Master's Thesis – Sustainable Business and Innovation

Solar Electric Vehicles with Distributed Energy Storage in the European energy transition

A socio-technical system analysis

Author: Jim Böck 1886460

Supervisor: 1st Prof. Wilfried van Sark – Energy Sciences

2nd Prof. Simona de Negro – Sustainable Business & Innovation

Image generated by MidJourneyAI (2023), see Annex IIII for text prompt.

Universiteit Utrecht

Abstract

This research explores the potential of integrating Solar Electric Vehicles (SEVs) with Decentralized Energy Systems (DES) as a sustainable solution in Europe's energy and mobility transitions. By employing the Business Model Design Space (BMDS) and Multi-Level Perspective (MLP) frameworks, this study examines the drivers, barriers, opportunities, Business Model Innovation (BMI), technical specifications, digitalization, and policy measures associated with SEVs and DES in a socio-technical transition.

The findings emphasize the need for a paradigm shift in the European automotive industry, promoting alternative socio-technical energy and personal mobility systems that align with principles of democracy and sustainability. By offering innovative sustainable products and services, SEVs with DES can redefine customers' emotional relationships with conventional automobile paradigms and energy use, thereby inspiring collective reimagination of existing systems. By integrating SEVs with DES and Mobility-as-a-Service (MaaS) platforms, this BMI offers revolutionary customer experiences while reducing GHG emissions and minimizing environmental impact. The value capture opportunities arise from new revenue streams through MaaS and energy communities, fostering job creation along value networks.

The challenges lie in the technological and regulatory dimensions, highlighting the need for a technological benchmark for SEVs and harmonized regulations across European member states. Additionally, policy measures should facilitate the development of Vehicle-to-Grid (V2G) capabilities, virtual power plants, and peer-to-peer trading. Open innovation, data privacy and security, interoperability, and efficient IT infrastructures are crucial for the successful development of SEV systems.

Cross-sectoral collaboration between SEV niche-industry coalitions, governments, and industry incumbents is essential to overcome resource limitations and provide a platform for innovation in the SEV industry. The findings emphasize the importance of supporting niche-innovators and developing European standards and policies to enable SEVs with DES in Europe's sustainable energy and mobility transition.

While the study focuses on Western European energy systems, the BMDS and MLP methodology can be applied to comparative system analyses globally. Limitations include the need for further exploration of socially innovative methodologies to mitigate rebound effects associated with market-based solutions.

In conclusion, SEVs with DES have the potential to revolutionize the European energy transition by offering sustainable personal mobility and clean energy solutions. To realize this potential, greater investment in research and development, cross-sectoral collaboration, and the development of European standards for SEVs are necessary. By catalyzing the sustainability efforts of energy and mobility systems and inspiring users towards more sustainable norms and behaviors, SEVs with DES can contribute to the achievement of targets outlined in the European Climate Law.

Contents

Table of abbreviations

BEV	Battery Electric Vehicle
BMDS	Business Model Design Space
BMI	Business Model Innovation
DER	Distributed Energy Resource
DES	Distributed Energy Storage
EV	Electric Vehicle
GHG	Greenhouse Gas
MaaS	Mobility-as-a-Service
MLP	Multi-level Perspective
RES	Renewable Energy Source
SEV	Solar Electric Vehicle
V2G	Vehicle-to-Grid
V2H	Vehicle-to-Home
V2L	Vehicle-to-Load
V2X	Vehicle-to-Anything
VIPV	Vehicle Integrated Photovoltaic

1 Introduction

With conviction in technological development to prevent climate risk, fossil-fueled energy systems of the world's largest economies must undergo a critical transformation towards renewable energy systems (Rothfuß & Boamah, 2020). This path requires systemic measures to keep the global mean temperature rise below 1.5 to 2°C relative to pre-industrial levels, as recommended by the Intergovernmental Panel on Climate Change (IPCC) and as commenced in the Paris Agreement (United Nations, 2015; IPCC, 2022). In line with the Paris Agreement, the European Commission adopted the European Climate Law (European Union, 2021), which enshrines the European Green Deal's goals to become climate-neutral by 2050 in law. Thereby, the European Commission is committed to a 55% reduction of greenhouse gasses (GHGs) compared to 1990 emissions by 2030. If the ambitions are realized, Europe will become the first climate-neutral continent in 2050 (European Commission, 2021c). The European Union's (2021) law acknowledges, among other things, that renewable energy and energy efficiency are crucial for delivering its targets.

1.1 Problem statement

Between 1990 and 2019, climate and energy policies have reported emission reductions for all sectors in Europe, however, road transport emissions have increased by almost 28%. In 2019, road transport was responsible for 17% of Europe's GHG emissions (Figure 1). Beyond transitioning from Internal Combustion Vehicles (ICEVs) to Electric Vehicles (EVs), there is a need for higher energy efficiency vehicles (European

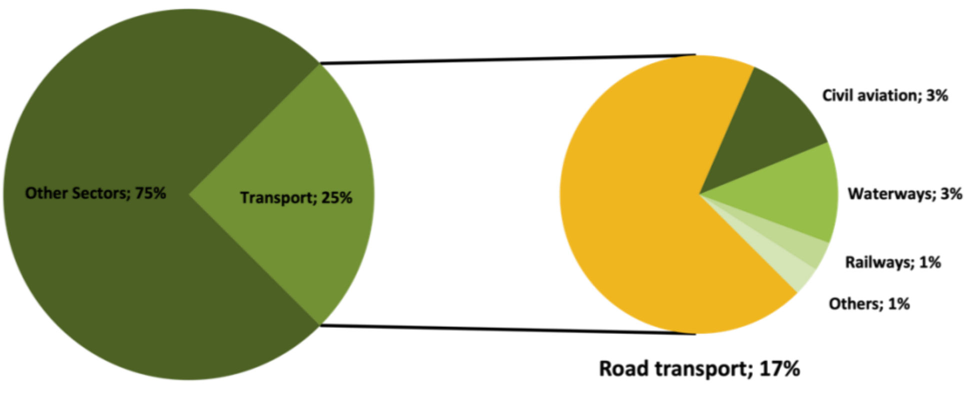

Figure 1: the 2019 GHG emissions of the European transport sector in relation to other sectors, and road transport (European Commission, 2019; European Environmental Agency, 2022)

Environmental Agency, 2022).

In the last decade, Battery Electric Vehicles (BEVs) have shown promising potential in enabling pathways toward more sustainable energy and mobility systems (Wainstein & Bumpus, 2016; Berkeley et al., 2017; Kumar & Alok, 2020; Xu et al., 2021). BEVs have practically no tailpipe emissions compared to internal combustion ICEVs. However, BEVs rely solely on the local electricity supply to charge their batteries and are therefore still responsible for a significant amount of GHG emissions, as carbon footprint of electricity for charging is still appreciable, depending on the country. Europe's renewable energy consumption in 2020 indicates that in general, only 22% of the electricity used for among others charging BEVs came from renewable sources (European Environmental Agency, 2022). A quarter of all European GHG emissions come from the transport sector (European Commission, 2019).

In 2021, the European Commission revised the Renewable Energy Directive (RED) to increase the 2030 target for the share of renewables in the European energy mix to 40% and increase energy efficiency to 36% (European Commission, 2021b). In response to the Russian invasion of Ukraine, the European Commission initiated the REPowerEU plan to reduce dependence on Russian fossil fuel imports (European Commission, 2022). This plan includes an additional 5% increase in the 2030 target for renewables and a 4% increase in energy efficiency and regulatory measures to increase energy efficiency, specifically in the transport sector.

These ambitious targets require a rapid increase of Renewable Energy Sources (RESs) in the European grid. The intermittent nature of the most abundant RESs, such as solar and wind, causes a significant increase in the demand for energy storage for flexibility services. Unlocking the demand side of flexibility with Distributed Energy Resources (DERs) and empowerment of customers is crucial for the energy transition (Lampropoulos et al., 2018). As such, the technological transition from fossil to RESs goes along with a transition from a centralized unidirectional industry, towards a decentralized multidirectional energy society (Burke & Stephens, 2018; Brisbois, 2019; Parra & Mauger, 2022; Valdivia & Balcell, 2022).

As part of such a collective flexibility solution, many have proposed to extend the value and functionality of BEVs from personal mobility to complementary solutions like Distributed Energy Storage (DES) (Lampropoulos et al., 2013; Cardoso et al., 2020; van Oorschot, 2022). Hildermeier et al. (2019) explain that about 85% of the BEV's operational lifetime can be utilized for flexibility services. Besides, unrestrained BEV charging causes additional load on the grid, especially during afternoon peaks (Yong et al., 2015). This enables new revenue models for BEVs, like Demand Response and Vehicle-2-Grid (V2G), which encourage Mobility as a Service (MaaS) business models (Bohnsack et al., 2014; Gerritsma et al., 2019; Hildermeier et al., 2019; Corinaldesi et al., 2022). Shared car ownership would directly decrease material throughput (Prettenthaler & Steininger, 1999; Carrara et al., 2023). Beyond that, such value propositions can further drive social and technological change in incumbent automobile and energy paradigms (Bocken et al., 2014; Wainstein & Bumpus, 2016).

As an evolutionary child of the BEV, two European entrepreneurial firms have developed Solar Electric Vehicles (SEVs) (Lightyear, 2023b; Sono 2023). In essence, SEVs yield energy with their Vehicle Integrated Photovoltaics (VIPV), are energy efficient, and have a sustainability-centered design. For example, the Dutch Lightyear 0 concept vehicle reaches high efficiency of only 9.8 kWh per 100 km (Lightyear, 2023b), making it 50% more efficient compared to the most efficient commercial EV today (Tesla, 2022). In other words, the SEV's synergetic integration of a RES, DES, and (shared) mobility, efficiently combines automotive and energy functionalities into one product. As such, SEVs could embody the technical conditions necessary for innovative business models that drive the energy transition. However, both Lightyear and Sono have recently terminated the development of their first vehicles due to financial constraints (Lightyear, 2023a; Sono Motors, 2023).

This research will explore the barriers, drivers, and opportunities for SEVs in the evolution of BEVs. Through a system analysis, this paper explores the potential of SEVs with DES to catalyze the systemic paradigm shift necessary to achieve the European Climate Law targets and reveals how stakeholders can enhance their strategic alignment toward each other to accomplish this.

1.2 Research gap

Despite public controversies and scientific consensus concerning the social and environmental impacts of global BEV supply chains (Rajaeifar et al., 2022), and the evident sustainability benefits of SEV technology, SEVs remain relatively under-researched in sustainability literature.

Rogge & Reichardt (2016) argue that interdisciplinary research can enable more precise policy recommendations and that interdisciplinary policy mixes can help redirect and accelerate technological change towards sustainability objectives. Such interdisciplinary research involves an analysis of complex (Mikulecky, 2001), multi-dimensional systems, found in a research area known as sustainability transition studies (Köhler et al., 2019). Much sustainability transition research evolves from the intersections of multiple scientific disciplines. In this study, these multiple issues at hand will be articulated through the single case of DES with SEVs.

In prior research, Wainstein & Bumpus (2016) noticed a research gap in the impact of business models on interactions between incumbent and new business actors in the energy system; using the Multi-Level Perspective framework (MLP), they showed how business models can be relevant for energy system transition research. Wesseling et al. (2020) offered the Business Model Design Space (BMDS) framework, which connects firm- and system levels to facilitate the exploration of how much novelty niche actors can introduce into a socio-technical system. Although some have applied this framework to study Business Model Innovation (BMI) for EVs with DES, no research has been found where the framework is used to analyze BMI for SEVs with DES, leaving a knowledge gap in the relations and interactions of socio-technical paradigms between European incumbent and niche-level (S)EV firms. In other words, the scientific literature has not yet provided a comprehensive insight into the impact of SEVs on existing automotive and energy regimes, and society.

1.3 Research questions

This study explores if and how BMI for SEVs with DES can help catalyze the systemic paradigm shift necessary to achieve the European Climate Law targets. It aims to reveal drivers, barriers, and opportunities of niche-level BMI for the sustainability transition in the European energy system and derive empirical recommendations. By collecting and examining empirical perspectives around state-of-the-art developments for SEVs with DES against the background of a socio-technical system transition research framework, this study looks for optimal regulatory conditions that could facilitate BMIs to drive the energy transition forward, as well as internal alignments for SEV pioneers.

The main research question is:

- What is the potential role of Solar Electric Vehicles with Distributed Energy Storage in the European transition towards a sustainable energy system?

This research question can be divided into multiple sub-questions:

- What are technical specifications of Solar Electric Vehicles with Distributed Energy Storage?
- What are the drivers, barriers, and opportunities of the sustainability transition in the European energy and mobility systems?
- How can the digitalization of automotive and energy systems contribute to a democratic and sustainable European energy transition?
- How can Business Model Innovation for Solar Electric Vehicles with Distributed Energy Storage contribute to the European energy and mobility transition?
- How can Business Model Innovation for Solar Electric Vehicles with Distributed Energy Storage manifest in the Business Model Design Space?
- What measures would facilitate the development of Business Model Innovation for Distributed Energy Storage with Solar Electric Vehicles?

The scope and research questions enable the research to go beyond conventional BEV discourses and enable passages towards system-wide realignments for holistic, democratic, sustainable, and user-centered energy and mobility systems. The study builds from a technical understanding of SEVs with DES and is substantiated by the empirical perspectives of diverse experts in the socio-technical system. Illuminating the innovation through MLP and BMDS frameworks facilitates the evaluation of how various levels and dimensions in the socio-technical system interact. This provides insights into why and how SEVs should and can be sufficiently supported.

1.4 Literature review

Holtz (2012) acknowledged the need to empirically ground abstract discussions in transition research to bridge the gap between abstract frameworks and tangible policy development. Berkeley et al. (2017) explored multi-level forces against BEV market penetration and argued that more holistic and effective policies were required. Köhler et al. (2019) explain that sustainability transition research needs to exercise caution for abstractions and oversimplification of complex unfolding processes of events. Ford and Newell (2021) combined Multi-Level and neo-Gramscian perspectives to dissect power and political dynamics in the sustainability transition of energy regimes, thereby exposing resistant operations of incumbent actors. By analyzing the low-carbon energy system transition, Wainstein & Bumpus (2016) show how BMIs in electricity markets will have an important impact on future energy transition research. Huijben et al. (2016) introduced the concept of BMDS and demonstrated that BMI, sometimes in combination with technological innovation, can stretch the regulatory regime. Wesseling et al. (2020) argued that the confinement of BMDS to the regulatory regime was unnecessarily limiting, and expanded this view and conceptualized the BMDS framework into five dimensions of a socio-technical system.

In the wake of prior research, this proposed study employs empirical developments to map the BMDS for SEVs with DES and use this to reveal potential reconfigurations at the regime-level through BMI. This case study should help overcome common abstractions of existing socio-technical analysis as noted by (Holtz, 2012; Wainstein & Bumpus, 2016; Köhler et al., 2019), and could enable new insights for policymakers that seek to optimize drivers for the sustainability transition. By exposing differences in innovation pathways of incumbent and niche actors with empirical cases, this study contributes to the body of research that approximates the impact of BMI on socio-technical sustainability transitions. Contrary to the contemporary echo chamber in energy and personal mobility transition research that is mostly focused on the transition from ICEVs to BEVs, the outstanding case of SEVs might enrich and empower alternative imaginations of sustainability of automotive industries. Future studies might generalize the findings of this research with caution or use its methods to assess comparable socio-technical matters.

1.5 Societal relevance

With sufficient public backing to scale up, SEVs can significantly reduce the EU's reliance on raw materials, fossil fuels, and associated social and environmental impacts. Most research projects at Lightyear are conducted by Dutch technical universities, which primarily focus on environmental, energy management, and techno-economic quantifications (Juch, 2022; van Oorschot, 2022; Thewessen, 2023). However, the social aspects of these projects remain underexplored. The Copernicus Institute of Sustainable Development at Utrecht University occupies a unique position in the interdisciplinary realm of natural and social sciences, contributing to the Dutch and European SEV research field. By moving beyond the arena of automotive and energy economics and company politics, this study helps to initiate and guide the discussion for the expansion of industry incentives for the development of highly efficient vehicles and SEVs.

By assuming that regulators take responsible action for sustainability, this research aims to bridge levels of abstraction between which policymakers must navigate. By doing so, it could help accelerate the realization of the EU's commitments to increase consumption of renewable electricity sources and become energy independent. Recommendations that result from this study may level the playing field between automotive incumbents and niche-level SEV pioneers and thereby decrease the costs of sustainable energy and personal mobility for European citizens.

2 Theory

The socio-technical (ST) system is a dynamic construct that emerges from the sum of its components. This study builds on MLP theories, which illuminate key insights into three different levels of the socio-technical system that influence and sometimes overlap each other (Geels, 2012). Based on the BMDS framework presented by Wesseling et al. (2020), this study explores potential transitions in energy and mobility systems by illuminating the multi-dimensional design space in which BMI for SEVs with DES are allowed to develop. By extrapolating multi-level and multi-dimensional dynamics, a comprehensive socio-technical system analysis emerges (Figure 2). The next paragraph elaborates the theories in more detail individually, and an overview of the integrated conceptual framework is presented in Figure 2.

Because many innovative developments in Europe have in common that they depend on various parts of the same ST system, the results of this study may overlap with studies in other innovation cases.

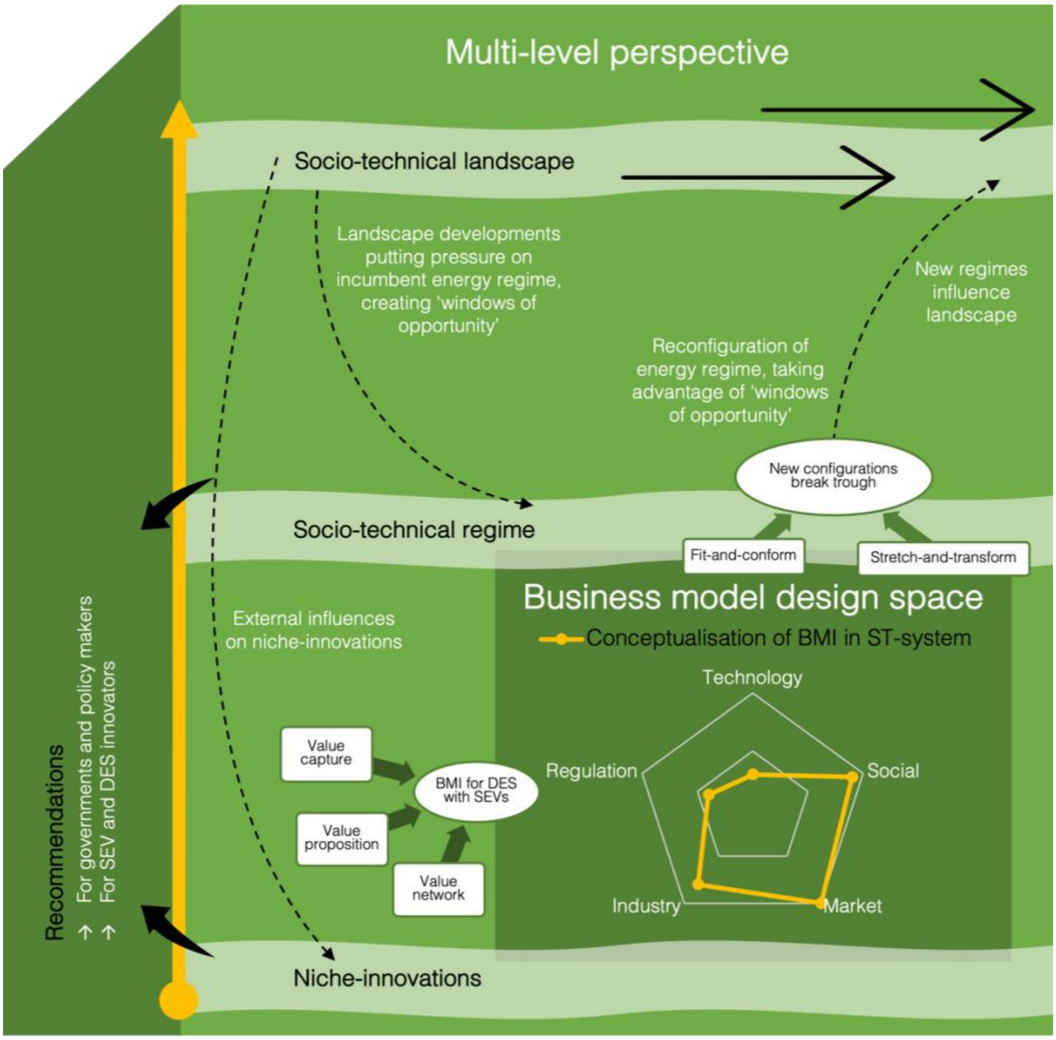

Figure 2: The theory offers an analytical framework that connects system- and firm-level dynamics and interactions. On the system-level, the MLP framework provides context of the socio-technical transition. Most significantly for this research, the BMDS framework is integrated to explore the potentials and effects of firm-level BMI on the contextual system and vice versa.

2.1 The Multi-Level Perspective

The MLP framework (Geels, 2012) was developed with the argument that transitions can be explained through dynamic processes between three analytical levels, see Figure 1.

The niche-level (1) can be seen as a protected space and nursery for niche innovations that emerge, by definition, in the face of a (2) socio-technical regime (Walrave et al., 2018). In this research, SEV start-ups are observed as the niche-level, but they could be different types of actors, such as researchers and early adopters who develop and experiment with new ideas, technologies, and business models (Wainstein & Bumpus, 2016). Higher levels can stimulate activity on the niche-level by pressuring the regime-level (2), or by supporting niches with resources (Berkeley et al., 2017; Ford & Newell, 2021), like for example Europe's key-funding program for research and innovation (*European Commission*, 2021a).

The regime-level (2) focuses on the existing systems, with norms, and practices within specific fields or sectors. It looks at how dominant actors, such as incumbent corporations, industry associations, and governments, maintain and reproduce existing systems and norms. For example, it can be observed in elite networks that gather in Monaco, lining up their private yachts to witness the highly esteemed Formula 1 Grand Prix. This level is also referred to as the socio-technical regime, as it is characterized by resilience and lock-in of technological and social subsystems (Wainstein & Bumpus, 2016). Entities on this level tend to facilitate incremental innovation and impede radical change (Holtz, 2012). Although niche innovations (1) are not always in competition with the regime, they generally counteract the inertia of socio-technical regimes and can thereby disrupt established and incumbent markets (Berkeley et al., 2017). Vis-à-vis, regimes are not always in competition with niche developments, some niche innovations are absorbed by regimes, who then accommodate, and slow down counter-hegemonic developments (Ford & Newell, 2021).

The landscape-level (3) serves as the backdrop for niche-level (1) and regime-level (2) developments (Berkeley et al., 2017). It focuses on the broader context within which a specific field or sector is embedded. This is the least flexible dimension of the framework, as it is defined by gradual and naturally established practices (Wainstein & Bumpus, 2016; Ford & Newell, 2021). It suffers 'landscape shocks' that lead to 'windows of opportunity' for reconfigurations in regimes (Berkeley et al., 2017). For example, European energy prices witnessed a sharp increase following the announcement of cutting Russian gas supply due to the war in Ukraine, creating a significant disruption in the energy landscape.

2.2 Business Model Design Space

In this study, the multi-level system analysis with the MLP functions as a contextual framework. It is combined with a multi-dimensional dissection of the socio-technical system based on the proposed BMDS framework from Wesseling et al. (2020). The BMDS is explored through five socio-technical dimensions:

1. The *Technology* dimension refers to the scientific knowledge and technical capabilities that underpin the development of niche products and services. It relates to the research and development for SEVs with DES and includes the prerequisites like manufacturing capacities, supply chains, and infrastructure.
2. The *Social* dimension is about comparing BMI to cultural values, beliefs, and attitudes in society that influence the acceptance of niche products or services. This research might include, among others, the behavior of end-users in energy systems, or the norms around sustainability in automobile paradigms.
3. The *Market* dimension includes the potential and opportunities for BMI to overcome barriers to large-scale adoption by creating and capturing value for and from customers. In the energy sector, for example, it relates to the economic competitiveness of SEVs with DES compared to other energy storage solutions and potential new customer groups.
4. The *Industry* dimension reflects the structure and dynamics of the competitive and collaborative business environment in which the niche product is developed. It may involve investment, coalition, and acquisition strategies, and the restructuring of value networks for facilitating SEVs with DES.
5. The *Regulation* dimension refers to the governance and political environment and explores how this facilitates or complicates BMI for the niche-level. This ranges from direct subsidies and tax incentives to the political discussions surrounding data-access frameworks. It determines the boundaries in which forms business models for SEVs with DES can be integrated.

In line with earlier BMDS models as proposed by Huijben et al. (2016), the theory suggests that the development and integration of a firm's BMI vary for different value propositions, employing different methods of value capture, and along different value networks. The combination of these methods anticipates two contrasting BMI strategies that describe a firm's expansion into the external regimes and landscapes.

1. With *fit-and-conform* strategies, firms overcome restraints to niche expansion by developing products and services in ways that conform to a regime. These often involve a value network of established industry players, and value-capture and -proposition models that are easy to integrate into the regime's mainstream selection environment.
    - This process has also been described as passive revolution and trasformismo strategies from a neo-Gramscian perspective and is also known as accommodation (Levy and Newell, 2002).
2. Firms that apply *stretch-and-transform* strategies exploit opportunities for niche expansion with products and services that outcompete and replace those of the regime in the context of unmet landscape pressures. Value networks of such BMI appreciate a rich niche ecosystem. Value capture and value proposition methods counteract the mainstream selection environment, and potentially disrupt and replace the regime.

- In the context of technological regimes, these types of strategies are more aligned with path-breaking innovation as mentioned by (Wesseling et al., 2020); Dyerson & Pilkington, 2005).

3 Methodology

The study adopts the structure of a qualitative case study and relies on empirical data obtained through interviews, as well as scientific data from relevant literature. This chapter illuminates the research methods that have been employed in the undertaking of this research.

3.1 Research design

The aim of this research is to unravel the potential of BMI for SEVs with DES in accelerating the sustainability transition in Europe, reveal barriers, and define how key decision-makers can support these path-breaking innovations.

Although the research involves both automotive and energy sectors, its focus on BMI can be considered a case study, which according to Köhler et al. (2019), has been a successful format for articulating complexity in socio-technical system transitions such as the energy transition. Wesseling et al. (2020) argued that case studies enable to differentiate between fit-and-conform and stretch-and-transform strategies and reveal the regulatory conditions necessary to break path dependencies and facilitate creative destruction (Dyerson & Pilkington, 2005). To create a comprehensive overview of the current state of the system through the BMDS framework, various empirical perspectives have been collected during this research and substantiated with scientific and grey literature.

3.2 Data collection

Besides a literature review that formulates a groundwork for this research. The collected data mainly consists of qualitative data, that was gathered in semi-structured interviews with diverse experts (Table 1). This empirical data is supplemented with peer-reviewed, and grey literature discovered through desk research on the internet or recommendations from interviewees. This research project originated from an internship at Lightyear from November 2022, until February 2023 when Lightyear filed for insolvency. This short period provided valuable insights into the Lightyear organization and fostered a network that proved valuable for data collection. Moreover, access to the outstanding theses from preceding graduation interns at Lightyear provides an extra dimension to the data portfolio of this research (Juch, 2022; van Oorschot, 2022; Thewessen, 2023).

3.3 Operationalization

The aggregated research areas in this study can be loosely identified as energy, automotive, sustainability, business, socio-technical transition, and innovation studies. In this multidisciplinary understanding, it will be crucial to consult the interviewed experts in their respective disciplines to achieve well-defined operationalization of the concepts.

Also, academic literature from the different research areas will be compared for unifying concepts appropriately.

For the proper interpretation of the outcomes of this research, it is important to define the main concepts SEV and DES. As such, the individual concepts and combination of those technological and legal definitions are complex, and comprehensively defined in the findings of the report.

Expert	Function	Experience	ST-level	Dimension
B.N. (2023)	Chair of the board @ Alliance for Solar Mobility (ASOM) Head of product solar @ Lightyear	SEVs, Physics Ph.D., photovoltaic technology research and innovation	Niche	Technology, industry & regulation
C.C. (2023)	Policy advisor Greens/EFA @ EU Parliament	Journalism, energy, transport, and mobility	Regime	Regulation
C.G. (2023)	Policy Officer Climate Action @ EU Commission	Climate Action, Transport, and Mobility, Regional Policies	Regime	Regulation
F.B. (2023)	Strategic Business Analyst @ TNO Lecturer @ Rotterdam UAS	Collaborative business models, innovation community business models, business for societal transition	Niche	Social, market
G.H. (2023)	Co-founder @ Energy21 & Quantoz	Data-driven systems for renewable energy, blockchain technology	Niche	Market, industry, technology
K.H. (2023)	Business Developer System Operations Europe @ TenneT Director @ Beheerder Afspraken Stelsel (BAS)	TSO system operations, energy data-agency and standardization	Regime	Industry, regulation
R.J. (2023)	Former lead Energy @ Lightyear Entrepreneur in predictable flexibility @ Simpl Energy	Entrepreneurship, distributed energy systems, energy markets, smart grids	Niche	Market, technology, industry
S.C. (2023)	Co-founder @ Energy21 Director @ Energie Nederland	Entrepreneurship, incumbent innovation, advocacy for energy sector	Regime	Industry, regulation, market
T.L. (2023)	Product manager bi-directional charging @ Sono Motors	SEVs, Energy engineering, business development, funding	Niche	Technology, industry, regulation
T.S. (2023)	Solar team Eindhoven world champion 2014/2015 Former VP Business Development & Strategy @ Lightyear Entrepreneur in predictable flexibility @ Simpl Energy	SEVs, Business development, public affairs, funding, marketing & strategy	Niche	Market, regulation, industry

Table 1: The research mainly relies on semi-structured interviews with 11 diverse empirical experts from automotive and energy sectors, divided over various levels and dimensions of the socio-technical system

The respondents agreed to participate in 60-minute interviews, during which the interviewer briefly presented the research project within the initial 15 minutes. A general interview guide was developed, formatted according to the research questions, and for each interview customized to suit the different proficiencies of the respondents (see Annex III).

3.4 Sampling strategy

Relevant stakeholders in the socio-technical system were selected based on their relations to the different levels in the MLP and dimensions in the BMDS. For example, industry and regulatory experts from both niche-, and regime-level were interviewed.

With a theoretical basis and access to the Lightyear knowledge network, the first strata of potential respondents were identified by quota sampling. The suitability of respondents was determined based on recommendations and professional records. Some respondents naturally emerged through snowball sampling. A conclusive list of the respondents and their specifications is provided in Table 1.

According to Guest et al. (2006) a sample size of twelve participants is considered a good starting point for qualitative research. The limited resources and time constrained this research to eleven interview participants.

3.5 Data analysis

The collected data consists of interviews, recordings, and transcriptions. The data was deductively analyzed by applying the theoretical conceptualizations from existing theoretical foundations, and key themes were identified based on BMDS and MLP frameworks. Subsequently, these key themes were further refined to construct viable answers to the research questions. In other words, a theoretically inspired, directive coding approach was adopted, in which the coding was based on a pre-established list of main categories. The data collection and data analysis were iterative processes, which in practice means that after the interviews were conducted, the data was immediately processed and analyzed so new findings and data gaps were fed back into the ensuing interview guides. The transcribed interviews have been coded using NVivo software, after which the findings from the codes were merged into findings from the desk research.

3.6 Research quality

To ensure the quality of academic data, this research preferred peer-reviewed papers from renowned scientific databases for transition research, like Web of Science and Science Direct. Additionally, valuable grey literature was accessed from reputable sources on the internet.

Interviews have been conducted with acknowledged partners, like working groups, competitors, and other leading actors across different system levels and ST dimensions. As noted by Faber & Fonseca (2014), small sample sizes can potentially compromise the validity of a study by reducing the ability to generalize findings to the larger population. To mitigate this limitation, the study employs a mix of data collection approaches with the aim of gathering a complete set of expert perspectives.

This study is limited by the inimitable perspectives and resources available to the researcher, specifically those of Lightyear, this makes the research unique but limits its transferability. Time constraints have confined the highest potential of data extraction from the participating respondent, although not considerably. Also, some of the interviews have been conducted in Dutch, which may elicit more authentic responses from the interviewees, but requires extra attention in the translation to English during coding. Besides, the individual undertaking for this research project might have influenced the interpretation of raw interview data.

3.7 Ethical considerations

To ensure the ethical handling of issues related to data collection, data handling, and data storage, participants of the interviews have been requested to agree to the standard informed consent form for interviews provided by Utrecht University. The researcher will always ensure integrity to the matters in the agreement.

4 Results

This section presents the most pertinent findings from the collected data, organized according to the five dimensions of the BMDS framework. These dimensions are explored based on the relevant topics derived from diverse data-collection methods. By examining BMIs for SEVs with DES within the BMDS framework, one can deduce stretch-and-transform and fit-and-conform strategies.

4.1 Science & Technology

4.1.1 A technological benchmark for light duty SEVs

Looking at the concept vehicles from Lightyear and Sono Motors, Europe's SEV start-ups, it appears both companies make different design choices (Lightyear, 2023b; Sono, 2023). An extensive table with specifications is provided in Table A1 in Anex I, the most remarkable aspects are discussed in the following.

Figure 3: The Lightyear 0 has an aerodynamic exterior silhouette with large roof surface for VIPV yield optimization and grid-independency, while the Sono Sion has three types of sockets for DES optimization and grid-symbiosis (Lightyear, 2023b; Sono Motors, 2022).

The Lightyear 0 concept vehicle has an aerodynamic exterior silhouette with a low coefficient of drag (Cd 0.175), shaped around its large flat roof and hood surfaces that are equipped with 5m2 VIPV. The characteristic design of the exterior embodies its efficiency-centered technology underneath. To achieve minimal mechanical efficiency losses, it has a highly efficient custom drivetrain consisting of four in-wheel motors. Those are connected to a 60 kWh NMC-811 Li-ion battery, a high energy density power pack generally preferred for lightweight performance. All-in-all, Lightyear boldly claims a practical range of 1000 kilometres*, achievable with an energy efficiency of 9,8 kWh/100 km (WLTP), which is significantly higher than the efficiency of the Sono Sion with 16 kWh/100 km energy efficiency. For reference, the benchmark for commercial EVs is the Tesla Model 3 RWD, which achieves 14,9 kWh/100km efficiency (Tesla, 2022).

Compared to the Lightyear 0, the exterior silhouette of the Sono Sion is not considerably designed around VIPV yield or aerodynamics. It has a 50% larger VIPV surface all-around the body but produces a slightly lower solar yield, and its drag coefficient is unspecified. Despite its lower volume, the vehicle is also 155 kg heavier than the Lightyear 0. The Sion has a standard drive train with a single electric motor driving the front wheels through a mechanical transmission. Yet, Sono is ahead in the development of bi-directional charging and DES systems. Sono was already piloting its systems in close collaboration with local grid operators (T.L., 2023), while Lightyear was still a year away from the piloting phase (R.J., 2023). The maximum discharging rate for Sono was 11kW AC, and the distribution and charging unit of the Lightyear 0 was only able to do DC charging. The Sono delivers 3.6 kW vehicle-to-load (V2L) for compatibility with typical 220V electric devices, while the Lightyear 0 has no V2L socket. Additionally, whereas the Lightyear battery optimizes for lightweight performance, the Sono Sion uses a Li-ion phosphate (LFP) battery, which is generally more used for high-frequency battery cycling applications and reduces degradation. Also, the pre-order price levels were considerably different, with €30 thousand for the Sono, and €250 thousand for the Lightyear (EV Database, 2023).

*Driving range will vary depending on driving habits, location, and season. 1,000 km range based on a 50 km workday commute in Amsterdam during summer.

These differences reveal fundamentally different product strategies. Lightyear is more focused on efficiency, and delivering a high-end, effortless ‘grid-independent’ driving experience, while Sono conceived the Sion as an affordable multi-purpose vehicle to stabilize the grid with bi-directional charging and DES. The first successful technological benchmark for light-duty SEVs is most likely to be somewhere in between these two concept vehicles. For example, this would embody the efficient automotive design from the Lightyear, with a dedication to grid symbiosis as Sono Motors.

4.1.2 A technological benchmark for DES

To overcome the issues of integrating decentralized assets in the energy system on a large scale, a computation system is required to exchange data in a decentralized, verifiable, and immutable way (Van Sark et al., 2020). Challenges for the future system lay in the computational burden for system operators, and the vulnerability to cyber threats of such complex systems (Ma et al., 2021). Distributed Ledger Technologies (DLTs) have been proposed as a potential solution for a transparent, tamper-proof, and secure backbone system for integrating DER devices in the energy system (Andoni et al., 2019).

From the interviews, it appears that there are some challenges to overcome in making DES systems more affordable and user-friendly to achieve democratic access and widespread adoption. Also, not all European member states have the net-metering infrastructure required to support such systems. However, there are no significant technological barriers to developing DES devices. All technological components required for the integration of these systems are already widely available for innovators to put together. Neither Sono nor Lightyear got the opportunity to test their SEVs and DES with commercial customers before they had to terminate the projects.

Although the Lightyear 0 was not optimized for DES, Lightyear Energy had a clear strategy. They were developing an IT system that predicted the optimal charging schedule for customers based on weather forecasts, energy prices, and user preferences. For example, (van Oorschot, 2022) conceived a model that estimated potential revenues from TenneT's balancing markets, the automatic frequency restoration reserve (aFRR) market specifically. With a user-friendly application, customers were helped to optimize the VIPV yield of their SEVs. They could schedule their charging sessions based on predicted hourly prices on day-ahead markets and could potentially adapt their schedule with simple pop-ups that would recommend when to charge, and when to stop charging based on real-time imbalance markets. Besides, Lightyear Energy negotiated with a third-party partner for charging hardware, with energy suppliers for dynamic energy contracts, and internally for configurations of the Lightyear 2.

Utilizing EV batteries for grid balancing with bi-directional charging and DES will cause additional charge and discharge cycles on top of the preliminary one-directional charging cycles. This would cause the EV batteries to degrade faster, leading to a shorter battery lifecycle and increased material demand. Thewessen (2023) notes that battery degradation is one of the main contributors to the costs of V2G business models and requires further research. Battery degradation was one of the main concerns in utilizing the Lightyear 0 for DES. Lightyear Energy believes LFP batteries would be more fruitful because they have half the degradation rate of NMC batteries (Elliott et al., 2020), and second, they take learnings from large industry players such as Tesla who switched from NMC to LFP.

4.1.3 SEV efficiency and energy infrastructure

The degree to which VIPV systems in SEVs impact the grid varies not only per vehicle type but also per user, time, and location. For example, during the Northern- and Middle-European winters, and in underground urban parking lots, there is limited solar radiance. In more sunlit parts of the world, VIPV systems can significantly help reduce the grid dependency of SEVs. In the practical range use case scenario, the Lightyear 0 decreased the annual grid dependency on average by 47% in The Netherlands, and up to 75% in Spain (Juch, 2022).

Generally, the more efficiently a (S)EV can convert its energy [kWh] into kilometers [km], the less energy it needs to get from A to B. Efficient energy conversion increases the relative VIPV generation compared to energy use, thereby increasing practical range and decreasing dependence on grid infrastructure. Furthermore, efficient vehicles will charge more kilometers per hour [km/h] with the same amount of charging power [kW]. Basically, an efficient vehicle charges more kilometers of range [km] per power input over time unit [kWh]. For example, the Lightyear 0 allows for 50kW of DC charging, while the Sono Sion can charge up to 75kW DC. However, because the Lightyear 0 has a 60% more efficient drivetrain, it still charges faster (520 km/hour) than the Sono Sion (469 km/hour). For reference, Tesla claims 1100 km/h charging with 170kW with its Model 3 RWD and heavy V3 Supercharger infrastructure (Böck, 2018; Tesla, 2023). This gives the Lightyear 0 the advantage of faster charging from light charging equipment like its VIPV, or from light infrastructure like power sockets or one-phase AC chargers.

For example, Dutch households are connected to the distribution-level grid, and most have at least a one-phase 230V/16A connection of 3,7kW available from a power socket, which allows for 32 km/h charging, compared to approximately 23 km/h for the Sono Sion. In comparison, an electric SUV like the Volkswagen ID4 Pure charges up to a maximum of 34 km/h with a three-phase 230/25A connection and 22kW charge point (*EVBox*, 2023).

In essence, highly efficient vehicles need to charge less often, while having a higher charging speed, thereby allowing for more BEVs charged per charger and a more capital-efficient approach to charging infrastructure. In fact, Lightyear and Ubitricity developed a cooperative business case for integrating charge points in lamppost infrastructure (Lightyear & Ubitricity, 2021). The amount of EVs in Europe is growing rapidly, and the revised Alternative Fuels Infrastructure Regulation demands members to expand their charging infrastructure in line with zero-emission vehicle sales (Carrara et al., 2023). Interviews confirm that a mandate in the European Parliament presented that less charging infrastructure would be required if there were more efficient SEVs. However, without any type approval for SEVs, it was impossible to approximate the demanded charging infrastructure in such a scenario.

4.2 Social

4.2.1 The automobile paradigm

With decreasing battery prices, more affordable (S)EVs will be introduced to the market, enabling more households to afford the initial purchasing costs (Kumar & Alok, 2020). Additionally, the total costs of ownership might decrease further when (S)EVs will be able to generate a profit with energy and potentially autonomous driving services while not directly used (König & Neumayr, 2017). Most interviewed niche actors believe that not too far into the future, the costs for energy will significantly decrease when households utilize their (S)EVs for ancillary and grid services and that this will be a large driver for the adoption of such products.

The concern was raised by actors from the regime industry that SEVs are too expensive and will therefore only enable the wealthiest groups in society to benefit financially from energy services such as DES, thereby widening the wealth gap. Most interviewees agreed that SEVs like the Lightyear 0 are too expensive for most households. When (S)EVs with DES become more mainstream, concerns regarding social equality should not be disregarded. In 2021, the average European disposable income per capita was about €18 thousand (Eurostat, 2023b). It is true that currently, EV technologies are still unaffordable for most people, and there is significant income inequality between individual member states (Cantante, 2020). Besides, the distribution of smart EV charging services is unevenly distributed across the continent (Hildermeier et al., 2022).

However, the discussion regarding social equality might be an unavoidable part of transitioning from the horsepower and hypercar paradigm towards an energy efficiency and sustainability vehicle paradigm. For instance, horsepower and hypercar OEMs continuously cater to society's most affluent and influential individuals at the pinnacle of the consumerist pyramid by offering increasingly powerful and exclusive cars. For example, the Rimac Nevera electric hypercar with 1914 horsepower costs €2 million (*Rimac Nevera*, 2023), which is significantly higher than the Lightyear 0 with €2.5 tons. Automotive incumbents are lining up to invest in Rimac technology. As such, it seems that the automotive regimes reproduce social constructs upheld by consumer sentiments towards high-performance vehicles by accommodating fit-and-conform niche developments. An illustration of this phenomenon is the accommodative arrangement between established players, namely Porsche and Bugatti, and the electric hypercar OEM Rimac. This collaboration rejuvenates the consumerist horsepower and hypercar paradigm, breathing new life into it (Rimac Automobili, 2021).

B.N. (2023) recognizes the inertia of the automobile performance paradigm since its initiation 100 years ago. She also notes that a €2 million vehicle is unlikely to reach mass markets, and thinks government incentives should stimulate innovations with high-volume level potential. For example, the Rimac Nevera with an energy efficiency of 30kWh/100km could exploit the same zero-emission vehicle pooling frameworks as the 9.8kWh/100km Lightyear 0 (Lightyear PA, 2023). It remains unclear if Rimac would have survived without the support and interest of automotive incumbents, however, it seems that Lightyear and Sono struggle to fully develop and deliver their commercial vehicles without the necessary support.

4.2.2 Behavior change

Where the current main driver for buying ICEVs are price, acceleration, and top speed, for EVs it is currently range, and in the next 40 years, T.S. (2023) foresees this will gradually shift towards sustainability. For roughly one-third of the Sono Motors customers who made a down-payment, bi-directional charging and the possibility of using the vehicle as home storage was the most, or second most important feature of the SEV.

"A lot of our customers were quite like, energy people you know, homeowners with PV systems already at home and they're kind of into all this electricity and renewable stuff." (T.L., 2023)

T.S. (2023) believes that price, together with convenience are currently the largest incentive for achieving behavior change with consumers. He thinks it seems likely that people will change their behaviors if they are enabled to save a few hundred Euros per year on charging with dynamic electricity prices. Kessels et al. (2016) have demonstrated that dynamic pricing with easy-to-use applications provides a sufficient financial incentive to cause a substantial adjustment in energy consumption behavior within households.

"It makes quite a difference, right? I mean, I've been driving an electric car for 5 years now, and it really makes a lot of difference per charging station what you pay, so for example at one charging station, you pay 70 cents per kilowatt or 60. At the other one you only pay 30, that's just half cheaper huh? That's really a lot." (T.S., 2023)

Most respondents agree that price signals are the most effective tool for changing behavior. Some point out that they do not expect all consumers to become prosumers. It seems energy is a low-interest product, and it is not clear yet how much effort citizens will put into effectively handling their own energy management. F.B. (2023) finds it difficult to estimate the effects of price signals on behavior change. He thinks there are multiple approaches to balancing the grid with demand-response to be explored. Instead of price-based incentives, he proposes the exploration of different methods for incentivizing civil involvement. This comes from the idea that when price-signals prevail for incentivizing prosumer behavior. Rebound effects could emerge where people exploit the legal grey areas of the market, by for example working from home to profit from their lease-car doing grid balancing. It is still unclear what societal and economic costs this could cause.

G.H. (2023) believes that citizens will be more incentivized to participate in balancing the grid if they can control their energy management with some sense of freedom and autonomy. He thinks citizens will feel more empowered if they can take personal preferences into account, than when a centrally controlled entity controls large parts of their energy management, and users receive a reward at the end of a certain time period. This view is shared on the European governance level, where respondents believe people are unlikely to offer their vehicle and battery to be used by some party who decides everything.

4.2.3 Sharing communities

F.B. (2023) analogizes the shared ownership value proposition with SEVs as the 'witte fietsenplan' (white bike plan), initially proposed by Luud Schimmelpennick in 1965. In this plan, (white) bicycles were offered for free as a collective solution to the mobility issues in Amsterdam. Ploeger & Oldenziel (2020) describe how in 1968, Schimmelpennick pioneered his Witkar (White-Car) project for shared EVs. The White-Car project ceased, but its legacy lives forth as the basis for the IT systems of today's payment for shared mobility programs and companies.

Behavioral developments like the transition towards MaaS should be considered in defining future energy fleets (Carrara et al., 2023). MaaS requires fewer vehicles to provide a comparable grade of personal mobility, potentially to a wider customer segment. Among other things, lower EV production results in reduced material throughput, social en environmental impacts, and geopolitical tensions in global supply chains (Carrara et al., 2023). Survey results show that roughly 70% of people believe that 50% of the market in 2050 will be autonomous vehicles (König & Neumayr, 2017).

"I will share my own wish with you. I don't know if I'll still be alive by 2050, but my current big wish is: that I don't own a car, but instead have an app through which I can order a car to come pick me up whenever I need it. There doesn't have to be anyone in it, it can drive all by itself, and I'll specify where I want to go and what my schedule is." (S.C., 2023)

4.2.4 Socio-technical system design

Today's choices in the arrangement of energy and mobility systems will fundamentally impact socio-technical systems and transform future societies. Historically, the unregulated development of Web 2.0 has resulted in a handful of multinational big-tech companies that accumulated a lot of data power (Van Dijk & Jansen, 2023). Looking further into the future, the cumulative development of AI applications creates opportunities for improved quality of life and sustainability all around the world (Filho et al., 2022). The increased scale of integration and communal dependability on these systems, make our societies more vulnerable (Galaz et al., 2021). Risks appear for unjust system biases and for highhanded systems of control. Without the proper guidelines to align these technologies with democratic values in society, there is a risk that capitalistic pressures, market ideologies of unlimited growth, and modernist agendas will drive centralized energy politics (Burke & Stephens, 2018).

C.H. (2023) illustrates, that during the unregulated development of Web 2.0, Apple was the only innovator who realized that control over data systems translated into an increased market share and was capable enough to exploit this vision. Today, big tech is penetrating automotive markets. For example, Google recently started collaborating with General Motors and Mercedes-Benz for infotainment system software, to compete with Apple Carplay and Android Auto (Chee, 2023). With the purpose of accelerating the world's transition to sustainable energy, Tesla is an industry leader, and developing an Apple-like ecosystem of DER appliances. In the UK, they launched the Tesla Energy Plan, a groundbreaking virtual power plant with Tesla Powerwalls. The concern here is that Tesla's system is incompatible with other inventions, it is developed as a so-called 'black-box' system (Van Dijk & Jansen, 2023).

In their report on the open-source development of Home Energy Management (HEM) systems, Van Dijk & Jansen (2023) present the 'private-stack' and 'public-stack' models. Essentially, the public-stack model keeps data in the control of users, while the private-stack model resembles the 'extended vehicle data model' where OEMs own the user data, thereby controlling access to this data from after-market service providers. In defense of this model proposed by automotive OEMs, interviews reveal that the sector expresses its concerns about data security, and the risks of unintendedly opening access to malicious third parties, sometimes outside of Europe. Lightyear Energy preferred a closed data-access model, mainly for user privacy concerns and prevention of battery degradation through overexploitation of third-party apps.

On the other hand, European regulators notice risks involved with advances in computer intelligence and IT systems. Actors with data power can scale up faster, thereby establishing regimes, complicating niche competition, and making (local) governments dependent on a limited number of market players. Aftermarket and consumer organizations are concerned that the data access model proposed by the automotive industry is inconvenient and unfair. They are concerned about multinational entities with exclusive access to user data, thereby dominating aftermarket players, and deciding which services are delivered to users. In fact, C.H. (2023) oversaw a study for the Fédération Internationale de l'Automobile (FIA) in Europe, which investigated the 'extended vehicle' data access model proposed by the incumbent automotive markets. These models seem to obstruct aftermarket products and services, which will be heavily dependent on that data, such as DES and other connectivity solutions. With the anticipated levels of connectedness in 2030, this will result in an estimated €33 billion potential loss for independent aftermarket actors, and an additional €32 billion burden for consumers (Carroll et al., 2019).

4.2.5 Civil underrepresentation

Although civil concerns about data access are recognized on the European level, this is not reflected in industrial sectors. For example, In the new Dutch Energy Act, the Market Facilitation Forum and System Operator Agreements (MFFBAS) is mentioned as the new data exchange entity. The industry initiative is dedicated to creating standards for responsible data exchange in the Dutch energy sector. However, Van Dijk & Jansen (2023) show that of the more than sixty coalition partners, there are zero energy communities or civil cooperatives directly involved. The director of BAS acknowledges the problem of civil underrepresentation and finds the lack there off in the coalition difficult to justify. From his perspective, many Europeans perceive energy as a basic commodity. It is a low-interest product, of which the reliable supply is taken for granted.

"When you tell people at a birthday party that you have a dynamic product, people look at you like, 'Okay, well, are you all right?' Yeah you know, that's not something that captures the imagination yet." (K.H., 2023)

Dutch energy industry representative S.C. (2023) explains how the recent developments in Ukraine have led to an increase in energy prices, and thereby a significant reduction in energy consumption. He acknowledges that societal awareness is an important aspect of the energy transition and that society members must come to understand that a reliable electricity supply will require behavior change. K.H. (2023) seems to agree largely on this point but is afraid that the increased awareness about energy consumption will be short-lived.

"I always say, the energy transition is not an energy transition, it is a societal transition. We will all have to change our behavior." (S.C., 2023)

With the large potential impact of the energy transition, underrepresentation of the civil sector in industry coalitions form a legitimate concern. A survey in a bottleneck analysis by Klimaatstichting HIER & Bureau 7TIEN (2023), ordered by the Netherlands Enterprise Agency confirms that human resources are the second-most important barrier in the operations and upscaling of Dutch energy cooperatives.

4.3 Market

4.3.1 Energy suppliers and flexibility

Energy suppliers buy cheap energy on wholesale and imbalance markets based on data-driven forecasts and sell this to customers through energy contracts. Basically, they buy energy in volatile markets, and sell this through time-bound contracts with fixed prices, thereby insuring consumers with a fixed price. The trade models they rely on combine historical data with real-time grid conditions, market intelligence, and weather-based models (Northpool, 2022). The war in Ukraine creates shockwaves throughout European energy systems, disrupting conventional forecasts. For example, when real-time energy prices skyrocketed shortly after the Russian Gas debacle, some energy suppliers withdrew their multi-year energy contracts from consumer markets (G.H., 2023). Besides, landscape pressures continue to increase the uptake of renewables, which goes along with intermittency in the energy supply and the increased dependence of trade models on the accuracy of weather forecasts. These developments make real-time and dynamic pricing models more advantageous for energy suppliers compared to the conventional insurance contract model with fixed tariffs.

"So, this winter we already saw that when things really go off the rails, the government steps in. So, the role of being an energy insurer has already diminished somewhat." (G.H., 2023)

S.C. (2023) believes that the lack of zero-emission flexibility is one of the biggest bottlenecks in the transition towards sustainable energy systems. Developments in hydrogen will take at least another decade to become significant, while carbon capture and storage, and utilization are controversial. While hydrogen storage is more efficient at large-scale facilities, he thinks batteries come better to their right when distributed. C.G. (2023) believes that in the storage market, (S)EV batteries have the advantage that they are already there, while industrial battery storage facilities require an initial purchase. Based on ongoing European research, he estimates that about 20% of the long-term flexibility will be provided by EVs

4.3.2 Potential markets for SEVs with DES

The European carbon goals boost targets for net-zero emission energy and mobility, which are the main drivers for the penetration of EVs in the European transport sector. Thereby, in 2030, the European automotive industry is expected to be the second largest globally, after China, and before the US (Carrara et al., 2023).

"Why is it needed? It is needed not only for the potential of zero-emission vehicles and other grid services but because transport is the most damn difficult sector to decarbonize. It is the one which is basically bound to hydrocarbons and where even the total amount of emissions and energy consumptions has kept on increasing, not decreasing." (C.G., 2023)

Respondents agree that the market for EVs in general is continuing to grow fast together with the EV ecosystem and aftermarkets. It seems that markets are growing for charge points, e-mobility services, third-party EV maintenance, home energy management systems, energy management for businesses, and other software for data insights. The European markets are fragmented across 27 member states, which complicates the development of innovative technologies; different market regulations in each state require niche actors to design products that comply with specific market requirements. There are incentives to harmonize European energy markets by interconnecting balancing markets for example. It seems unlikely that there will be a completely uniform European market model shortly. But the respondents from the multiple sub-groups recognize a trend toward the convergence of different market models in Europe. Moreover, S.C. (2023) argues that market developments can push legislation for the harmonization of energy markets forward. Despite the unconformity of European markets, the most essential prerequisites for commercial DES products and services seem present in numerous European member-states.

"There are challenges, but at the same time, it's nothing. It's not a roadblock for anything." (T.L., 2023)

Mass-producing affordable SEVs for the wider marketplace seems to be the most fundamental problem. Historically, positioning a high-cost, low-volume EV on the market as a first product, like the Tesla Roadster in 2008, has proven to be a suitable strategy for accumulating the necessary resources to scale up toward mass production over time (Musk, 2006). Unfortunately, SEV firms have not been able to replicate this strategy as economic conditions do not allow this. In current market configurations, SEVs could be more of a niche product. Early adaptors of SEVs could be for example taxi companies or other business cases where vehicles need a considerable range to charge as little as possible for preventing any downtime.

"I think it would have helped if we could have put a few Lightyears on the road as well. That would have helped to accelerate the adoption of those incentives because we were on a good path. But because Lightyear never actually delivered a car, we were still seen as, well, is that something real or just a kind of show?" (T.S. 2023)

Complementary technologies such as VIPV, DES, and autonomous driving will decrease the operational costs of SEVs. Just like self-driving vehicles will enable new value-capture models from autonomous ride-hailing and ride-sharing services (König & Neumayr, 2017), VIPV generation also enables new revenue streams. With an estimated annual VIPV generation of 601kWh in The Netherlands, and 952 kWh in Spain (Juch, 2022), owners can yield around €144 and €228 based on the average European kWh price in 2022 (Eurostat, 2023a). The potential revenues from DES are considerably higher (T.S., 2023). In collaboration with Lightyear, Thewessen (2023) estimated that in 2030, a V2G fleet of 0.5M EVs could generate a gross profit of €182 per EV, including battery degradation and costs for charging electricity, excluding VIPV yield. Brinkel et al. (2020) assumed financial benefits from smart charging business cases can range between €106 and €1008 depending on different energy markets.

Moreover, incentive models for the decarbonization of the transport sector will be increasingly complemented and integrated with the European Emission Trading System (ETS). Whereas the ETS I applies mainly to energy generation and manufacturing, the ETS II will include emissions from roads and buildings starting from 2026. In the ETS I, emission reductions in (S)EV manufacturing are rewarded with carbon allowances, and renewable electricity generally holds a price advantage over non-renewable sources. In the ETS II, zero-emission vehicles will benefit from non-discriminatory, it appears that there is no additional incentive for energy efficiency or SEVs. It is too early to say whether future replacements of existing incentive models such as the zero-emission vehicle pooling schemes will integrate incentives for energy efficiency and SEVs. More research is required into exploring the potential revenues from market-based government incentives for SEVs.

4.3.2.1 Dynamic pricing wholesale markets

Currently, the most convenient way households can reduce their charging costs is through charging behind the meter with a dynamic pricing energy contract. Dynamic contracts help in the downward regulation of demand. Through the application, users can schedule their charging sessions based on predictions of energy prices per time unit on the day-ahead market. During high supply peaks, users can appreciate negative charging costs (Thewessen, 2023).

R.J. (2023) explains that the day-ahead market is the first market where a smart charging service provider (SCSP) would optimize its offer. Schedules based on dynamic prices can be complemented with pop-ups that offer end-users the choice to adjust their charging schedule close to real-time. These signals could, for example, be based on the carbon intensity of the grid, or renewable energy share based on updated weather forecasts (Hildermeier et al., 2022; R.J., 2023). Moreover, bi-directional charging stations and services can enable extra revenues on intraday markets by discharging the (S)EV batteries during high price peaks.

4.3.2.2 Imbalance and congestion markets

Whereas dynamic price products and services are primarily based on day-ahead forecasts and involve some intraday adjustments. Price signals based on imbalance and congestion markets are generally closer aligned to the real-time grid operations. As such, end-users can financially optimize their charging schedules, while balancing the electricity grid in real-time.

In a study for Lightyear, van Oorschot (2022) showed that SEVs with DES can supply upward and downward adjustment in both Frequency containment reserve (FCR) and automated Frequency Restauration Reserve (aFRR) markets from the TSO TenneT. This basically means that over time, the SEVs variate between upward and downward regulation of charging to compensate when an imbalance occurs on the grid.

4.3.2.3 V2G markets

K.H. (2023) explains that commercial V2G charging systems are not yet established in Europe due to the absence of an effective framework. C.G. (2023) clarifies that European research for V2G, and virtual power plants is still a work in progress. Like trains in rail networks, (S)EVs change their location over time through road infrastructure. Facilitating a V2G platform could open an ecosystem for market parties to advance business models that deploy virtual power plants, potentially combined with MaaS propositions.

4.3.2.4 Local energy communities and peer-to-peer markets

Local energy communities are a crucial part of the European energy transition because they allow for higher energy efficiency and acceptance of renewable energy projects, while creating new local job opportunities, increasing citizen involvement in the energy transition, and decreasing energy bills (DG for Energy, 2023). In their whitepaper for the Layered Energy System, Energy21 & Stedin (2018) propose local markets to organize energy communities as an intermediary market between DSO- and TSO-level infrastructure. By matching supply and demand closer to the source, for example, by utilizing local DES systems via peer-to-peer transactions, direct consumption of renewable supply is increased locally (Parra & Mauger, 2022). Peer-to-peer markets are believed to empower individuals in managing and trading energy with neighbors, or with regional civil and industry communities. Many developments will be needed before universal solutions lead toward standardizations in local markets (G.H., 2023; R.J., 2023; T.S., 2023). Besides, the social mandate to orchestrate and maintain local energy communities is currently lacking (R.J., 2023).

4.3.3 Dutch vs. German system

The Dutch energy system has historically been evolving more towards a market-based device in which commercial and contained activities are strictly divided. In this system, for example, energy suppliers, regulators, and grid operators have their separate responsibilities. In Germany, these responsibilities are more of a grey area. As a result, German grid companies have more operational authority within the boundaries of their infrastructure, than in the more liberalized market system in The Netherlands (Kooshknow & Davis, 2018). The governance models in these energy systems can be distinguished by grades of implicit and explicit management (G.H., 2023). The Dutch model is more implicit and tends to lean towards market-based governance, with more decentralized decision-making. While the German model is more explicit, and decision-making is more centralized. Although G.H. (2023) prefers implicit models, he admires the Germans' collaborative approach to problem-solving. He says grid operators and regulators are more explorative in legally grey areas, for example allowing some small grid operators to supply energy simultaneously. Still, the German energy market model is not particularly beneficial for consumer prices, as energy politics prioritize cheap energy for the industry (G.H., 2023).

As mentioned earlier, EV OEMs prefer the implicit, extended vehicle data model to develop a business model around it. After all, they spend a lot of resources on developing these products, with the intention to market them. Meanwhile, grid companies seek to optimize grid stability and prefer explicit control. For example, T.L. (2023) mentions a pilot study with Sono Motors and a German DSO, where they collaboratively developed and distributed a network of microprocessors to measure and control the charging speeds of Sono Sions in the DSO grid. Although the hardware for this system was distributed over the grid, they were controlled by a centralized entity with explicit signals. The network controlled the charging with explicit signals from the DSO, thereby optimizing charge sessions exclusively for the DSO. T.L. (2023) suggests that only a part of the flexibility should follow an explicit signal, and the rest would be incentivized by the preferences of end users and their responses to implicit price signals.

4.3.4 Beyond markets: energy democracy

The respondents agree that a market-based strategy is the best approach for the energy transition. In capitalist markets, wealthier households could still afford more DER devices, potentially accumulating additional benefits. Nevertheless, with increased societal distribution of energy infrastructure ownership and bottom-up mandate, power balances between transnational industries and local societies seem better aligned with democratic and ethical values. After all, the decentralized nature of renewable DER-based energy systems, and the developments in DLT and IoT applications, enable pathways to democratize our energy systems more deeply (Burke & Stephens, 2018).

Without DES and local energy communities, industry actors would build large-scale centralized energy storage facilities. In this scenario, technology would be privatized, and molded into existing constructs of centralized power. Industries would increase their weight of influence and lead away from democratic decision-making (Burke & Stephens, 2018). In such a scenario, these powerful entities, referred to as 'energy dictators' by G.H., (2023), would exercise explicit control over the energy system. Energy storage assets that are explicitly managed by a centralized entity will cause dominant optimization for that entity. An energy democracy scenario, on the other hand, aligns with citizens, workers, and communities (Burke & Stephens, 2018). In such a scenario, industries aim to make solutions such as SEVs with DES accessible for as many households as possible. Here, DES is implicitly managed, which allows for optimization amongst multiple stakeholders. This scenario emphasizes community participation and broader energy citizenship, which is more closely aligned with democratic decision-making. As such, implicit management leaves choices around the direction and flow of electrons up to the end user (B.N., 2023).

This implicates that energy systems will be better aligned with the collective limbic system of humanity. They will therefore not dictatorially serve large centralized industrial systems but serve as an energetic extension of humanistic civilizations. Implicit management can enhance the user experience and incentivize active engagement while decreasing probabilities for a 'Brave New World' scenario (Huxley, 1932/2004).

4.4 Industry

4.4.1 Competitive advantage SEVs

To follow up on the ambitious predictions for European EV markets (Carrara et al., 2023), European OEMs will have to keep developing dynamic capabilities and preserve their competitive advantage (Teece, 2017). As one of the largest industries, the automotive and energy sectors are deeply ingrained in the European economy. This means the reconfiguration of ICE value chains to EV supply chains and energy transition are enormous projects. Misguided industries can lead to huge losses; therefore, it is essential for the industry to align this with Europe's ambitious long-term climate targets. There is no definitive answer in the interviews on whether large European investments for the innovation of SEVs in Europe will result in substantial competitive benefits compared to leaving the development of these innovations to other global powers like China and the US.

T.S. (2023) explains that DES systems are on the roadmap of almost all automotive OEMs, but highly efficient and sustainably produced SEVs are not on the 7-year roadmap of most OEMs. The incumbent European automotive industry is foremost challenged with basic electrification and generally lacks behind with digitalization. He estimates the chance for Lightyear for being acquired by an incumbent OEM is rather small (around 15%) but thinks this would significantly increase in 10 years. B.N. (2023) notices that Europe is leading in VIPV development, partially because European vehicles are generally more efficient than US vehicles. R.J. (2023) explains that the Lightyear 0 was designed to be as efficient as possible, but that mass production is still a challenge. According to (T.S., 2023), it is still uncertain whether the most significant cost reductions for (S)EVs will come from smaller batteries, or from new production techniques and battery technologies. Higher-efficiency vehicles need smaller batteries, which will in turn make the vehicles cheaper (and lighter). Moreover, the (Carrara et al., 2023) report emphasizes that the expected growth of the European e-mobility sector includes the materials with the highest relative increase in demand and that critical raw materials are still largely outsourced from third countries, mainly China. C.G. (2023) confirms these concerns and foresees the fierce competition between European, Chinese, and US BEV producers. However, he also sees a reconfiguration for a domestic European value chain for EV components and strategic advantages for the leading European automotive industry. C.H. (2023) expresses concern about European interests versus the interests of big-tech information companies, like Google and Amazon, who are increasingly gaining market share in-vehicle infotainment systems, as mentioned earlier by Chee (2023). If the automotive sector becomes too dependent on these companies, this will have implications like for example domestic sovereignty and job security for European countries.

4.4.2 Grid companies

Today's grid operators' main priority is maintaining power security, and they achieve this by operating within their familiarity. The European climate targets do not seem to be specific enough for grid companies to move away from the current model and incentivize DER innovation (K.H., 2023). F.B. (2023) thinks that grid operators are driven by a limited set of KPIs.

About 20 years ago, TenneT was an energy monopolist in The Netherlands. Since then, TenneT has undergone a profound transformation, in line with the energy market liberalization as demanded by the EU in 1996 (van Oorschot, 2022). As a senior TenneT employee, K.H. (2023) explains that about 15 years ago, TenneT had to change from a 'consumption' administration towards a more 'customer-centered' administration and that the transition to a 'prosumers' paradigm requires renewed change. Personally, K.H. (2023) believes TenneT should stick to conventional and essential system operators' tasks, like grid expansions and adaptations where necessary. For the energy transition, this would mean improved measurement, collection, and aggregation of data, and allowing other market parties to pioneer by platforming this data. However, TenneT's system operation department has barely increased in size, while offshore and large projects departments expanded with thousands of employees.

An important limiting factor in these developments is the structural malinvestments by (trans)national grid companies and governments into large-scale energy projects (S.C., 2023). It seems that grid operators seem to overlook DERs, and rather have explicit control over large-scale flexibility plants (K.H., 2023; B.N., 2023).

"They make money, and everything else we do on the grid makes their lives more difficult." (B.N., 2023)

B.N. (2023) believes that grid companies are driven by financial shareholder incentives, and negotiations with niche actors for relatively small storage solutions are just not cost-effective. For example, the largest European research and innovation program between 2014 and 2020 totaled a budget of nearly €80 billion (*Horizon Europe*, 2023). Despite the many innovative DER projects resulting from this, and a call to test grid integration of novel technologies, most DSOs and TSOs overlooked potential collaborations.

4.4.3 Aggregators are essential

The potential of DES depends on the total capacity at which it can be combined into one pool of flexibility. Therefore, the scale at which DES is aggregated into virtual power plants is crucial for inclusion in the flexibility operation portfolios of grid companies. In current grid operator systems, large-scale flexibility service providers simply decrease overhead costs (B.N., 2023).

From his experience as a system operator, K.H. (2023) emphasizes that the reliability of aggregated flexibility systems is one of the main concerns for grid operators. For example, he describes a case where Tesla offered frequency control products to TenneT from their Dutch fleet of around 10.000 EVs. At that time, the aggregated flexibility from the EVs was not reliable enough for the system operators to depend on. Besides, the equivalent flexible capacity Tesla offered was not nearly enough to meet TenneT's minimum bid value.

4.4.4 Collaboration in an ecosystem

According to F.B. (2023), both the energy and automotive sectors should be more collaborative. Currently, competition and first-mover advantage are very dominant in the development of BMI. Also, there is a lack of collaboration between governments and businesses as also noticed by (K.H, 2023; T.S., 2023; B.N., 2023; G.H, 2023). As a European policy advisor, C.H. (2023) notes that there is a tendency for silo-thinking across sectors and governmental departments.

F.B. (2023) refers to his collaborative work with Derks et al. (2022), which suggests an untapped potential for accelerating sustainability transitions through Collaborative Sustainable Business Models (CSBMs). Multi-stakeholder collaboration is essential to realign sustainable business models and value networks in system transitions. This requires a reconfiguration of incumbent value networks and scaling of new value networks. Which is currently happening in incumbent automotive supply chains. F.B. (2023) believes that closer collaboration would improve society, but this is often taken for granted, or substituted by competition. He says that educational institutions could do more to teach students collaboration instead of competition.

R.J. (2023) thinks that a lack of collaboration was one of the reasons that Lightyear got into trouble. For example, scale and corporate reliability provide automotive incumbents significant advantages in sourcing materials and components in value chains. Despite the high costs, Lightyear did not take part in collaborative battery acquisitions because they choose the very distinctive Li-NMC-811 battery.

Another example was the Clean Energy Summit in Brussels, 2019, where the Directorate-General Energy and Directorate-General communications networks, organized a conference for energy. During this conference, energy innovators presented their newest innovations.

"It was really great to see, projects from all kinds of different countries were presented, and they were all successful." (K.H., 2023).

After some presentations about electric transport, a delegate member from the European Commission started a discussion about the feasibility of a road trip from Southern Spain to Sweden. The conclusion was that it was not impossible, but the risk of suffering incompatible charging systems during the journey was very high. It seems that due to a lack of collaboration under common standards, many niche innovators operate within the boundaries, or standards of the different member-states. This decreases interoperability, confines the user experience, and the limits effectiveness of an innovation ecosystem (F.B., 2023). Also, one of the big challenges for aggregators comes forth from a lack of standardization in the industry, this limits the interoperability of different devices and aggregation into usable pools of flexibility.

F.B. (2023) explains that in the growth process of start-ups, new barriers emerge constantly. On the one hand, it requires entrepreneurial capabilities to oversee future hurdles, but on the other hand, it seems that some entrepreneurs must overcome too many collective barriers before they can even start their company, and constantly adapt to conflicting regulations on different levels, which decreases the effectiveness of BMI and simultaneously opens the market for competitors.

(F.B. 2023) refers to Better Place, back in 2007, founded in Palo Alto, they introduced a groundbreaking BMI for battery sharing, which would make EVs cheaper to produce. To achieve this, battery swap stations were developed and deployed, which was a costly venue. Besides, they required resources and collaboration across automotive and energy industries, and a reasonable amount of public support (Noel & Sovacool, 2016). For example, mainstream OEMs had to integrate their batteries, and they required cooperation from grid utilities for their battery swap stations (F.B., 2023). However, there was no supportive ecosystem or value network. Better Place was ahead of its time, and they were declared bankrupt in 2013 (Bohnsack et al., 2014).

Closer involvement of governments in the developments of niche-industries would improve the vision that the government is currently lacking (K.H., 2023). However, the niche parties indicate a lack of resources to influence large government bodies (B.N., 2023). If niche actors want to increase their affluence and influence, they might want to explore opportunities in collaborative business models. For example, by taking an assertive attitude towards standard development, which can impact the entire energy industry. An important part of Rimac's business model is providing their electric hypercar technology to third parties such as Porsche and Bugatti (*Rimac Automobili*, 2021). Both Lightyear and Sono Motors are now selling technological components to third-party OEMs as part of their business models. Lightyear's VIPV technologies are marketed by Lightyear Layer B.V., a legally separate entity from Lightyear (B.N., 2023).

4.4.5 Coalitions

To further enhance the lobbying power for niche actors in the SEV industry, Lightyear, Sono, and IM Efficiency collaboratively started the Alliance for Solar Mobility (ASOM) in 2020. T.S. (2023) and B.N. (2023) helped establish this industry coalition, with the aim to cluster the communication and lobby capabilities and resources of the SEV industry. And to become the cooperative European platform to establish and foster the solar mobility industry (ASOM, 2023). As co-founder and board chair of ASOM, B.N. (2023) explains that it is crucial for niche actors in the SEV industry to collaborate to increase impact at a European level. By uniting behind one advocacy group, ASOM produces a strong voice that can impact EU-level politics. ASOM is recently getting increasing traction as for example Toyota and Nissan joined the alliance. Volkswagen is no member of ASOM, however, according to T.L. (2023) they are one of the leading industry actors pushing forward the harmonization of European grids. Also, Daimler is no member of ASOM yet, although they developed a concept SEV with a 1000 km claimed range (Mercedez-Benz, 2022). B.N. (2023) welcomes all serious SEV actors to ASOM and is looking for volunteers to expand the coalition more proactively. The incumbent industry can be influential in public opinions about alternative technologies and in governmental decision-making and possesses more resources to organize and influence policy-making processes (C.H., 2023).

To provide a platform for innovators in the energy transition, MFF BAS is uniting a Dutch coalition of energy innovators to collaboratively develop standardization. Still, according to H.K. (2023) director of BAS, the most automotive-related participant is the National Knowledge Platform for charging infrastructure (NKL).

4.5 Regulation

The regulatory dimension extends into all other BMDS dimensions. The European Union currently has twenty-seven member states with each their own energy system with different levels of sophistication, consisting of unique regulations, markets, technological standards, industry structures, and national cultures and languages.

4.5.1 Raw materials for SEVs

Some European citizen groups are concerned that BEVs are not as sustainable as claimed by manufacturers (Rajaeifar et al., 2022; F.B., 2023). (Carrara et al., 2023) reports that BEVs will move the EU closer towards zero-emission transport, but their production demands various critical and non-critical raw materials for mainly their batteries and electric motors. In terms of tonnage namely cobalt, lithium, and natural graphite, and most significant in relation to the current global supply: lithium (Li), graphite (C), cobalt (Co), and dysprosium (Dy). Additionally, the multi-crystalline silicon solar cells used in the SEVs VIPV require silicon metal (Si), which is defined as critical raw material in Europe (European Commision, 2020), Silver (Ag), and additional materials for production. Currently, the EU supplies only 4% of the raw materials in PV systems, the supply chain is dominated by China, and the risk for the PV supply chain is labeled as 'significant'. There are opportunities for diversification, rare earth deposits have been found in Sweden, Finland, Greece, and Spain. To employ these, European industries and policymakers will have to develop a domestic rare earth ecosystem (Carrara et al., 2023).

Although no experts on this subject have been interviewed, data suggests that China currently possesses a large part of all critical metal supply which is necessary for the energy transition. It is yet unclear how new discoveries of domestic rare earth deposits will influence Europe's access to affordable critical materials for the European production of capital-heavy industries (Carrara et al., 2023).

Although Europe is the second producer of EVs (with almost 20% of global EV production), it is still highly dependent on third countries for the key components, importing batteries and their components mainly from China, which represented more than 75% of the global EV battery capacity in 2022. Permanent magnets come from China and Japan, and fuel cells from Korea (IEA, 2022; Carrara et al., 2023). In this context, regional investment planned or announced in recent years supports the diversification of the components and car markets. C.G. (2023) sees a growing domestic EV supply chain in Europe.

4.5.2 Technological benchmark

According to C.H. (2023), technological development is still in a rather premature stage, and this is a reason why we don't have such standards yet. He explains that from the European Green Party's perspective, legislative proposals for technologies that have no common underlying standardization are often rejected. This would mean that it is crucial to develop European standards. He thinks there are some technical issues that need to be solved first.

"I mean, ultimately there isn't confidence among EU decision makers to have any binding requirements for bi-directional charging." (C.H. 2023)

C.H. (2023) explains that to align regulation with technological innovations, first there should be an empirical motivation, such as a product that is widely available on commercial markets. In other words, until there is no affordable SEV for commercial markets that can function as a proper technological benchmark, it will remain difficult to develop a guiding policy for incumbent automotive industries. For example, F.B. (2023) mentions that SEVs would need a quality and performance assessment by for example insurance companies, and until now there has not been a type of approval for SEVs. As such, it is suggested that markets seem to be able to change the regulatory landscape.

4.5.3 SEV incentives

Currently, the automotive regime industry is still largely transforming its supply chains from ICEV production to EV production. In essence, the vehicle manufacturers are optimizing their businesses to comply with EU policy that demands a halving of new ICEV sales by 2030, and a complete phase-out by 2035 (C.G., 2023; T.S., 2023). Beyond current EV subsidies, there are no equivalent industry-wide incentives that drive the facilitation of innovation and development of highly efficient EVs, let alone the development of SEVs.

"There's no incentive currently today to deploy a solar electric vehicle because it would go beyond what the existing regulations require, I think it's as simple as that." (C.H., 2023)

"I mean, you know, if you're a car manufacturer today, what is the incentive of you developing solar panel if you're not seeing if it's going to be a substantial cost to you, first of all?" (T.S., 2023)

S.C. (2023) thinks that governments should free more budgets to subsidize innovation at the source. T.S. (2023) thinks more subsidies for SEVs would have been granted if Lightyear would have succeeded in delivering some commercial vehicles on the road. Technological and regulatory standards can help in facilitating the development of these kinds of subsidies. For example, C.H. (2023) explains eco-credits support the innovation of various sustainable technologies. However, for a SEV pioneer to gain this benefit, it has to officially prove the technology enhances vehicle efficiency. Besides, there is no eco-credit score for solar panels yet, although it has been discussed for a long time.

4.5.4 Dutch energy policy

The new Dutch Energy Law (Tweede Kamer, 2023) should be the foundation and framework for a market organization in the energy transition and replace the existing electricity and gas laws dating from 1998, which was the origin of many practical issues for various DER systems (Akkerboom & Scholten, 2014). At the time of the interview, K.H. (2023) was critical and thinks the proposed new legislation lacks vision for the future energy system as it, for example, fails to actively facilitate the further development of V2G, virtual power plants, or peer-to-peer trading for local energy communities. He thinks there should be more room for experimentation, and that certain parties should be given an extra advantage. He hopes that Lightyear succeeds in delivering its promise on the Lightyear 2, this will mandate suitable policy innovation from regulators.

"If you purely look at the law, you can clearly see that large sections of the current legislation have been rewritten." (K.H., 2023)

The EU electricity market directive was launched in 2019 and accommodates behind-the-meter energy storage solutions (Parra & Mauger, 2022). For example, the double tax that was being paid with battery storage has been abolished since January 2022 in The Netherlands (Ministerie van Finaniciën, 2022), and earlier in Germany (S.C., 2023). Before abolishment, double taxes disincentivized people from supporting the grid with DES because it prevented them from profiting from feed-in tariffs.

Besides, T.S. (2023) mentions that despite the support from local governments, the Dutch government could have put more effort into collaborating with Lightyear. It seemed that the national government prioritized incumbent internationals such as ASML over Lightyear.

4.5.5 Lack of common standards

National standards could have benefits for internal industry developments. However, when member states develop different national standards, their industries will optimize within these national borders. Overarching European standards could help open a collective European market, thereby supporting industries to effectively scale up DER. In the US, for example, there is a more centralized governance layer at the federal level. There are still differences between the grid operators in the US, but it will be more difficult to aggregate DES for a fleet of SEVs in Europe because the US is dealing with the same set of rules at a federal level (B.N., 2023). The European Commission cannot force member-states into complying with one deterministic set of rules to harmonize the grid.

"It's a mess, I work in it and we looked in the grid codes of a lot of different countries. And yeah, it's a painful work." (T.L., 2023)

Last year, the ISO15118/20 was published, which contains the communication protocol standards for the bi-directional charging of EVs and helps drive forward the collective innovation of such technologies. However, T.L. (2023) and T.S. (2023) mention that standards for communication between different DER devices remain, which obscures the interoperability of different DER devices. For example, an open protocol through which different devices can communicate with each other, like solar inverters, EVs, laundry machines, and heat pumps within a HEM system, or standardized APIs through which EVs can buy into bid ladders of energy suppliers. G.H. (2023) envisions a nonhierarchical DER ecosystem, based on a standard that requires DER devices to both receive orders, as well as to issue orders to other DER devices.

To advance the configuration of large and complex IT systems for energy management with aggregated DES, a farsighted European framework is essential. Besides, aligning industry developments with the norms and values of European societies will require a proactive regulatory guiding framework (Burke & Stephens, 2018). To facilitate convenient and fair data access, the European Commission has recently implemented the 'Data Market Act', a horizontal legislation to achieve a fair and contestable digital market in the European Union. However, a concern is that current regulatory frameworks like the Data Act, Digital Markets Act, and Clean Energy Package are not extensive enough to counteract the development of profit-optimized systems (C.H., 2023). The European Commission intended to come forward with a complementary piece of legislation for the automotive sector, however, this has not been manifested yet (C.H., 2023).

4.5.6 European Union towards V2G and virtual power plants

K.H. (2023) and B.N. (2023) note that the European discussion on how to integrate (S)EVs for V2G has only just begun. To further enable V2G, the integration of V2G and virtual powerplants demands the registration of devices that are not fixed in one location with unique registration codes, this means administrations of European Article Number (EAN) codes, and Energy Identification Codes (EICs) (ENTSO-E, 2023) must be modernized (K.H., 2023).

C.G. (2023) explains that V2G research in Europe is currently still a work in process while Korea and China are developing V2G and virtual powerplants fast. He informs that the European Commission focuses on energy efficiency and sustainability among others through the smart readiness of buildings, adhering to the Energy Performance Directive with bi-directional energy flows, meters, and real-time pricing. Within the Horizon Europe research program, Europe established a dedicated 2Zero partnership. Which contains a target for a commonly agreed charging protocol for enabling V2G by 2030 and approximates V2G is utilized for ancillary services at 20% system capacity in 2025, and 50% by 2030 (2Zero, 2021). Moreover, Europe identified V2G barriers in each Member State through a LIFE-funded scouting project. These efforts by Europe promoted a sustainable, interconnected energy landscape for a greener future.

4.6 Business Model Innovation

Various BMIs for EVs have been revealed by Wesseling et al. (2020). The following section proposes a BMI that covers both the energy and personal mobility sectors for SEVs with DES. The proposed BMI is based on the aggregated empirical data from the BMDS dimensions. The multi-dimensionality is essential for composing a sustainable solution for the illustrated problems in the European energy and mobility transitions.

The foundational purpose of this BMI is to revolutionize the paradigm of automobile horsepower in Europe, and to promote alternative behavior around energy and personal mobility use. The aim is to implement this transformation before and while the existing paradigm is inevitably disrupted by the widespread adoption of self-driving robot cab (S)EVs. By doing so, the BMI aligns with the principles of democracy and sustainability, addressing the need to reduce GHG, combat climate change, and minimize environmental impact.

Such a socio-technical transformation can only be achieved by offering radically innovative sustainable products and services, that achieve to reconfigure the emotional relationships of customers with conventional automobile paradigms and energy use. Therefore, the BMI must deliver unprecedented customer experiences, provoking the collective reimagination of existing automotive and energy systems. Below, the BMI is broken down into its subsidiary elements, value proposition, capture, and network.

The ambition of the value proposition should be to increase access to sustainable personal mobility democratically, by distributing services throughout persistent levels in society equally. An appealing application should be available through wearable devices to help users and communities organize MaaS and optimize their energy management with SEVs or SEV fleets. The product and service should interest and empower societies into considering their mobility needs within the boundaries of energy availability. MaaS will require fewer vehicles, decreasing demand for raw materials, and reducing environmental and social strains on automotive value chains. The high efficiency of SEVs and VIPV reduce energy use while increasing renewable share and requires less charging infrastructure. By providing flexibility for the increased intermittency in electricity grids, DES services will enable further decarbonization of the European energy system. Domestic SEV industries sustain sovereignty and job security in Europe, while pushing worldwide climate regulations to align more deeply with the Paris agreement goals.

In terms of value capture, BMI for SEVs with DES can enable new revenue streams through MaaS and energy communities. Value creation with VIPV and DES during idle time will yield revenues that draw interests of new customer groups. Developments in smart energy and personal mobility ecosystems will result in the creation of new jobs. SEVs will be economically superior to BEVs when shared ownership models gradually emerge and MaaS models become more mainstream.

Along value networks, SEVs enrich ecosystems for MaaS and energy communities in European economies. Through a farsighted strategy, European automotive value networks are reconfigured towards more sustainable baselines and circular manufacturing ecosystems. Domestic industries for integrated PV and energy efficient components for SEVs will emerge. Open innovation ecosystems deepen collaboration along SEV and IT value networks and will likely lead to parallel developments and symbioses with DLT, AI, and IoT ecosystems.

4.7 Fit-and-conform & stretch-and-transform scenarios

In the optimally configured BMI scenario proposed above, the hard-edges of today's socio-technical system have not been considered. In the following, a BMI for SEVs with DES is more closely aligned with the earlier illustrated BMDS dimensions and configured through fit-and-conform and stretch-and-transform strategies as aggregated in Table A2 in Annex II. For these strategies to come to fruition, a scenario consistent with current developments between 2025-2030 is considered.

It is deduced that BMI for SEVs with DES can considerably stretch-and-transform the social dimension by improving the financial incentive for the development of MaaS and V2G platforms. These can gradually shift mental models from private vehicle ownership towards shared vehicle ownership, and the behavior of electricity consumers toward electricity prosumer communities. Generally, market barriers for shared business models and DER management systems stretch-and-transform as SEV with DES technology becomes more affordable over time, and new revenue models evolve because of enabling policy frameworks. This will also create new jobs along evolving industries and value networks. In the industry, incumbent automotive value networks are increasingly stretching-and-transforming, driven by energy efficiency and sustainability. Circular manufacturing ecosystems foster more future proof industries and help achieve a low-demand scenario for raw materials from third countries (Carrara et al., 2023).

The analysis shows that although there are numerous barriers to overcome, the largest potential impact of BMI for SEVs with DES lies not only in the dimensions individually, but in the fundamental beliefs, norms, and values held by individuals and organizations in mainly regime-levels of the socio-technical system. Consistent with the BMDS theory, it seems that the hardest barriers to overcome by BMI are in the technology and regulation dimensions (Wesseling et al. 2020). It seems that if Europe is taking its climate targets seriously, there should be more incentives to support the technological development of SEVs with DES, which could be enabled by incentivizing policies. In turn, the regulation of such policies would rely on a technological benchmark for SEVs, which results in somewhat of a paradox.

5 Discussion

The research reveals that a technological benchmark for SEVs is crucial for its industry. Where the Lightyear 0 focusses on high-end personal mobility and grid-independency, the Sono Sion focusses on low-cost personal mobility and grid-balancing. It has become clear both development vehicles have enabled sustainable new pathways for automotive innovation, but more support and resources are required. Their inability to reach mass-markets can be attributed to premature technological development and uncomplete product strategies from the niche-innovators, but also more ominously from a lack of incentives for regime-actors to advance in this innovation. Today, there is insufficient reason for the incumbent automotive industry to develop these technologies at masses. There is a paradox between creating incentivizing policy for technological development of SEVs with DES, and requiring a technical benchmark before SEV policy can be created. With scale up barriers across the SEV industry, a collaborative approach towards conceptualizing a legal definition for different types of SEVs seems sensible. The ASOM industry coalition is a potential starting point for exploration of such regulatory device. Consolidation of this SEV coalition will increase access to decision-makers in regulatory institutions over time.

The exploration of digitalization in the energy and automotive systems limited, especially considering the scale of socio-technical transformation as severe as the energy transition. The challenges associated with data governance and large IT-systems must be addressed to ensure the democratic and sustainable integration of SEVs and DES into the energy system. Industry actors show a bias towards the private stack models, which does not necessarily result in democratic, civil-centered systems. It is recommended that SEV industries explore collaborative opportunities for digital development with citizen and consumer organizations, and open-source communities. The development of open innovation ecosystems, collaboration along value networks, and the integration of digital technologies such as blockchain, AI, and IoT present opportunities for the sustainable transition of the energy and mobility systems in Europe.

The findings indicate strong support among all respondents for a market-based approach with implicit price signals to promote the growth of energy storage and renewable energy. However, further research is needed to explore socially innovative methodologies that can mitigate any rebound effects associated with market-based solutions. Despite this, markets remain a crucial tool for driving the necessary social change. Considering the trajectory of markets, niche innovators are expected to increasingly benefit from the expanding (S)EV and DES markets. Nevertheless, it is important to recognize that consumer preferences and the demand for new vehicle purchases are deeply rooted in European societies. This report does not address the potential for a more circular approach to (S)EV production. Given the multidimensional complexity of socio-technical systems, there is inherent uncertainty in predicting the precise short-term outcomes of markets. Therefore, the potential impacts and unintended consequences of market-based strategies should be carefully considered.

It is worrying that SEV development seems like a blind spot in governments. There is too little research & development for SEVs compared to the size of the automotive industry. Considering the clear potential advantages of SEVs with DES, Europe needs a strategy to support the development of related BMI. Closer collaboration between SEV niche-industry coalitions and governments is crucial. Incumbent energy and automotive innovation should be guided towards sustainable development trajectories, but governments lack the vision to compose a profound, farsighted directive in line with their climate goals. In this research, broad policy measures have been identified that can support and facilitate BMI for SEVs with DES, further research should conclude how these are designed. The findings highlight (1) that the industry-wide incentives and subsidies should be expanded to support the innovation and development of highly efficient SEVs, (2) the need for harmonized regulations, grid codes, and communication protocols across European member states to ensure interoperability and aggregation of SEVs in energy markets, (3) legislative barriers should continue to be addressed to actively facilitate the development of V2G capabilities, virtual power plants, and peer-to-peer trading, and (4) policymakers are advised to explore open innovation, data privacy & security, interoperability, and efficient IT infrastructures for the development of SEV systems. Besides vital European support, closer involvement of Dutch and German national governments, and collaboration among niche actors can overcome resource limitations and provide a platform for innovation in the SEV industry.

As a case study, findings from this report should be interpreted within the context that they derived from. It should be considered that automotive manufacturers are part of a complex industry ecosystem, and deeply rooted in the European economy and society. Therefore, the outcomes of this study cannot be generalized to other economies, or different industries and cultures. Neither can assumptions be made about the potential of SEVs with DES in other nation systems. The BMDS methodology, however, can be used to produce comparative system analyses for BMI with SEVs and DES in nation systems across the globe. With interviews as a primary means of data-collection and restrictions in time and resources, one of the key limitations of the research design is the sample size and diversity. For example, there was no response from regime actors in the automotive industry on interview requests. Besides, this study is biased towards the western-European energy systems, mainly The Netherlands and Germany, and assumes that less-developed electricity systems will catch-up along the same development path. However, there is insufficient evidence to make decisive conclusions about the development paths of European member-states with different energy and mobility systems.

6 Conclusion

In conclusion, the study aimed to investigate the potential role of SEVs with DES the European energy transition. To address this topic, several research questions where examined, covering drivers, barriers, opportunities, technical specifications, digitalization, BMI, and policy measures.

Paradigms of incumbent automobile industries are deeply ingrained in Europe's regime systems, and their supply chains have substantial social and environmental footprints. If the huge European consumer demand for personal mobility is to be met, it is common-sense to do this as sustainable as possible. To achieve the vital disruptions in

Europe's socio-technical regimes and reduce negative impacts, it is essential that niche-innovators are supported by governments to stretch-and-transform these regimes. SEVs with DES can become the multi-purpose vehicles for transitioning Europe's largest industries towards a more sustainable future with collective clean energy and personal mobility solutions. However, there are several challenges that need to be addressed to ensure the successful integration of SEVs.

Current European SEV innovations like the Lightyear 0 and Sono Sion are an immense first step but fail to appeal to mass-markets affordably. To become successful BMIs, European institutions and industry incumbents must invest more in research and development of European SEV technologies. Research and collaboration along DES and V2G developments are also important, but already receive relatively broad support. The key to facilitating BMI for SEVs with DES is to foster cross-sectoral collaboration in automotive and energy industries, governments, and societies.

SEVs with DES are an excellent example for showcasing how BMI can contribute to socio-technical system transitions. It is crucial to develop European standards for SEVs to guide policy development and incentivize their development and adoption. Definitions of a SEV should at minimum capture a VIPV powered, energy efficient system for sustainable personal mobility. Such a platform, combined with decentralized IT-systems and DES services can empower DER uptake, while supporting democratic energy communities. Within the European energy transition, the technology can catalyze the sustainability efforts of energy and mobility systems by appealing users towards more sustainable norms, values, and behaviors. Thereby, SEVs with DES can empower the collective achievement of the targets in the European Climate Law. The transformative power of SEVs with DES should not be overlooked, and their integration should be a priority in the pursuit of a sustainable future.

7 References

2Zero. (2021). *The Towards Zero Emission Road Transport (2Zero) Strategic Research and Innovation Agenda (SRIA)*. European Commission on the Horizon Europe partnership candidates dedicated webpage.

Akerboom, S., & Scholten, D. (2014). *Legal restrictions and solutions for local solar pv markets in the Netherlands*. Utrecht University.

Andoni, M., Robu, V., Flynn, D., Abram, S., Geach, D., Jenkins, D. J., McCallum, P., & Peacock, A. J. (2019). Blockchain technology in the energy sector: A systematic review of challenges and opportunities. *Renewable & Sustainable Energy Reviews*, *100*, 143–174. https://doi.org/10.1016/j.rser.2018.10.014

ASOM. (2023). *ASOM: Alliance for Solar Mobility*. Retrieved June 23, 2023, from https://asom.solar/

Berkeley, N., Bailey, D. H., Jones, A. M., & Jarvis, D. (2017). Assessing the transition towards Battery Electric Vehicles: A Multi-Level Perspective on drivers of, and barriers to, take up. *Transportation Research Part A-policy and Practice*, *106*, 320–332. https://doi.org/10.1016/j.tra.2017.10.004

Bohnsack, R., Pinkse, J., & Kolk, A. (2014). Business models for sustainable technologies: Exploring business model evolution in the case of electric vehicles. *Research Policy*, *43*(2), 284–300. https://doi.org/10.1016/j.respol.2013.10.014

Brinkel, N., Schram, W., Van Sark, W., & Lampropoulos, I. (2020). Should we reinforce the grid? Cost and emission optimization of electric vehicle charging under different transformer limits. *Applied Energy*, *276*, 115285. https://doi.org/10.1016/j.apenergy.2020.115285

Brisbois, M. C. (2019). Powershifts: A framework for assessing the growing impact of decentralized ownership of energy transitions on political decision-making. *Elsevier*, *50*, 151–161. https://doi.org/10.1016/j.erss.2018.12.003

Burke, M., & Stephens, J. C. (2018). Political power and renewable energy futures: A critical review. *Elsevier*, *35*, 78–93. https://doi.org/10.1016/j.erss.2017.10.018

Cantante, F. (2020). Four profiles of inequality and tax redistribution in Europe. *Humanities & Social Sciences Communications*, *7*(1). https://doi.org/10.1057/s41599-020-0514-4

Cardoso, C., Torriti, J., & Lorincz, M. J. (2020). Making demand side response happen: A review of barriers in commercial and public organisations. *Elsevier*, *64*, 101443. https://doi.org/10.1016/j.erss.2020.101443

Carrara, S., Bobba, Blagoeva, D., Alves Dias, Cavalli, A., Georgitzikis, K., Grohol, M., Itul, A., Kuzov, T., Latunussa, C., Lyons, L., Malano, G., Maury, T., Prior Arce, Á., Somers, J., Telsnig, T., Veeh, C., Wittmer, D., Black, C., . . . Christou, M. (2023). *Supply chain analysis and material demand forecast in strategic technologies and sectors in the EU: A foresight study* (No. JRC132889). Publications Office of the European Union. https://doi.org/10.2760/386650

Carroll, C., Quantalyse Belgium, & Schönenberger Advisory Services. (2019). *The automotive digital transformation and the economic impacts of existing data access models*. Schönenberger Advisory Services. https://www.fiaregion1.com/study-on-economic-impact-of-existing-data-access-models/

Corinaldesi, C., Lettner, G., & Auer, H. (2022). On the characterization and evaluation of residential on-site E-car-sharing. *Energy*, *246*, 123400. https://doi.org/10.1016/j.energy.2022.123400

DG for Energy. (2023, April 24). *Energy communities*. European Commission - Energy. Retrieved June 22, 2023, from https://energy.ec.europa.eu/topics/markets-and-consumers/energy-communities_en

Elliott, M., Swan, L. G., Dubarry, M., & Baure, G. (2020). Degradation of electric vehicle lithium-ion batteries in electricity grid services. *Journal of Energy Storage*, *32*, 101873. https://doi.org/10.1016/j.est.2020.101873

Energy21 & Stedin. (2018). *Whitepaper Layered Energy System*.

ENTSO-E. (2023). *Energy Identification Codes (EICs)*. https://www.entsoe.eu/data/energy-identification-codes-eic/eic-approved-codes/

European Commission. (2019). *Sustainable Mobility - European Green Deal*.

European Commission. (2020). *Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability: Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions*.

European Commission. (2021a). *Horizon Europe: the most ambitious EU research & innovation programme ever*. Publications Office of the European Union. https://doi.org/10.2777/202859

European Commission. (2021b). *Energy System Factsheet: Decarbonising our energy system to meet our climate goals*.

European Commission. (2021c). *"Fit for 55": delivering the EU's 2030 Climate Target on the way to climate neutrality: Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, and the Committee of the Regions*.

European Commission. (2022). *REPowerEU Actions*. Retrieved January 3, 2023, from https://commission.europa.eu/document/download/831d72e7-43ab-442e-847e-51dd6987953f_en

European Environment Agency. (2022). *Transport and environment report 2021 Decarbonising road transport: The role of vehicles, fuels and transport demand*. Publications Office of the European Union.

European Union. (2021). *Regulation (EU) 2021/1119 of the European Parliament and of the Council: establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law')*. Official Journal of the European Union. Retrieved December 14, 2022, from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R1119

Eurostat. (2023a). *Electricity prices for household consumers: bi-annual data (from 2007 onwards)*. Eurostat Databrowser. https://ec.europa.eu/eurostat/databrowser/view/nrg_pc_204/default/line?lang=en

Eurostat. (2023b, January 13). Income inequality across Europe in 2021. *Eurostat*. https://ec.europa.eu/eurostat/web/products-eurostat-news/w/DDN-20230113-1#:~:text=In%202021%2C%20the%20median%20disposable,8%20703%20PPS%20in%20Romania.

EV Database. (2023). *EV Database*. Retrieved April 26, 2023, from https://ev-database.org/nl/

EVBox. (2023). Retrieved June 19, 2023, from https://evbox.com/nl-nl/elektrische-autos/volkswagen/volkswagen-id4

Ford, A., & Newell, P. (2021). Regime resistance and accommodation: Toward a neo-Gramscian perspective on energy transitions. *Elsevier*, *79*, 102163. https://doi.org/10.1016/j.erss.2021.102163

Gerritsma, M., Van Sark, W., Fidder, H., & Van Sark, W. (2019). Flexibility of Electric Vehicle Demand: Analysis of Measured Charging Data and Simulation for the Future. *World Electric Vehicle Journal*, *10*(1), 14. https://doi.org/10.3390/wevj10010014

Haas, T. (2019). Struggles in European Union energy politics: A gramscian perspective on power in energy transitions. *Energy Research and Social Science*, *48*, 66–74. https://doi.org/10.1016/j.erss.2018.09.011

Hildermeier, J., Burger, J., Jahn, A., & Rosenow, J. (2022). A Review of Tariffs and Services for Smart Charging of Electric Vehicles in Europe. *Energies*, *16*(1), 88. https://doi.org/10.3390/en16010088

Hildermeier, J., Kolokathis, C., Rosenow, J., Hogan, M., Wiese, C., & Jahn, A. (2019). Smart EV Charging: A Global Review of Promising Practices. *World Electric Vehicle Journal*, *10*(4), 80. https://doi.org/10.3390/wevj10040080

Holtz, G. (2012). The PSM approach to transitions: Bridging the gap between abstract frameworks and tangible entities. *Technological Forecasting and Social Change*, *79*(4), 734–743. https://doi.org/10.1016/j.techfore.2011.10.005

Huijben, J. B., Verbong, G. G., & Podoynitsyna, K. (2016). Mainstreaming solar: Stretching the regulatory regime through business model innovation. *Environmental Innovation and Societal Transitions*, *20*, 1–15. https://doi.org/10.1016/j.eist.2015.12.002

Huxley, A. (2004). *Brave New World*. Random House. (Original work published 1932)

IPCC. (2022). *Sixth Assessment Report: Summary for Policymakers*. Intergovernmental Panel on Climate Change.

Jedlix. (2023). *Jedlix Smart Charging: Home Page*. https://www.jedlix.com/

Juch, N. D. (2022). *Environmental Impacts of Vehicle Integrated Photovoltaics: a Life Cycle Assessment of a Solar Electric Vehicle* [MSc Thesis Industrial Ecology]. Leiden University & Delft University of Technology.

Klimaatstichting HIER & Bureau 7TIEN. (2023). *Knelpunteninventarisatie energiecoöperaties: Knelpunten en kansen voor het opschalen van energiecoöperaties in Nederland*. Rijksdienst voor Ondernemend Nederland.

Köhler, J., Sovacool, B. K., Kern, F., Markard, J., Wieczorek, A. J., Alkemade, F., Avelino, F., Bergek, A., Boons, F., Fünfschilling, L., Hess, D. C., Holtz, G., Hyysalo, S., Jenkins, K., Kivimaa, P., Martiskainen, M., McMeekin, A., Mühlemeier, M. S., Nykvist, B., . . . Wells, P. E. (2019). An agenda for sustainability transitions research: State of the art and future directions. *Environmental Innovation and Societal Transitions*, *31*, 1–32. https://doi.org/10.1016/j.eist.2019.01.004

König, M., & L, N. (2017). Users' resistance towards radical innovations: The case of the self-driving car. *Transportation Research Part F-traffic Psychology and Behaviour*, *44*, 42–52. https://doi.org/10.1016/j.trf.2016.10.013

König, M., & Neumayr, L. (2017). Users' resistance towards radical innovations: The case of the self-driving car. *Transportation Research Part F-traffic Psychology and Behaviour*, *44*, 42–52. https://doi.org/10.1016/j.trf.2016.10.013

Kooshknow, S. M. M., & Davis, C. (2018). Business models design space for electricity storage systems: Case study of the Netherlands. *Journal of Energy Storage*, *20*, 590–604. https://doi.org/10.1016/j.est.2018.10.001

Kumar, R., & Alok, K. (2020). Adoption of electric vehicle: A literature review and prospects for sustainability. *Journal of Cleaner Production*, *253*, 119911. https://doi.org/10.1016/j.jclepro.2019.119911

Lampropoulos, I., Van Den Broek, M., Van Der Hoofd, E., Hommes, K., & Van Sark, W. (2018). A system perspective to the deployment of flexibility through aggregator companies in the Netherlands. *Energy Policy*, *118*, 534–551. https://doi.org/10.1016/j.enpol.2018.03.073

Levy, D. E., & Newell, P. (2002). Business Strategy and International Environmental Governance: Toward a Neo-Gramscian Synthesis. *Global Environmental Politics*, *2*(4), 84–101. https://doi.org/10.1162/152638002320980632

Lightyear. (2023a). We decided to fully focus on Lightyear 2. *lightyear.one*. https://lightyear.one/articles/lightyear-decides-to-fully-focus-on-lightyear-2

Lightyear. (2023b, June 6). *Long Range Solar Electric Vehicle — Lightyear 0*. https://lightyear.one/lightyear-0/

Lightyear Public Affairs. (2023). Internal communication at Lightyear [Dataset]. In *Lightyear shared STRICTLY CONFIDENTIAL data from their Public Affairs databank to support this research*. Lightyear.

Lightyear & Ubitricity. (2021). *Go further with less: What is needed to roll out EV charging infrastructure by considering highly efficient EVs*. Ubitricity. https://ubitricity.com/en/ubitricity-lightyear-whitepaper/

Ma, J., Yan, Z., & Chen, S. (2021). A Two-stage Autonomous EV Charging Coordination Method Enabled by Blockchain. *Journal of Modern Power Systems and Clean Energy*, *9*(1), 104–113. https://doi.org/10.35833/mpce.2019.000139

Mercedez-Benz. (2022, January 3). *The Mercedes-Benz VISION EQXX*. Mercedes-Benz Media. https://media.mercedes-benz.com/vision_eqxx

MidJourneyAI. (2023). *MidJourney AI*. Retrieved July 5, 2023, from https://www.midjourney.com/home/

Mikulecky, D. C. (2001). The emergence of complexity: science coming of age or science growing old? *Computers & Chemistry*, *25*(4), 341–348. https://doi.org/10.1016/s0097-8485(01)00070-5

Ministerie van Financiën. (2022). *Aanpassen energiebelasting ter voorkoming dubbele belasting bij batterijopslag*. Rijksfinancien. https://www.rijksfinancien.nl/belastingplan-memorie-van-toelichting/2022/d17e2179

Musk, E. (2006, August 2). *The Secret Tesla Motors Master Plan (just between you and me) | Tesla Netherlands*. Tesla. Retrieved June 21, 2023, from https://www.tesla.com/nl_nl/blog/secret-tesla-motors-master-plan-just-between-you-and-me

Noel, L., & Sovacool, B. K. (2016). Why Did Better Place Fail?: Range anxiety, interpretive flexibility, and electric vehicle promotion in Denmark and Israel. *Energy Policy*, *94*, 377–386. https://doi.org/10.1016/j.enpol.2016.04.029

Northpool & Utrecht University. (n.d.). *Trading Energy - The impact of RES and Congestion Management on the Power Markets* [Slide show]. Lecture - Energy in the Build Environment, Utrecht, Netherlands. northpool.nl.

2023

Parra, D., & Mauger, R. (2022). A new dawn for energy storage: An interdisciplinary legal and techno-economic analysis of the new EU legal framework. *Energy Policy*, *171*, 113262. https://doi.org/10.1016/j.enpol.2022.113262

Prettenthaler, F., & Steininger, K. W. (1999). From ownership to service use lifestyle: the potential of car sharing. *Ecological Economics*, *28*(3), 443–453. https://doi.org/10.1016/s0921-8009(98)00109-8

Rajaeifar, M. A., Ghadimi, P., Raugei, M., Wu, Y., & Heidrich, O. (2022a). Challenges and recent developments in supply and value chains of electric vehicle batteries: A sustainability perspective. *Elsevier*, *180*, 106144. https://doi.org/10.1016/j.resconrec.2021.106144

Rajaeifar, M. A., Ghadimi, P., Raugei, M., Wu, Y., & Heidrich, O. (2022b). Challenges and recent developments in supply and value chains of electric vehicle batteries: A sustainability perspective. *Elsevier*, *180*, 106144. https://doi.org/10.1016/j.resconrec.2021.106144

Rimac Nevera. (2023). Rimac Automobili. Retrieved June 20, 2023, from https://www.rimac-automobili.com/nevera/

Rogge, K. S., & Reichardt, K. (2016). Policy mixes for sustainability transitions: An extended concept and framework for analysis. *Research Policy*, *45*(8), 1620–1635. https://doi.org/10.1016/j.respol.2016.04.004

Rothfuß, E., & Boamah, F. (2020). Politics and (Self)-Organisation of Electricity System Transitions in a Global North–South Perspective. *Politics and Governance*, *8*(3), 162–172. https://doi.org/10.17645/pag.v8i3.3636

Sono Motors. (2022). *The Sion: Information Sheet*.

Sono Motors. (2023). *Sion Program Sell Off | Sono Motors*. https://sonomotors.com/en/sion-sell-off/

Tesla. (2022). *European Union Energy Label*. Retrieved January 9, 2023, from https://www.tesla.com/en_eu/support/european-union-energy-label

Thewessen, M. (2023). *Model-based Techno-Economic Analysis of Large-scale Vehicle-to-grid on the Dutch Day-ahead Electricity Assessment committee Market in 2030* [MSc Thesis Electrical Engineering]. Eindhoven University of Technology.

Tweede Kamer. (2023). *Voorstel Nieuwe Energiewet*.

United Nations. (2015). *PARIS AGREEMENT*. COP21.

Valdivia, A. D., & Balcell, M. P. (2022). Connecting the grids: A review of blockchain governance in distributed energy transitions. *Energy Research and Social Science*, *84*, 102383. https://doi.org/10.1016/j.erss.2021.102383

Van Dijk, T. v. D., & Jansen, J. J. (2023). *open HEM nu!: Waarom dit het moment is voor de ontwikkeling van open Home Energy Management*. Waag Futurelab. https://waag.org/nl/project/open-hem-nu/

Van Oorschot, S. (2022). *Effective charging strategies for (solar) Electric Vehicles*. Utrecht University.

Van Sark, W., Holthuizen, B., Schram, W., Lampropoulos, I., & Van Sark, W. (2020). A Blockchain-Based Configuration for Balancing the Electricity Grid with Distributed Assets. *World Electric Vehicle Journal*, *11*(4), 62. https://doi.org/10.3390/wevj11040062

Vandebron. (2023). *Vandebron slim laden*. https://vandebron.nl/elektrisch-rijden/slim-laden

Wainstein, M. E., & Bumpus, A. G. (2016). Business models as drivers of the low carbon power system transition: a multi-level perspective. *Journal of Cleaner Production, 126*, 572–585. https://doi.org/10.1016/j.jclepro.2016.02.095

Walrave, B., Talmar, M., Podoynitsyna, K., Romme, A., & Verbong, G. (2018). A multi-level perspective on innovation ecosystems for path-breaking innovation. *Technological Forecasting and Social Change*, *136*, 103–113. https://doi.org/10.1016/j.techfore.2017.04.011

Wesseling, J. H., Bidmon, C., & Bohnsack, R. (2020). Business model design spaces in socio-technical transitions: The case of electric driving in the Netherlands. *Technological Forecasting and Social Change*, *154*, 119950. https://doi.org/10.1016/j.techfore.2020.119950

Xu, B., Sharif, A., Shahbaz, M., & Dong, K. (2021). Have electric vehicles effectively addressed CO2 emissions? Analysis of eight leading countries using quantile-on-quantile regression approach. *Sustainable Production and Consumption*, *27*, 1205–1214. https://doi.org/10.1016/j.spc.2021.03.002

Yong, J. Y., Ramachandaramurthy, V. K., Tan, K. H., & Mithulananthan, N. (2015). A review on the state-of-the-art technologies of electric vehicle, its impacts and prospects. *Renewable & Sustainable Energy Reviews*, *49*, 365–385. https://doi.org/10.1016/j.rser.2015.04.130

Zonneplan. (2023). *Zonneplan slimme laadpaal voor thuis*. https://www.zonneplan.nl/laadpaal

Annex I: Lightyear 0 vs Sono Sion

	Lightyear 0	**Sono Sion**
Socket charging	3,7kW	3,7kW
Socket charging speed	32 km/hour	*23 km/hour
AC charging	22kW	11kW
AC charging speed	200 km/hour	*69 km/hour
DC charging	50kW	75kW
DC charging speed	520km/hour	*469 km/hour
AC discharging rate	(?)	11 kW
Vehicle-to-Grid & Vehicle-to-Home	Hardware bi-directional charging ready, software in early development (over-the-air update)	Hardware ready bi-directional charging ready, software in development (over-the-air update)
Vehicle-to-Load	(?)	3.6kW
Total weight	1575 kg	1730 kg
Dimensions LBH	5083 x 1972 x 1445 mm	4454 x 1832 x 1660 mm
Drag coefficient	Cd 0.175	(?)
Battery capacity	60 kWh	54 kWh
Battery type	NMC-811 Li-ion battery	Li-ion phosphate (LFP) battery
Battery weight	350 kg	(?)
Powertrain	32kW (4x in wheel)	120kW 400V Front-wheel-drive
Torque	1720 Nm (?)	270 Nm
Efficiency	9,8 kWh / 100 km	16 kWh / 100 km
0-100 time	10 sec	9 sec
Top speed	160 km/u	140 km/u
Battery range	625 km WLTP	305 km WLTP
Practical range* **	>1000 km	(?)
Daily solar range	70 km	*43,4 km
VIPV generation	1,2 kW (T.S., 2023) 1.05kW (Lightyear, 2023b)	0,9 kW (T.L., 2023) 1,2kW (Sion Motors, 2022)
VIPV charging speed	10 km/hour	*6,2 km/hour
solar cell efficiency	23% (Juch, 2022)	21% (T.L., 2023)
VIPV surface	5 m2 on top	7,5 m2 all-around
Cell technology	782 IBC monocrystalline silicon solar cells	Monocrystalline silicon solar cells
Interior	Vegan, naturally sourced materials	‘Standard’ materials
Exterior	Lightweight aluminum & reclaimed carbon fiber	Conventional steel and Polymer
App handheld device	Lightyear App in development	Sono App in development
Software	Custom infotainment system	Custom infotainment system
Price	€250.000**	€30.400**

Table A1: Data derived from (Lightyear, 2023b; Sono Motors, 2022) unless referenced otherwise.

*Derived data, based on calculations from available data
**These are estimated market prices, the development processes of both vehicles have been terminated, and officially no commercial production vehicles have been sold.
***Driving range will vary depending on driving habits, location, and season. 1,000 km range based on a 50 km workday commute in Amsterdam during summer.

Annex II: BMI strategies

	Dimension	BMI component	BMI Strategy
Lightyear 0			
DES development in existing market frameworks	Technology	Value proposition	Fit-and-conform
Sustainable, circular, lightweight and high-end materials	Technology	Value proposition	Stretch-and-transform
Smaller battery size	Industry	Value capture	Stretch-and-transform
Market-based, implicit approach towards flexibility	Market	Value capture	Stretch-and-transform
Grid independency, high performance battery, and drivetrain	Technology	Value proposition	Stretch-and-transform
Fostering some circular manufacturing ecosystems	Industry	Value network	Stretch-and-transform
Energy efficiency and charging infrastructure	Technology	Value proposition	Stretch-and-transform
Decreased need for raw materials for battery	Industry	Value proposition	Stretch-and-transform
Aerodynamic and VIPV optimized exterior design	Technology	Value proposition	Stretch-and-transform
Sono Sion			
Conventional material use for cost reduction	Technology	Value Proposition	Fit-and-conform
DES development with grid operators	Technology	Value Proposition	Fit-and-conform
No aerodynamic exterior design	Technology	Value Proposition	Fit-and-conform
No innovation on energy efficiency	Technology	Value Proposition	Fit-and-conform
Conventional battery size	Industry	Value capture	Fit-and-conform
Grid symbiosis, high cycle PFS battery and standard drivetrain	Technology	Value Proposition	Stretch-and-transform
Full-body VIPV integration	Technology	Value Proposition	Stretch-and-transform
Market-based, semi-implicit approach towards flexibility	Market	Value capture	Stretch-and-transform
Lightyear & Sono			
Black box-development instead of open-innovation	Social	Value network	Fit-and-conform
Closed data-access model	Technology	Value Proposition	Fit-and-conform
No active involvement of civil energy cooperatives	Social	Value network	Fit-and-conform
Not optimized for industrial SEV manufacturing	Technology	Value proposition	Fit-and-conform
Unable to establish SEV benchmark or definition	Regulation	Value proposition	Fit-and-conform
Bi-directional charging conform ISO15118/20 standards	Regulation	Value proposition	Fit-and-conform
Unable to create sufficient industry support	Industry	Value network	Fit-and-conform
No disruptive circularity strategy	Industry	Value proposition	Fit-and-conform
Enabling of MaaS	Social	Value capture	Stretch-and-transform
Potential to reach new customer groups and markets	Market	Value capture	Stretch-and-transform
Potential to provoke believe systems in incumbent paradigm	Social	Value proposition	Stretch-and-transform
Potential to change behavior and consumer preferences	Social	Value proposition	Stretch-and-transform
Potential to harmonize European markets	Market	Value network	Stretch-and-transform
Founding member of ASOM	Industry	Value network	Stretch-and-transform
Platform for V2G and peer-to-peer markets development	Market	Value capture	Stretch-and-transform
Platform for MaaS and energy communities	Social	Value capture	Stretch-and-transform
New revenue streams through MaaS and energy communities	Market	Value capture	Stretch-and-transform
Potential to shift mental models from private, to shared ownership	Social	Value proposition	Stretch-and-transform
New jobs as industries and societies evolve	Industry	Value network	Stretch-and-transform

Table A2: BMI characteristics derived from aggregated data and their dimensions, BMI components and strategies for the reconfiguration of socio-technical regimes.

Annex III: Interview Guide template

This interview guide is created for an interview with a field expert in the energy or mobility sector. The purpose of the interview is to explore the role of Distributed Energy Storage with Solar Electric Vehicles in the European energy transition.

The interview is executed as a semi-structured interview, which means that the listed questions can be interpreted as a guide rather than a strict rule. As such, the interviewer is responsible to make sure questions are matched to the expertise of the respondent, so that the most relevant matters are addressed.

Interview information
Date: *dd-mm-yyyy*
Location: *online/offline*
Respondent: *name*
Expertise: *job description*

Checklist
Consent form: *agreed/not agreed*
Language: *Dutch/English*
Recording: *yes/no*
Agreed duration: *60 minutes*

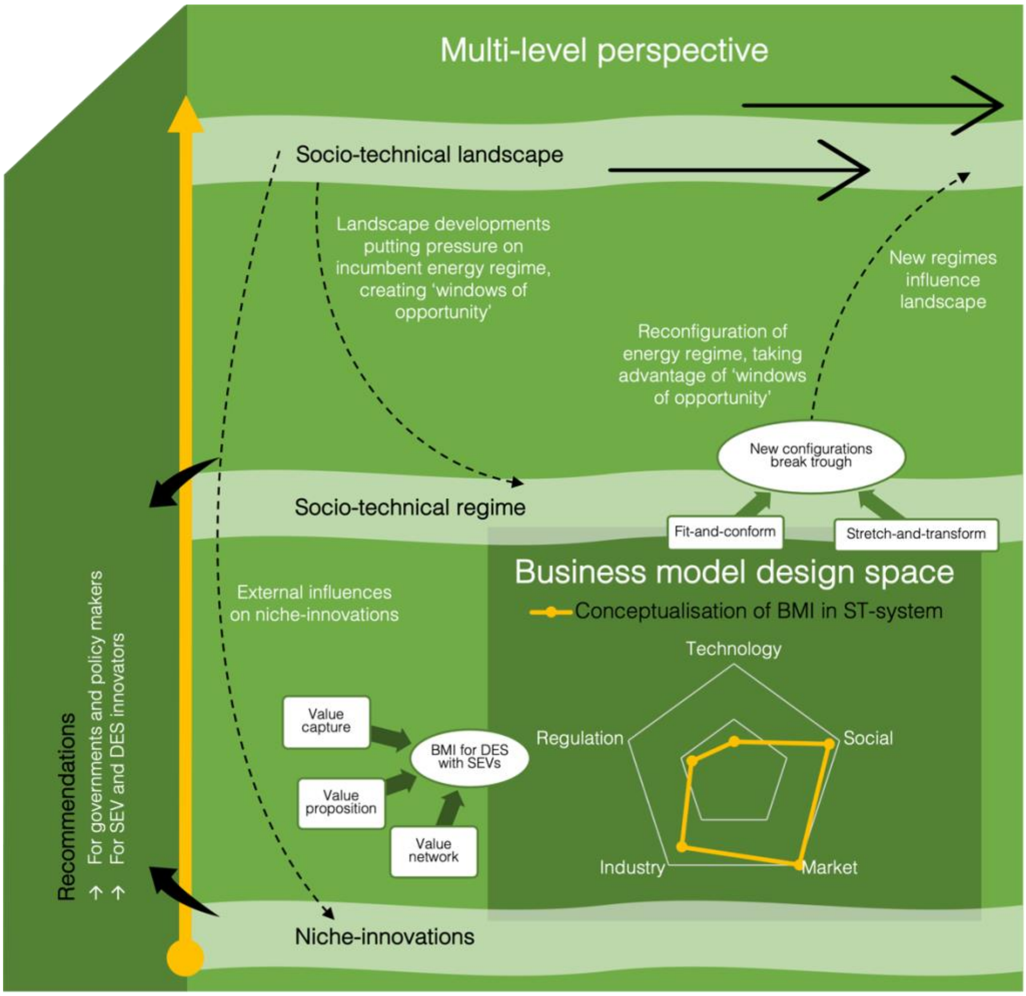

Figure A1: If necessary, share screen and explain research framework to respondent

Introduction

My name is Jim Böck, and I am currently graduating from my MSc program Sustainable Business and Innovation at Utrecht University. I was initially hired by Lightyear, but this internship was interrupted when they had to declare insolvency. Despite this, my research proposal was still accepted by my MSc thesis supervisors on Utrecht University, which brings us at our conversation here.

The purpose of the research is to explore the role of Solar Electric Vehicles with Distributed Energy Storage in the European energy transition. More specifically, the technical focus will be on the case of hyper-efficient SEVs for personal transport with lithium-ion battery storage and bi-directional charging capability. And from a system perspective, their advantage compared to conventional EVs, and the drivers, barriers and opportunities this has for business models.

Therefore, I am doing a system analysis with the Multi-Level Perspective (MLP), combined with the Business Model Design Space (BMDS) framework, do these frameworks say anything to you?

» Yes: Shortly discuss the main concepts of the framework(s) and how these relate to the energy system. Suggest applying those during the interview if this is in the respondents' abilities.
    - MLP: niche-level, niche-developments, regime-level, accommodation, landscape-level, windows of opportunity.
    - BMI: emphasize the importance of BMI of DES with SEVs
    - BMDS: market & user, cognitive, industry, science & technology, regulation.

» No: Shortly explain the system analysis and contextualize the main structure of the research in the energy system, suggest keeping this in mind during the interview.
    - MLP: niche-, regime- and landscape-level
    - BMI: emphasize the importance of BMI of DES with SEVs

I have sent you the data protection consent form, if you haven't yet, please make sure to read and sign the form. I invite you to speak freely and truthfully in this interview, let's start!

(Example) Questions

General

- Can you please talk about your expertise, your background and the purpose that drives you forward in life?

During the interview, let's stick to our five dimensions: regulation, market, industry, social, and technology. I'll try to cover specific topics within each dimension and ask related questions. Of course, we can be flexible and allow for some creative discussions and overlapping topics as well.

- With these dimensions in mind, can you provide a short overview of where you see the largest barriers and opportunities for solar electric vehicles and distributed energy storage?

Technology

- What were the main components in which you would divide the product and service for Lightyear Energy?
- What are the main technical challenges that need to be addressed in order to make solar electric vehicles with distributed energy storage more viable?
- Are there any particular technological breakthroughs that you think would be particularly impactful in this area?
- What are the main challenges for European tech companies in modernizing their supply chains for EVs?

Social

- How does Lightyear plan to make their products available for everyone, everywhere? What are the challenges here?
- Would you say that SEVs with DES are particularly fit for stimulating behavior change in mobility and energy systems and why (not)?
- Are there any segments of the population that you think are most likely to adopt these technologies, and why?
- What is the European vision about the fair distribution and access of consumer data?
- With the ongoing digitalization of the energy systems, does the EU prevent data-power centralization in Energy markets? And how?
    - Do you see an opportunity for the SEV niche industry to contribute to this goal if they can remain their autonomy, i.e. not owned by big-tech?

Markets

- Do you think energy communities and local energy markets are an important part for BMI for DES with SEVs?
- Do you think market-based approach towards the mobility and energy transitions are sufficient and why?
    - Can you think of more social-based approaches to behavior change?
- Do you think SEVs with DES can significantly generate markets that can initiate regulations that would further facilitate integration of demand-side flexibility? Or should this be the other way around?
- How do you see the market for these technologies develop in the coming years? Can you give a timeline?
- What markets do you think companies can enter with products and services around solar electric vehicles with distributed energy storage and where are the barriers and opportunities?

Industry

- To what extend do you think big tech is interested in acquiring Lightyear or Sono Motors for their technology?
- Do you think that incumbent, or regime actors are actively working against the integration of DES technologies like with SEVs?
    - If yes, how?
        - Can you give an example?
    - If no, do you think incumbent and regime actors benefit from centralized production and flexibility provision in the energy system?
- Tesla is developing a closed system that will eventually lead to a lot of centralized data-power, do you know Lightyear's philosophy on Black Box innovation?
    - Where do you think is the sweet spot in combining open-source and black box innovation?
- Do we as Europe get a significant competitive advantage on global markets from being a first mover and leader in the development of SEV technologies and hyper efficient vehicles?
    - What would theoretically be the consequence of letting e.g. China develop SEV technologies and catch up later?

Regulation

- A common concern is that regime-industry have the most resources for lobbying, while the transformative types of innovation required for the energy transition historically come from the niches. However, the niche-industry has limited resources.
    - Do European governments have enough resources to help develop the types of policies that facilitate a level-playing field for niche-innovation?
        - Do you think these resources are also allocated with this goal in mind?
- What do you think are the main reasons for why there is no incentive, or target for SEVs yet?
- Who and what are the barriers against setting a definitive target for V2G in 2030?
    - And apart from the lack of technological benchmark, what would be the barrier for a point on the horizon for SEV development?
- Chris mentioned that the EU wants to legislate a complementary data act for the automotive industry, who or what are holding this back?
- What do you think are the biggest challenges in aligning emerging technologies/developments and regulation? And this innovation in particular?

Closing

- Where do you think I could improve myself?
- What would you do if you were me doing this research?

Thank you for your participation, and I will be glad to share the results of the research project with you.

Annex IIII: MidJourney AI text prompt

MidJourney AI is an advanced image generation AI that employs state-of-the-art deep learning algorithms to generate realistic and visually appealing images based on text prompts. This cover image was generated to incite imagination around a social and sustainable mobility and energy future (MidJourneyAI, 2023).

The following text prompt was fed to the MidJourney AI:

'Generate a photorealistic image of a Lightyear solar electric vehicle in a natural setting surrounded by a group of enthusiastic onlookers. The image should be taken on a sunny day with bright, clear skies, and the vehicle should be positioned in a green area with trees and other vegetation. The vehicle should have a low air - resistance, streamlined design, and its photovoltaic panels should be clearly visible on the roof and engine cover. The onlookers should be positioned at various angles around the vehicle, looking at it with admiration and taking photos. In the background, there should be a residential building with a solar panel array installed on the roof, and a charging cable should be visible connecting the vehicle's chargeport to the building's power supply. The materials of the vehicle and the surrounding objects should be realistic and detailed, with clear reflections and shadows that capture the nuances of the lighting conditions. The image should convey the idea of a sustainable future, clean energy use, and efficient transportation.'

"The crisis requires a realignment of paradigm which as to happen, but not (only) in the lab, but in our own minds..."

~ Copernicus