRASIL, 2020). The experiment's objective was to bring to Brazil an Italian technology used to manage Distributed Energy Resources with interoperability between customers and service providers (ANEEL, 2019av). The experiment included the installation of a laboratory at

University of Brasília (UnB), and four charging stations for field tests in Brasília, Goiânia, São Paulo, and the BR-060 highway. The estimated cost of the experiment was R$ 37,996,656.00 (ANEEL, 2019av).

ANEEL (2019av) considered that this proposal was original and had reasonable applicability and relevance. However, the agency (2019av) considered that this proposal did not meet the requirements of SRDP-22, as Celg Distribuição did not detailed the counterpart of the organizations involved in the experiment and did not present the Economic Feasibility Study of the experiment. Therefore, the agency reproved this proposal (ANEEL, 2019av).