Master's degree thesis

LOG953

Assessing the Drivers of

Green Road transport electrification:

A case of Europe

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Preface

This master thesis is written as the final requirement by Stephen Antwi and Snorre Opsal Grytli. Both of whom are studying for a master's in Sustainable Energy Logistics for their master's degree at the Molde University College - Specialised University in Logistics.

This thesis is independent, extensive research conducted under the supervision of Professor Harald Martin Hjelle. The findings of this thesis can be used by businesses or governments as part of their energy transition plans.

Acknowledgement

This master’s thesis would not have been accomplished without the help of several people. As a result, we would want to take this chance to express our gratitude. We would like to thank Professor Harald Martin Hjelle, first and foremost for his supervision, assistance, and professional guidance during this project. Also, we would like to thank Sunita Knudseth, a PhD research fellow for her help at the latter part of this project. We owe a debt of gratitude to our Program Coordinators, particularly Professor Arild Hoff and the library staff, for their unwavering support and leadership during this master's program. More so, our special gratitude to:

Stephen Antwi writes:
Ragnhild Brakstad, our international coordinator, has been extremely helpful. My uncle, Dr. Andrew Antobreh, my auntie, Cecielia Antobreh, my cousin, Gloria Nketia and all of my cousins deserve my deepest and most heartfelt gratitude. Again, to my mum, Helena Hoffman, my brothers Emmanuel Akowuah Antwi, Caleb Antwi, and Obed Antwi, and my fiancé, Emmanuella Amankwatia in Ghana, I appreciate your unwavering support and encouragement, as well as your patience while I study overseas.

Snorre Opsal Grytli writes:
We dared to explore, and the journey of writing the thesis has been meaningful. There have been great weeks filled with progress, and there have been weeks without wind. So, I would like to thank friends and family for their patience, distraction, and motivation. A special gratitude to the researchers who chose to find time for us students when others did not. This means much for us students, and we applaud you for that.

Abstract

Transport electrification and electricity greening are two of the energy transition initiatives that have been considered globally to help minimise global emissions. The successful execution of the "*green electromobility*" concept is heavily reliant on green energy supply solutions for green electric vehicles.

The study seeks to determine the potential drivers that are likely to influence the growth of both green electricity and heavy-duty vehicle electrification in Europe from 2022 to 2030. By identifying the drivers, it can help to predict how “green road transport electrification” will evolve within the period from 2022 to 2030 in Europe, and also identify which drivers need considerable attention as Europe seeks to achieve its 2030 goals for both the transport and energy sector.

The study used a survey method consisting of expert interviews and literature review to acquire perspectives on the research problem. The findings of the study show that both shifts, heavy-duty electrification and electricity greening, will develop significantly in Europe from 2022 to 2030. The drivers that are likely to influence these developments include the decision-maker, consensus on technology and standards, technological and infrastructural development, to mention a few. However, technical shortcomings exist that will demand more research and improvement in the coming years. To stay up with the global competition, knowledge generation must be accelerated, particularly in the transition of technology into reliable and cost-effective items. To attain market success and competitiveness, these prerequisites must be met.

The findings of this study could serve as a basis for further research specifically for creating plausible scenarios for the development of heavy-duty vehicle electrification and electricity greening in Europe by 2030.

Table of contents

List of abbreviations

BEHV	–	Battery Electric Heavy Vehicle
BET	–	Battery Electric Truck
BEV	–	Battery Electric Vehicles
CO_2	–	Carbon Dioxide
CH_4	–	Methane
ECV	–	Electric Commercial Vehicles
EDV	–	Electric Driven Vehicles
EREV	–	Extended-range Electric Vehicles
ERS	–	Electric Road Systems
EU	–	European union
EV	–	Electrical vehicles
EV-CS	–	Electric Vehicle Charging Stations
FCEV	–	Fuel cell Electric vehicles
GHG	–	Greenhouse gas
H_2	–	Hydrogen
HDT	–	Heavy Duty Trucks
HDV	–	Heavy-duty vehicles
IEA	–	International Energy Agency
IPCC	–	The intergovernmental Panel on Climate Change
MDT	–	Medium Duty Trucks
N_2O	–	Nitrous Oxide
OCL	–	Overhead Catenary Lines
PHEV	–	Plug-in hybrid electric vehicles

RES	–	Renewable Energy Sources
SPM	–	Summary for Policymakers
SPV	–	Solar Photovoltaic
VRE	–	Variable Renewable Energy

List of figures

List of tables

1. Introduction

This chapter contextualises the background of the study, including the existence of a research gap related to the potential interrelationship between transport electrification and green electricity and why the gap should be addressed. The research objectives were created to generate research questions that are relevant to the study.

1.1 Background of the study

Over the years, there has been growing concern about protecting the planet's natural environment through sustainable development in the energy market and emission reduction (Kowalska-Pyzalska, 2019). According to the International Energy Agency (IEA, 2022), global carbon dioxide (CO_2) emissions from energy are estimated to have increased by more than 4% in 2021, as the demand for coal, oil, and gas recovered along with the economy after the covid-19 pandemic. Both electricity generation and transportation produce higher levels of emission relative to other sectors, as they were responsible for over two-thirds of the overall emissions in 2019 alone (IEA, 2022).

“Transport electrification” and “electricity greening" are two of the energy transition initiatives that have been considered globally to help minimise global emissions. The Electric Vehicle (EV) is promoted as a clean alternative to traditional vehicles that use fossil fuels as an immediate solution to improve the environmental quality parameters including the reduction of emissions related to the transportation sector (Filote, Felseghi, Raboaca, & Aşchilean, 2020; Hall & Lutsey, 2017; IEA, 2020). On the other hand, increasing the contribution of renewables including variable renewable energy (VRE) technologies in power systems, such as wind, and solar photovoltaic power systems (SPV), is critical for decarbonizing the power sector while continuing to satisfy the rising energy demand.

The transition to clean electrified mobility must be considered from the standpoint of sustainability and developing a strategy for the implementation of EVs entails providing clean energy conditions from the start to move toward a green-to-green paradigm (Filote et al., 2020; IEA, 2020). According to Filote et al. (2020), it should be noted that the successful execution of the "*green electromobility*" concept is heavily reliant on green energy supply solutions for green EVs, so Electric Vehicle Charging Stations (EV-CS) should be powered by green energy generation systems.

Europe has set ambitious targets for road transport electrification and electricity greening for 2030 and 2050. The continent's goal of reducing greenhouse gas emissions by 55% by 2030 and becoming climate neutral by 2050 necessitates a massive growth in RES. These two periods are projected globally and especially in Europe, as the periods for achieving significant results in the zero-emissions agenda. To achieve these targets, there are certain drivers or factors that have to be considered.

However, this study aims to determine the potential drivers of heavy-duty vehicle electrification and electricity greening and how these drivers could affect the development of these two transitions in Europe from 2022 to 2030. This is a crucial topic for the future of heavy-duty vehicles (HDVs) and electricity greening since it is worth knowing the factors that could affect the achievement of their potential benefits in the years ahead. The study uses both expert interviews and a literature survey to acquire perspectives on the potential drivers of heavy-duty vehicle electrification and electricity greening in Europe from 2022 to 2030.

1.2 Scope of the study

This study seeks to assess the potential drivers of heavy-duty vehicle electrification and electricity greening in the Europe-Scandinavia region by 2030. HDVs account for a significant amount of transport emissions and thus need to be decarbonised. However, despite the growth in the electrification of passenger vehicles, only a little research has been done to cover the electrification of HDVs. This study focuses on the electrification of HDVs.

Furthermore, the commitment of Europe and the Scandinavian region toward climate change presents the region as an interesting case for this study. The policies, targets, and actions taken by the European Commission and the individual European countries depict how serious the region is about climate change. Europe presents an informative region as far as climate change is concerned. Europe is the case region of this study with a special focus on the Scandinavian countries including Norway and Sweden.

Additionally, the period from the year 2022 to 2030 is set as the scenario period for this study. The stated time frame presents 8 years, which is believed to have significant development with regards to energy transition as far as this period is concerned. Most targets on climate change which are made globally, especially in Europe consider 2030 and 2050 as the periods for achieving significant results. For this study, 2030 is more practical since it is closer and offers less uncertainty relative to longer perspectives such as 2050.

1.3 Significance of the study

This is a crucial topic for the future of transportation electrification and electricity greening, since it is worth knowing the factors that could affect the development of these two transitions. Several studies have been conducted on road transport electrification and electricity greening, but only a few have addressed "green road transport electrification".

It is expected that the study will help the auto manufacturers and governments, or policymakers understand the future of transport electrification, electricity greening, and the need to pursue a "green to green paradigm". The study sheds light on the factors that could affect the development of both transport electrification and electricity greening by 2030. The study provides insights into the bottlenecks of electricity greening and how these limitations could be minimised going forward. The drivers identified in this study are expected to aid policymakers in their sustainable energy development planning.

Additionally, the study also provides academicians in the sustainable energy field with useful knowledge on electricity greening. Lastly, the findings of the study serve as a stepping stone for future researchers on the related topics through the recommendations made for further research. The findings of this study could serve as a basis for creating plausible scenarios for the development of heavy-duty vehicle electrification and electricity greening in Europe by 2030.

1.4 Research objectives

The study's objectives are divided into two categories: general and specific objectives as presented below.

1.4.1 The general objective

The ultimate objective of this study is to assess the potential drivers that may influence the development of electricity greening and heavy-duty vehicle electrification in Europe from 2022 to 2030.

1.4.2 The specific objectives

The specific objectives of this study seek to find out from 2022 to 2030 in Europe:

I. How both heavy-duty vehicle electrification and electricity greening are likely to develop.

II. The potential drivers that are likely to affect the development of heavy-duty vehicle electrification.

III. The potential drivers that are likely to influence electricity greening.

IV. How the interrelation between road transport electrification and electricity greening is likely to develop.

1.5 Research questions

Based on the research objectives above, the following research questions are developed. *"Which are the potential drivers that may influence the development of electricity greening and heavy-duty vehicle electrification in Europe from 2022 to 2030?"* is the main research question of this study. As a result, the common element shared by all the minor research questions reflects the main research problem of this study. The research questions are listed below, together with explanations that demonstrate their relevance to the research problem.

RQ1: How likely will heavy-duty vehicle electrification and electricity greening develop in Europe from 2022 to 2030?

This research question seeks to find out how heavy-duty vehicle electrification is likely to develop in terms of electric vehicle stock and new registrations of electric vehicles in Europe-Scandinavia by 2030. Similarly, this research question seeks to determine how electricity greening in Europe-Scandinavia will develop from 2022 to 2030.

RQ2: Which potential drivers are likely to affect the development of heavy-duty vehicle electrification in Europe from 2022 to 2030?

This research question seeks to find out the factors which may affect the growth of heavy-duty vehicle electrification from 2022 to 2030. The study seeks to determine the critical factors for the progress of electrifying HDVs within the stated period, thus investigating the various drivers and bottlenecks which may facilitate the development or hinder the progress of HDVs electrification respectively. Also, a review of the current state of the technology for heavy-duty vehicle electrification is paramount in this sense. The study seeks to explore the various technological alternatives that are available for heavy-duty vehicle electrification and how these technologies will develop within the stated period.

RQ3: Which potential drivers are likely to affect electricity greening in Europe from 2022 to 2030?

Electricity greening depends on the development of renewable energy technologies. This research question seeks to identify the drivers that may influence electricity greening in Europe from now (2022) till 2030. This study seeks to determine the critical factors for the progress of electricity greening within the stated period, thus it investigates the various limitations in the provision of green energy which may hinder the progress of electricity greening in Europe. Additionally, the study seeks to explore the various technological alternatives that are available for electricity greening and how these technologies will develop within the stated period.

RQ4: How likely will the interrelation between road electrification and electricity greening develop in Europe from 2022 to 2030?

This research question seeks to determine how the interrelation between road transport electrification and electricity greening will develop from 2022 to 2030. RQ4 seeks to find out if road transport electrification will continue to depend on green electricity to be able to realise its emission reduction potential.

1.6 Structure of the thesis

The thesis is structured as follows: Chapter 1 introduces the study and the research objectives. Chapter 2 describes the chosen research methodology. Chapter 3 presents the literature review. Chapter 4 presents the experts findings and analysis. Chapter 5 presents the discussion of the findings in literature and expert interviews. Chapter 6 presents the conclusion and suggestions for further research.

2. Research methodology

Research is an endeavour to find answers to questions using scientific procedures. The major goal of the research is to uncover the truth that has been hidden and has yet to be uncovered (Pandey & Pandey, 2021). According to Kothari (2004), research is a scientific and systematic process of studying and seeking relevant information on a certain issue. This scientific process is made up of "*methodology*" which begins with problem enunciation, hypothesis formulation, data collection, analysing the facts, and arriving at a conclusion, either in the form of a solution(s) to the specific problem or a generalisation for some theoretical formulation (Pandey & Pandey, 2021; M Saunders et al, 2019). This chapter gives an overview of the research approach chosen during the research process and it outlines the available tools, the tools chosen, and why they are chosen for this study.

Research methods and methodology are critical while performing research to organise and control the study to produce proper, correct, and well-founded findings. Methodologies and research methods are processes, or specific courses of action, that ensure the quality of research and project outcomes (Melnikovas, 2018; M Saunders et al., 2019; Mark Saunders et al., 2019).

All the techniques that researchers employ to conduct research operations are classified as research methods, and they are divided into three groups: data gathering techniques, statistical techniques, and accurate evaluation procedures (Mark Saunders et al., 2019). Research methodology, on the other hand, is a methodical approach to tackling a research topic. It comprises the scientific and systematic steps that are commonly used in researching a research problem (Pandey & Pandey, 2021; Mark Saunders et al., 2019), as well as the rationale and beliefs that underpin them (Håkansson, 2013; Melnikovas, 2018). As a result, the researchers needed to understand both the methods and the methodology.

The "*Research Onion*" is one of the key research frameworks used by researchers to establish the research environment (Conticelli et al.,2021; Melnikovas, 2018; M Saunders et al., 2019). Saunders et al. (2019) defined the research onion as an overview framework for guiding research. The Research Onion proposed by Saunders et al. (2019) is a model in which the primary layers or steps, as displayed in figure 1, must be completed to build a good methodology (Melnikovas, 2018).

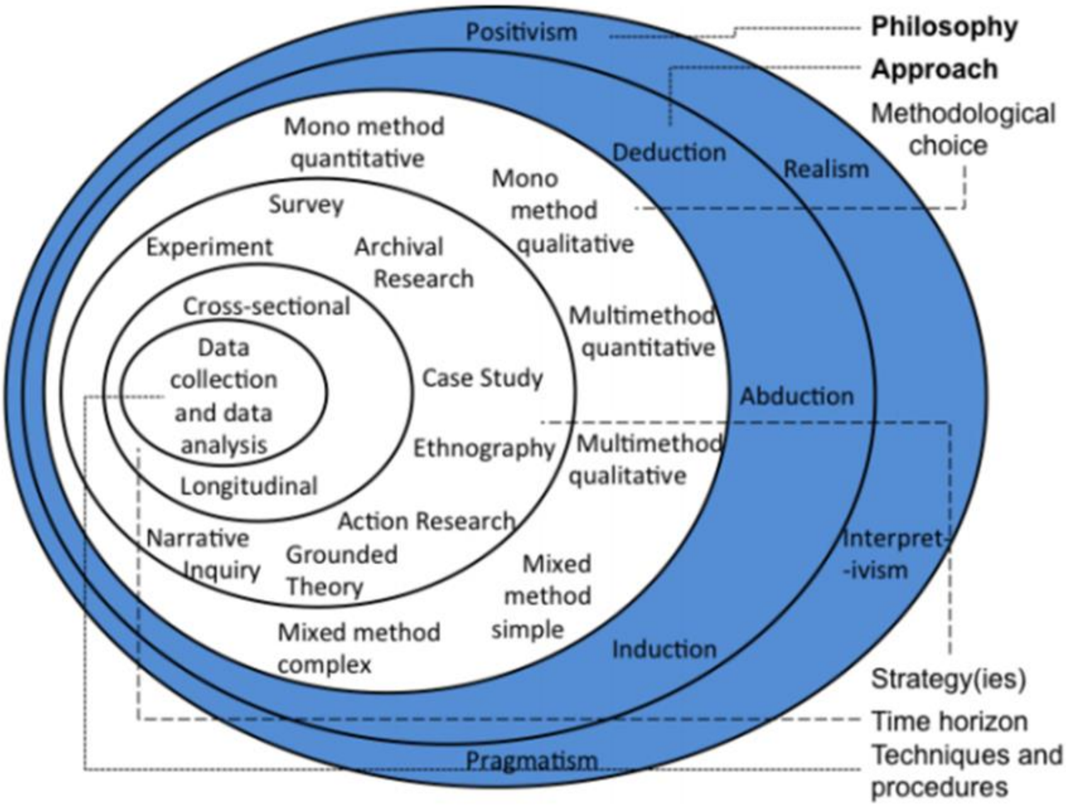

Figure 1 - The Research Onion (Revised version). Source: M Saunders et al. (2019)

Answering how research must be carried out utilising a defined methodology that is required to develop successful research is what research Onion is about (Conticelli et al., 2021; Melnikovas, 2018; M Saunders et al., 2019). The methodology of this study is based on the Research Onion as displayed in figure 1, starting with "philosophies" at the outermost layer, progressing through "approaches", "strategies", "choices", and "time horizons", and ending with "techniques and procedures" at the core. These dimensions are discussed in the following sections.

The research philosophy explains how the researcher intends to conduct the study and hence aids the researchers of this study in selecting the best research approach. The research approaches also help to explain the theory behind the study, allowing the researchers to design a method to examine the data; the methodological choice is used to develop the study’s strategy which affects the data collection process. The data collection method, however, serves as a guideline for the researchers to collect relevant data to answer the research questions through interviews and secondary sources.

2.1 Research philosophy

According to Saunders et al (2019), research philosophy is a set of beliefs and assumptions about how knowledge is created in each discipline. It is basically about how the research problem is understood and treated by the researchers. Researchers make specific assumptions while choosing qualitative research. According to Creswell & Poth (2016), there are five (5) philosophical assumptions namely ontological, epistemological, axiological assumptions, methodology, and rhetoric. These philosophical assumptions include a position on the nature of reality (ontology), how the researcher knows what she or he knows (epistemology), the role of values in research (axiology), research language (rhetoric), and research procedures (methodology) (Creswell & Poth, 2016).

The assumptions may relate to the realities encountered during the study (ontological assumptions), and these realities can be perceived both within and outside of the social phenomena (Melnikovas, 2018; Orth & Maçada, 2021). How research objects are seen and studied is shaped by ontological assumptions (Tamminen & Poucher, 2020). The research objects in business and management include organisations, management, individuals' working lives, organisational events, and artefacts, to mention a few. These objects can assist researchers in determining how to see business and management, allowing them to choose what to explore for their research objectives (Melnikovas, 2018; M Saunders et al., 2019).

"Axiological assumptions" refer to how much the values and ethics of the researchers influence their research approach (Melnikovas, 2018; Tamminen & Poucher, 2020). To the extent that they want to see the impact of their values and beliefs on the research as a positive thing, the researchers must make critical axiological decisions. Finally, a decision must be made about how to deal with the views and beliefs of the researchers, as well as the individuals being studied (Saunders et al., 2019). Saunders et al. (2019) indicated that ontology and epistemology are philosophies related to business and management study projects.

Epistemological assumptions are about human knowledge, what constitutes acceptable, valid, and legitimate information, and how knowledge can be conveyed to others (Saunders et al., 2019). Epistemological assumptions can be objective or subjective in the sense that objectivity reorganises the outside world as hypothetically impartial, whereas subjectivity argues that the outside world is classified by reflection (Tamminen & Poucher, 2020).

Epistemology can be divided into two categories: positivism and interpretivism (Omotayo and Kulatunga 2015). Many literature evaluations discuss realism, interpretivism, positivism, pragmatism, and other research philosophies as a connected research process (Edirisingha 2012)

The methodological assumption is the strategy, plan of action, or procedure that drives the selection and use of specific methods and links the methods' selection and application to the expected outcomes (Creswell & Poth, 2016). For example, whereas constructivists prefer qualitative approaches to conduct in-depth studies, positivists prefer to employ quantitative methods to test hypotheses. This explains why the philosophical position of a researcher influences the research methodologies they use.

However, research philosophy is regarded as the foundation of any research. It assists the researcher in making the best decisions on method, strategy, data collection techniques, and processes for answering research questions and interpreting findings (Omotayo and Kulatunga 2015, Saunders, Lewis, and Thornhill 2019). Interpretivism was chosen in this study because it is founded on business and management research, and it also incorporates components of ontological and epistemological assumptions, as indicated by Saunders et al (2019).

2.1.1 The philosophical stance of this study

Interpretivism is associated with qualitative research (Pulla & Carter, 2018). It is about how one can gain knowledge of the world, which loosely relies on interpreting the meanings that humans attach to their actions. Interpretivism considers every researcher who comes into the research environment to have some knowledge or preunderstanding of the research problem. However, these researchers enter the research setting with some pre-understanding and plan, and they endeavour to get new information that can be gained through the chosen data-collection techniques (Hudson and Ozanne 1988). The interpretive perspective invites the researcher to explore the meaning behind human behaviour, interactions, and society (Pulla & Carter, 2018). Using an interpretive view, the interest of this study lies in understanding the human behaviour factor of the energy transition. However, using this technique in the social sciences like this study is challenging since it is difficult to empirically assess and explain the complexity of human behaviour and the connections between individuals and their social and natural settings successfully and clearly (Pulla & Carter, 2018). The research philosophy explains how the researcher intends to conduct the study and hence aids the researchers of this study in selecting the best research approach.

2.2 Research approach

Researchers can use one of these approaches in their research: deductive research, inductive research, and abductive research. Deductive is where the conclusion is used to test the theory, inductive research is where the conclusion is used to develop a theory (Venable, 2011). Data is collected to develop new or change an existing theory that must be evaluated through additional data gathering in an abductive research approach (Saunders, Lewis, and Thornhill 2019). The inductive method is based on interpretivism philosophy, whereas the deductive method is based on positivism and looks at the research from a larger viewpoint than the core unit of investigation (Omotayo and Kulatunga 2015). A combined inductive and deductive technique is used in abductive research. This method entails creating a new theory or modifying an existing one based on data, and then testing the hypothesis with additional data. This study takes an inductive approach since it begins with research questions and objectives that are met after the study.

2.3 Research design

The nature of the inquiry might influence which scientific technique to use and how results are interpreted from one field to the next (Creswell and Creswell 2009, Edmonds, and Kennedy 2016). According to Yin (2009), a research design is a "*logic that connects the data to be collected (and the conclusion to be drawn) to the study's initial question*". According to Edmonds and Kennedy (2016), it is difficult to implement an appropriate design that is based on the research question due to a lack of effective conceptualization of a research design. As a result, a lack of a proper research design leads to meaningless, spurious, or invalid results.

There are different types of classifications of research (Hoffman et al., 2021; McKenney & Reeves, 2021). These can be defined as either (1) exploratory, (2) descriptive, (3) explanatory, or (4) improving. Exploratory research seeks to understand what is happening and gain new insight (Saunders et al., 2019). Descriptive research is describing an occurring situation, the explanatory research seeks to find a clarification of why this specific situation is happening, whilst Improving research has as a goal that the research will improve a situation or a present solution (Hofmann et al., 2021; McKenney & Reeves, 2021; Wennberg & Anderson, 2020).

However, this study is classified as exploratory in that it seeks to assess the potential drivers of green road transport in Europe and the Scandinavian region from 2022 to 2030. Since this study is future-oriented research, it involves an exploration of the various elements of the business environment, such as demographics, societal factors, economic conditions, political forces, and technological development, as well as consideration of the consequences of change (Walton et al., 2019).

2.4 Data collection approach

This is a vital element of research since it is a significant step towards finding answers to the research questions. To successfully deal with this activity, scientific techniques for gathering and analysing data must be followed.

In attempting to attribute qualitative data collection procedures to the interpretive worldview, it is evident that this approach can and does employ a variety of methodologies (Hudson and Ozanne 1988). There are two categories of data defined: Primary and secondary. Primary data is information collected with the purpose to solve a specific problem by researchers. When this data is processed and made public the data is transferred as secondary data, as it is now available for the world to use in further research. Yin (2009) stated that to conduct a high-quality case study, it is necessary to employ various sources of information rather than relying solely on one source because multiple sources of data allow a researcher to address a greater variety of historical and behavioural issues. The two commonly used data sources, primary and secondary sources, were employed in this study. Secondary data was used to better comprehend the problem's history and the state of the art, whilst the primary data provided perspectives based on experience and assessment of the present state developments in the energy sector.

2.4.1 Literature survey

The literature survey of this study was conducted using secondary data sources such as books, journal articles, websites, library databases, and internet sources. Google Scholar, Wikipedia, and sci-hub were some of the search engines used to search for articles, journals, books, policy reports, etc. Most of the articles were acquired from sites including ResearchGate, sciencedirect.com, and springer.com. Energy reports from the IEA, Intergovernmental Panel on Climate Change (IPCC), World Resources Institute (WRI), and others. Writing tools such as Endnote played a significant role in ensuring good referencing. Gathering primary data, on the other hand, can be both time-consuming and costly as compared to collecting secondary data.

2.4.2 Semi-structured research interviews

Expert interviews were conducted to generate primary data qualitatively and flexibly using semi-structured research interviews. A semi-structured interview was used in this study because it is proven to be both versatile and flexible, which is why it is such a popular data collection approach (Kallio, Pietilä, Johnson, & Kangasniemi, 2016). When a researcher intends to: (1) collect qualitative, open-ended data; (2) investigate participant thoughts, feelings, and opinions about a certain topic; and (3) delve deeply into personal and often sensitive matters, semi-structured interviews are an excellent data collection strategy (DeJonckheere & Vaughn, 2019). Since the study sought to investigate participant thoughts, feelings, and opinions, an application was sent to the Norwegian Centre for Research Data to secure approval for the interviews. In this study, interview guides which consist of predetermined open-ended questions were used in the interviews. The interviews unfolded into conversations enabling both participants of the interviews to explore issues that were/was of relevance to this study.

Three experts from Europe with experience in either “Electricity greening”, “Road transport electrification”, or both were interviewed. These experts were selected for the interview based on their experience in their fields. Two of the experts were contacted through email and the other one was contacted through social platforms such as LinkedIn. Three different but related interview guides were created to acquire specific perspectives based on the interviewee's fields of expertise. Both virtual and face-to-face interviews were conducted based on the preference and agreement of each expert. The interviews aimed at getting outputs including:

- Clarification of the expertise and job role of the expert.
- General perspective on “Electricity greening” and “Heavy goods road vehicles electrification” in the European setting.
- Specific perspective on “Electricity greening” and “Heavy goods road vehicles” in the Swedish setting.

Built-in reviews were conducted to improve the interview process. The interview questions and method were reviewed after a few interviews to ensure being on track. This was useful to ensure that the opinion-gathering process was working well. The review was to answer the following questions: are the interviews being completed in time? Are all the questions clear? Is there anything that needs additional explanation? And lastly, do schedules need amendment? The interviews were scheduled to last about 30 to 45 min. Each interview was recorded and transcribed, and the transcribed interviews were then sent to the interviewees for verification.

2.5 Analytical approach

Examining, categorising, tabulating, testing, and occasionally recombining evidence to conclude is what data analysis entails. It is one of the most challenging aspects of research because there aren't any well-defined procedures for dealing with its Yin (2009). The distinction between analysing quantitative and qualitative data is that quantitative data is analysed using statistics and mathematics, whereas qualitative data is analysed using conceptualization (Dey, 2003). Data must be evaluated and comprehended to be valuable. The data in this study was primarily qualitative, obtained through interviews and document reviews.

As Yin (2009) points out, there are no well-defined techniques for analysing qualitative data. This study adopts the data analysis technique employed by Aspelund and Helland (2019) in their case study. In their study, the different replies from transcriptions were reviewed and agreed upon on alternative meanings of the data and to identify every relevant point highlighted after transcribing the audio recorded. Following that, the various available data and notes were grouped into cases and coded in connection to the study topics. The table for each study topic was then prepared, and the responses from each respondent were summarised. After all, the examples had been coded, the analysis had been grouped into themes, and they had been presented. This approach inspired the analysis approach adopted by this study.

In this study, the responses to each interview were carefully assembled, coded, and presented. The outputs/responses of the interviews were then compared to determine patterns in the responses of the experts to the interview questions. The agreements and disagreements between the views of the experts were determined.

2.6 Chapter summary

The methodology of the study is described in this chapter. The study used a Literature survey and expert interviews to determine the potential drivers which may affect the development of heavy-duty vehicle electrification by 2030. As this study explores the potential future of green electricity and heavy-duty vehicle electrification, it is classified as exploratory research. Interpretivism serves as the philosophical basis for this study which served as a guide to making the methodological choices. This study takes an inductive approach since it begins with research questions that are answered in the findings of the study. Furthermore, the choice of this research is qualitative where the aim is to discover the potential drivers and how they are likely to affect the development of green road transport electrification (HDVs) through expert interviews and secondary sources. Lastly, a multi-method qualitative approach was used including interviews and document review.

3. Literature review

Literature review offers a thorough overview of the literature on a specific theory/ theme/method and synthesises prior studies to reinforce the basis of knowledge (Paul & Criado, 2020). This section entails a review of literature aimed at establishing the “state of the art” for two tracks including (1) Electrification perspectives on (European) heavy-duty vehicles and (2) Prospects for greening the grid from a European perspective. The main literature of this study focuses on climate change, heavy-duty vehicle electrification, and green electricity. At the end of this chapter, the reader will understand the dimension of the zero-tailpipe-emission transport electrification (green to green paradigm). To establish a thorough comprehension of the subject matter, literature on climate change will be presented first to prove the basis for heavy-duty vehicle electrification and electricity greening (green-to-green paradigm). This is conducted to provide a clearer picture of the foundation of the research problem.

3.1 Climate Change Problem

The expansion of scientific literature on climate change is a step towards climate change resolution. Climate change is defined in this study as the long-term changes in temperature and weather patterns causing significant damage to the natural environment. Allen et al. (2019) defines global warming as an increase in the global surface air and sea surface temperature averages over 30 years. Even though the terms are sometimes used interchangeably in this study, global warming is only one facet of climate change. "*Global warming*" refers to an increase in global temperatures caused primarily by rising greenhouse gas concentrations in the atmosphere (Allen et al., 2019). Climate change, on the other hand, is the gradual but significant changes in climate variables such as precipitation, temperature, and wind patterns throughout time. Although these changes are natural, human activities have been the primary driver of climate change since the 1800s, mostly due to the burning of fossil fuels (such as coal, oil, and gas), which creates heat-trapping gasses (Allen et al., 2019).

Climate change causes considerable harm to the globe as highlighted below. Global food security is under threat from climate change (Allen et al., 2019). More frequent droughts and severe storms, heatwaves, rising sea levels, melting glaciers, and warming oceans can all hurt animals, ruin their habitats, and disrupt people's livelihoods and societies. Dangerous weather events are growing more common and severe as climate change progresses (Chen et al., 2018; Swain et al., 2020).

Furthermore, greenhouse gas (GHG) emissions contribute to the worldwide phenomenon of climate change (Filote et al., 2020; IEA, 2020; MITKINA, 2020; Oreggioni et al., 2021), created by humans through the combustion of traditional fossil fuels for energy generation, transportation, industry, and residences (Filote et al., 2020; Sovacool et al., 2021). Concentrations of methane (CH_4) and nitrogen oxide are two additional important GHG (Filote et al., 2020) that require significant attention. The other GHGs are relatively lower quantities, but they capture heat far more effectively than CO_2 and are thousands of times stronger in some situations (Filote et al., 2020).

The IPCC released a special report in October 2018 on global warming of 1.5°C above pre-industrial levels. This report was subsequently termed the IPCC Special Report. According to the report (IPCC, 2018), global average temperatures have risen by around 1°C since pre-industrial times, and anthropogenic warming (human-induced) adds about 0.2°C to world average temperatures every decade.

At the current rate of anthropogenic GHG emissions, average global warming is expected to reach 1.5°C between 2030 and 2052, according to the report. According to Ogunbode et al., (2020), the official goal of global policy making was to keep global warming below 2°C for many years before 2015. The IPCC special report, on the other hand, shows significant variations between 1.5°C and 2°C global warming, with the latter implying a larger likelihood of severe consequences for the society and the environment.

However, the net global emissions need to be minimised by around 45% by 2030, and net-zero by 2050, to keep global warming below the 1.5°C thresholds (IPCC, 2021). And to meet these goals, an unprecedented magnitude of quick and far-reaching transformations across the global economy will be necessary (Allen et al., 2019; Ogunbode et al., 2020).

The following are some extracts from the IPCC Special Report on the observations on the state of climate change as according to Summary for Policymakers (IPCC, 2021). These observations are classified as either: very high confidence, high confidence, medium confidence, or low confidence to signify the level of confidence the authors are behind the observations.

3.1.1 The state of climate change

Since 1970, global surface temperatures have risen faster than in any other observed 50-year period in the last 2000 years (high confidence). Temperatures in the last decade (2011–2020) have surpassed those of the most recent multi-century warm episode, which occurred roughly 6500 years ago [0.2°C to 1°C above 1850–1900] (medium confidence). Before that, the most recent warm phase occurred around 125,000 years ago, when the multi-century temperature [0.5°C to 1.5°C relative to 1850–1900] coincided with the observations of the most recent decade (medium confidence) (IPCC, 2021).

CO_2 concentrations in the atmosphere were greater in 2019 than in at least 2 million years (high confidence), and CH_4 and nitrous oxide (N_2O) concentrations were higher than they had been in at least 800,000 years (very high confidence). CO_2 (47%) and CH_4 (156%) concentrations have increased significantly more than – and N_2O (23%) has increased similarly to – natural multi-millennial variations between glacial and interglacial eras over the past 800,000 years since 1750 (very high confidence) (IPCC, 2021).

Moreso, the yearly average Arctic Sea ice extent fell to its lowest level since at least 1850 between 2011 and 2020. (High confidence). In late July, the expanse of Arctic Sea ice was smaller than it had been in at least the last 1000 years (medium confidence). Since the 1950s, the global nature of glacial retreat has been remarkable in at least the last 2000 years, with practically all the glaciers across the world retreating at the same time (medium confidence) (IPCC, 2021).

Since 1900, the global mean sea level has risen faster than it has in any other century in at least the last 3000 years (high confidence). Over the last century, the global ocean has warmed quicker than it has since the previous deglacial transition (about 11,000 years ago) (medium confidence). Over the last 50 million years, the pH of the surface ocean has risen steadily (high confidence). However, in the previous 2 million years, a pH of the surface open ocean as low as it has been in recent decades is rare (medium confidence) (IPCC, 2021).

3.1.2 Anthropogenic warming

According to the SPM (2021) report, human activities are unequivocally responsible for observed increases in well-mixed GHG concentrations since roughly 1750. CO_2, CH_4, and N_2O concentrations in the atmosphere have continued to rise since 2011 (measurements reported in AR5), with annual averages of 410 parts per million (ppm) for CO_2, 1866 parts per billion (ppb) for CH_4, and 332 ppb for N_2O in 2019. Over the past six decades, land and ocean have taken up a nearly constant amount (globally about 56% per year) of CO_2 emissions from human activities, with regional differences (high confidence) (IPCC, 2021).

Heavy precipitation events have risen in frequency and intensity over most geographical areas where observational data are sufficient for trend analysis (high confidence), and human-induced climate change is most likely the dominant driver. Due to increasing land evapotranspiration, human-induced climate change has contributed to increases in agricultural and ecological droughts in several locations (medium confidence) (IPCC, 2021).

Since the 1950s, human involvement has most likely increased the likelihood of compound severe events (IPCC, 2021). This includes increased global frequency of simultaneous heatwaves and droughts (high confidence), fire weather in some regions of all inhabited continents (medium confidence), and compound flooding in some areas (medium confidence).

3.1.3 The future of Climate change

However, under all emission scenarios considered by Summary for Policymakers (SPM), global surface temperature will continue to rise until at least mid-century (IPCC 2021). Unless CO_2 and other greenhouse gas emissions are drastically reduced in the coming decades, global warming of 1.5°C and 2°C will be exceeded in the twenty-first century. The net global emissions need to be minimized by around 45% by 2030, and net-zero by 2050, to keep global warming below the 1.5°C thresholds (IPCC 2021). And to meet these goals, an unprecedented magnitude of quick and far-reaching transformations across the global economy will be necessary (Allen et al., 2019; Ogunbode et al., 2020).

EU greenhouse gas emissions fell gradually from 2010 to 2014, then climbed significantly from 2015 to 2017, before falling again in 2018. In comparison to 2018, emissions declined by approximately 4% in 2019, the largest drop since 2009.

3.1.4 European Union GHG emissions

According to Eurostat (2022) GHG emissions in the EU were over 1 billion tonnes of CO_2 equivalent lower in 2019 than in 1990. This equates to a 24% reduction from 1990 levels, which is higher than the EU's 2020 reduction objective of 20% (Eurostat, 2022). In comparison to 1990, the revised target for 2030 is a 55% reduction in GHG emissions (European Commission 2022). Moreso, in 22 Member States, GHG emissions were lower than in 1990. Estonia, Romania, Lithuania, and Latvia had the greatest declines, totalling more than 50% (Eurostat, 2022). The EU Greenhouse gas emission levels from 1990 to 2019 are displayed in figure 2.

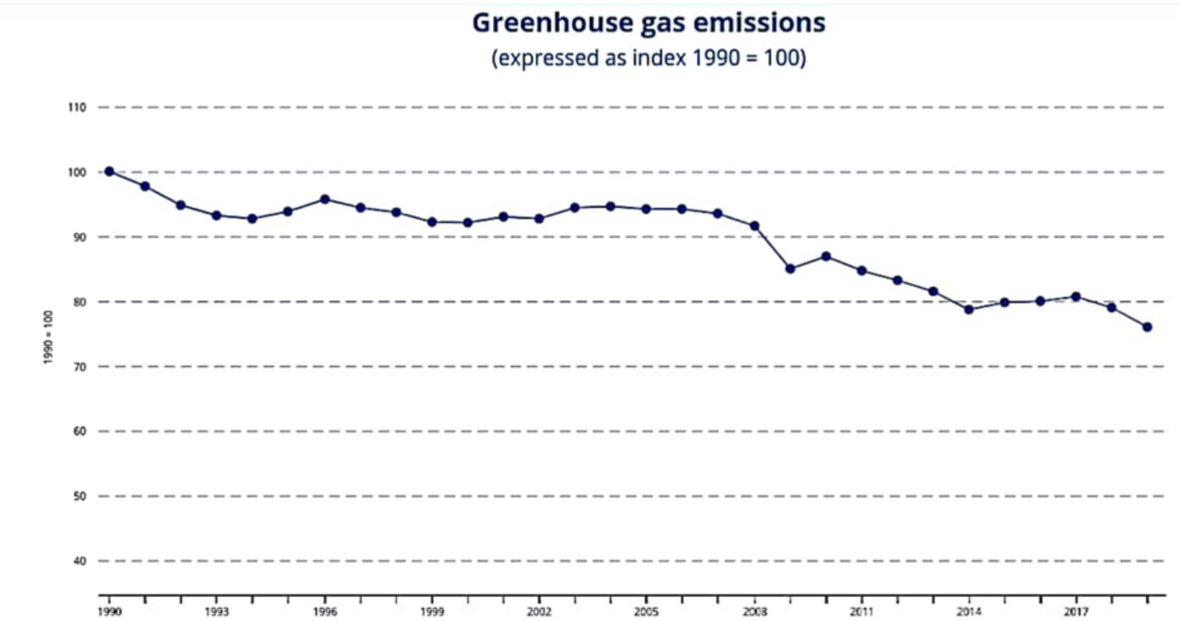

Figure 2 - EU Greenhouse gas emission levels from 1990 to 2019. Source (Eurostat, 2022)

Furthermore, according to Eurostat (2022) the energy-producing industries, consumer fuel combustion, and the transportation sector all contributed the same amount to total greenhouse gas emissions in 2019 (25.8% each). Except for transportation, which went from

14.8% in 1990 to 25.8% in 2019, and agriculture, which increased from 9.9% to 10.3%, all sectors' shares dropped from 1990 to 2019. This is displayed in figure 3.

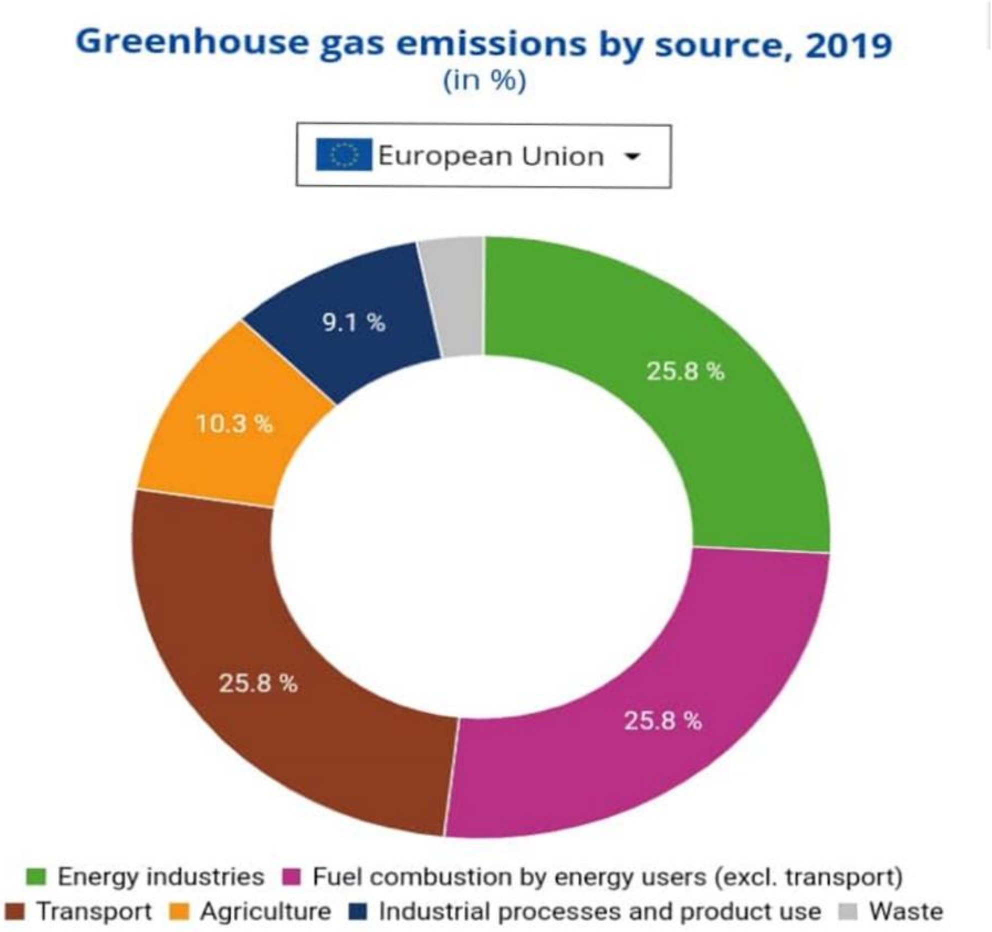

Figure 3 - EU Greenhouse gas emission by source. Source (Eurostat, 2022)

As a result, lowering emissions from the energy sector will create a significant impact. According to Filote et al. (2020) lowering greenhouse gas emissions by more than 80% by 2050 will put a lot of pressure on electricity generation systems. This situation necessitates the energy transition plans that are being put in place across the world, as well as in the EU Member States, to achieve the agreed-upon energy and climate eco-responsibility targets by 2030. This situation necessitates the need for energy sustainability and energy transition.

3.1.5 Energy Sustainability and Energy transition

Energy planning, analysis, and policymaking have increasingly focused on promoting sustainable growth and addressing climate change (IEA, 2020). Since the production of energy (fossil fuels) is responsible for a large portion of all greenhouse gas emissions, it is imperative to consider energy sustainability in attempts to cut emissions and mitigate climate change (IEA, 2020; Khan, Ali, & Ashfaq, 2018). Energy is sustainable if it satisfies current requirements without jeopardizing future generations' ability to fulfil their own needs (Kenig-Witkowska, 2017). Most definitions of sustainable energy take into account environmental factors like greenhouse gas emissions, as well as social and economic factors like energy poverty. (Abbasi et al., 2021). It is a multifaceted phenomenon (Labanca, 2017; Sareen & Haarstad, 2018).

The energy transition is perceived as the remedy to the global climate change problem. Given the gravity of the danger posed by global warming and climate change, which is largely caused using fossil fuels, energy transition is gaining more attention globally (Filote et al., 2020; York & Bell, 2019). An energy transition is an approach to transforming the global energy industry from fossil-fuel-based to carbon-free (Tian et al., 2022; R. Zhang & Fujimori, 2020). The global energy sector is transitioning away from fossil-based energy production and consumption systems, such as oil, natural gas, and coal, and toward renewable energy sources (RES) such as wind and solar, as well as lithium-ion batteries.

The energy transition is being accelerated by the rising penetration of renewable energy into the energy supply mix, the start of electrification, and improvements in energy storage (Johnson et al., 2019). The need to cut energy-related CO_2 emissions to limit climate change is at its core. Historically, the energy transition has been linked with concerns about rising energy demand and the availability of various energy sources (Newell, Raimi, Villanueva, & Prest, 2020; Smil, 2010). The current transition to clean energy is distinct in that it is largely motivated by a recognition that global carbon emissions must be reduced to zero, and that fossil fuels are the largest single source of carbon emissions (Abbasi et al., 2021; Filote et al., 2020; Tian et al., 2022; R. Zhang & Fujimori, 2020). The phrase "*energy transition"* however, describes a shift toward sustainability through the growing integration of renewable energy in everyday life.

There are several forms of energy transition initiatives that have emerged over the years. Prior research has identified several strategies including energy efficiency (IEA, 2020; L. Wang et al., 2016), improving industrial energy consumption (IEA, 2020; Peng, Yang, Wagner, & Mauzerall, 2017; S. Zhang et al., 2016) reduction in fossil fuel usage (Dong et al., 2015; IEA, 2020; Peng et al., 2017; Qin et al., 2017) and increasing renewable energy use (IEA, 2020; Peng et al., 2017). The push to switch from internal combustion engines to electric automobiles as a means of reducing global dependency on fossil fuels and lowering greenhouse gas emissions (Abid, Kany, Mathiesen, Nielsen, & Maya-Drysdale, 2021; Das, Rahman, Li, & Tan, 2020), reducing final energy use (Shove, 2018); and greening of the electricity grid (Das et al., 2020; Filote et al., 2020) are all specific examples of the energy transition. The next section discusses the two important transitions (road transport electrification and green electricity) from a green-to-green paradigm perspective.

3.1.6 The green-to-green paradigm

The concept of the green-to-green paradigm is defined in this study as the use of green electricity to power electric vehicles (EV). This concept views transport electrification and electricity greening as two forms of energy transition that should be linked together to facilitate our fight against climate change. The EV is touted as a clean alternative to traditional vehicles that use fossil fuels as a quick way to enhance environmental quality metrics in the transportation sector (Abid et al., 2021; Filote et al., 2020; García-Afonso, Santana-Méndez, Delgado-Torres, & González-Díaz, 2021).

However, transport electrification does not necessarily lead to a reduction in carbon emission, in addition, the source must be decarbonized. Peng et al. (2018) discovered that even though transport electrification can have significant air quality and health benefits if the source of the electricity is still powered by fossil fuel, it does not reduce carbon emissions. If electrification is fuelled by carbon-intensive electricity, the emissions resulting from the electricity generation will offset the emission reductions from replacing the direct combustion of fossil fuels with electricity in end-use sectors (Hofmann, Guan, Chalvatzis, & Huo, 2016; Peng et al., 2018). The research by Hofmann et al. (2016) confirms that replacing gasoline vehicles with EVs powered by 80% coal has no influence on overall emissions. According to Hofmann et al. (2016), the reduction in CO_2 emissions from the petroleum sector is offset by an increase in CO_2 emissions from the electricity sector, leaving the overall CO_2 emissions the same. Decarbonizing the electricity sector, for example, using 30% less coal in the electricity generation mix, could reduce overall emissions of CO_2 by 28% (from 10,953 to 7870 Mt CO_2) on a national scale (Hofmann et al., 2016). However, the benefits of EV including reduced fossil fuel dependency, improved air quality, and lower

CO_2 emissions can be achieved if they are introduced alongside aggressive decarbonization of the electricity sector.

The transition to EV must therefore be examined from a ‘clean grid’ standpoint and develop implementation strategies to necessitate the provision of clean energy from the start (electricity generation) to achieve a green-to-green paradigm (Das et al., 2020; Filote et al., 2020; R. Zhang & Fujimori, 2020). Fortunately, the electrification of the transportation sector enables vehicle integration into a dependable and efficient clean energy network (R. Zhang & Fujimori, 2020). It's worth noting that the success of the "*green electromobility*" concept is strongly reliant on green energy supply solutions for green EV, hence EV-CS should be supplied with green electricity (Filote et al., 2020; Hofmann et al., 2016). This, therefore, puts pressure on electricity sectors to switch from fossil fuels to renewables in electricity generation.

EVs do not emit CO_2 (Filote et al., 2020; R. Zhang & Fujimori, 2020), but the power in their batteries must come from somewhere. According to R. Zhang and Fujimori (2020), transportation electrification policy may result in an increase in electricity demand, which may lead to an increase in emissions if electricity is produced using fossil fuels. When implementing EV deployment, it is essential to consider the interaction between the transportation sector and the power sector (Filote et al., 2020; González Palencia, Nguyen, Araki, & Shiga, 2020; R. Zhang & Fujimori, 2020). Increasing the contribution of VRE technologies in power systems, such as wind and SPV, is critical for decarbonizing the power sector while continuing to satisfy rising energy demand (IEA, 2021).

However, the shift to green vehicles will not be simple, and technological advancements, particularly infrastructure improvements, are required for widespread consumer acceptance and adoption of the concept of electromobility. This also demands that EV-CS are as numerous as conventional fuelling stations, and the capacity to power them with energy from clean alternative sources is expanded to fully exploit the electromobility benefits (Filote et al., 2020). It is paramount for this study to review the state of the EU energy system.

3.1.7 European Union Energy System

The EU Energy System presents an interesting case for this study. Several important aspects of the EU energy system are discussed below.

EU energy production

The EU's energy production is divided into a variety of energy sources, including solid fuels, natural gas, crude oil, nuclear energy, and renewable energy (such as hydro, wind, and solar energy). Renewable energy contributed the most to primary energy production in the EU in 2020 (41% of total EU energy production). Nuclear energy was the second-largest source (31%), followed by solid fuels (18%), natural gas (7%), and crude oil (4%).

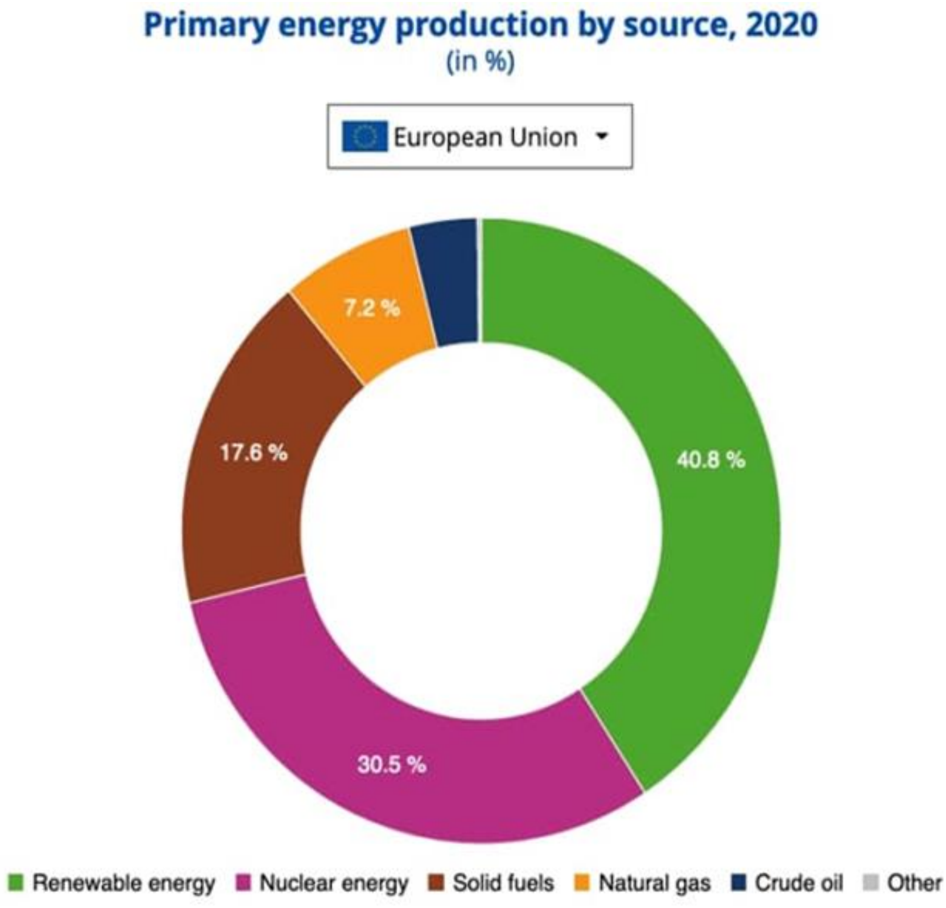

Figure 4 - EU primary energy production by source. Source (Eurostat, 2022)

However, energy production differs greatly from one Member State to the next as displayed in figure 5. Renewable energy is Malta's sole source of primary production, and it is also the dominant source in several other EU countries, with shares of over 95 % in Latvia, Portugal, and Cyprus. Nuclear power is very important in France (75% of total national energy production), Belgium (63%), and Slovakia (60%). Solid fuels are the primary source of energy in Poland (71%), Estonia (58%), and Czechia (45%). Natural gas has the highest percentage in the Netherlands (63%) and Ireland (47%), whereas crude oil has the highest share in Denmark (38%).

EU Energy Consumption

The consumption of energy in the EU presents a different situation. The EU is still reliant on fossil fuels, although it is working to reduce its carbon footprint as presented in figure 5. Petroleum products (such as heating oil, gasoline, and diesel fuel) were the most consumed in the EU in 2020, accounting for 35% of total energy consumption followed by electricity (23%). Natural gas and manufactured gases ranked third accounting for 22%, followed by direct use of renewables (energy not transformed into electricity, such as wood, solar thermal, geothermal or biogas for space heating or hot water production) which accounted for 12%, derived heat (such as district heating) (5%) and solid fossil fuels (mostly coal) (3%). Because other renewable sources are included in electricity, the real usage of renewable energy is higher than 12%. (e.g., wind power, hydropower, or solar photovoltaic) (Eurostat, 2022).

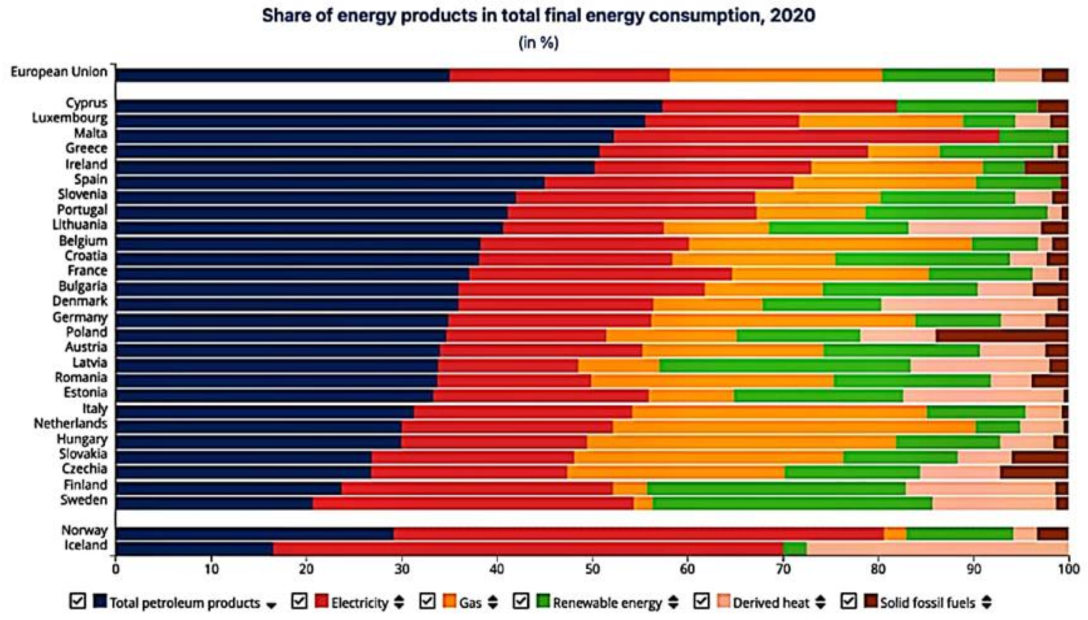

Figure 5 - EU share of energy products in total final energy consumption, 2020. Source (Eurostat, 2022)

The final energy consumption pattern differs greatly among the EU Member States as displayed in figure 5. In Cyprus and Luxembourg, petroleum products account for more than 55 % of total energy consumption. In Malta and Sweden, electricity accounts for more than 30% of total energy use, whereas gas accounts for more than 30% in the Netherlands, Hungary, and Italy. In Sweden, Finland, and Latvia, renewable energy accounts for more than a quarter (25%) of total energy consumption. “For its own consumption, the EU also needs energy that is imported from third countries” (Eurostat 2022).

Moreso, the EU is increasingly reliant on non-EU countries, especially Russia for fossil fuel imports. Russia (29%) accounts for nearly three-quarters of extra-EU crude oil imports in 2020, followed by the United States (9%), Norway (8%), Saudi Arabia, and the United Kingdom (both 7%), Kazakhstan, and Nigeria (both 6%). Over three-quarters of the EU's natural gas imports came from Russia (43%), Norway (21%), Algeria (8%), and Qatar (5%), while more than half of solid fossil fuel (mostly coal) imports came from Russia (54%), followed by the US (16%). This accounts for the reasons why some European countries were affected by the geopolitical war waged by Russia with regard to the “Russia-Ukraine war” in 2022.

EU actions towards Climate Change

There are leaders, policies, and targets pushing the energy transition agenda. Energy and climate policy have become more intertwined in EU decision-making over the years. The EU has developed integrated energy and climate policy packages for the years 2020 and 2030 and is currently executing the European Green Deal.

The European Green Deal is an ambitious climate policy that aims to achieve climate neutrality by 2050 (IEA, 2020: Eurostat, 2022). The European Green Deal seeks to ensure that there is clean air, water, soil, and biodiversity, as well as cleaner energy and cutting-edge clean technology innovation.

Europe is steadily shifting away from traditional energy sources and toward renewable energy technology, a movement facilitated partly by the EU Renewable Energy Directive (Directive 2009/28/EC, revised in 2018). According to the European Commission (2022), the EU seeks to speed up renewable energy adoption to contribute to the objective of decreasing net greenhouse gas emissions by at least 55% by 2030. The Renewable Energy Directive establishes guidelines for the EU to meet its objective of 32% renewable energy by 2030 (European Commission, 2022). "*The production and use of energy account for more than 75% of the EU's greenhouse gas emission*s" (European Commission, 2022). Increasing the share of renewable energy in all sectors of the economy is thus a critical component in achieving the EU's energy and climate goals, which include decreasing greenhouse gas emissions by at least 55% (relative to 1990) by 2030 and being a climate-neutral continent by 2050 (European Commission, 2022).

According to Eurostat (2022) reaching this goal will necessitate action from all sectors of our economy, including investments in environmentally friendly technologies, decarbonization of the energy sector, making buildings more energy-efficient, and the implementation of cleaner private and public transportation.

Furthermore, the EU Energy Union is a primary energy policy tool for bringing about the necessary changes to decarbonize the EU energy system. The mission of the Energy Union is to provide EU consumers – homes and enterprises — with safe, affordable, and sustainable energy (Eurostat, 2022). The Energy Union created a strong governance system based on integrated national energy and climate plans to ensure that policies and initiatives at all levels are coherent, complementary, and suitably ambitious (Eurostat, 2022). The legitimacy of

EU energy policy will be enhanced by using accurate, high-quality data to monitor policy aims under the European Green Deal and the Energy Union packages. It monitors the progress made toward a low-carbon, secure, and competitive economy and emphasises the areas that require more attention each year (Eurostat, 2022).

This section explains the reasons behind road transport electrification and green electricity (zero tailpipe emission). The section elaborates on the causes and impact of climate change, the EU energy system, and energy transition efforts that have been made by the EU over the years to ensure environmental sustainability. As indicated in this section, road transport electrification and electricity greening are two of the main energy transitions which form a green-to-green paradigm. The next two sections present both road transport electrification and green electricity in detail starting with road transport electrification.

3.2 Road transport electrification

3.2.1 Transportation

Transportation refers to the movement of people, animals, and products from one location via modes including air, land, sea, rail, cable, pipeline, and space. Transport has proven to be beneficial to the global economy and human life in different ways as it offers numerous advantages. However, there are environmental issues related to the current transportation systems as the emission levels from transport are quite significant. The EU has set a goal of reducing CO_2 emissions by 55% by 2030 and becoming carbon-neutral by 2050 (European Commission, 2022). However, the clock is ticking, and achieving these goals would need a concerted effort by governments and the related industries. So, what role does transportation play?

Transportation is a significant contributor to worldwide CO_2 emissions, accounting for 24% of total emissions (IEA, 2020). Most of these emissions are attributable to passenger transportation, although road freight traffic has a significant and growing part. In Europe, transport accounts for nearly a quarter of all greenhouse gas emissions (Plötz, Gnann, Jochem, Yilmaz, & Kaschub, 2019; R. Zhang & Fujimori, 2020) and according to Plötz et al. (2019), it is the only sector where emissions are still increasing since 1990. Road vehicles including cars, trucks, buses, and two- and three-wheelers account for nearly three-quarters of all CO_2 emissions from transportation, whilst emissions from aviation and shipping continue to rise (IEA, 2020), highlighting the need for more international policy attention towards this sector. Road transport is by far the largest emitter in the transportation sector, accounting for more than half of all transport related GHG emissions (R. Zhang & Fujimori, 2020). Rapidly increasing mobility needs, and private vehicle ownership are undermining global efforts to reduce GHG emissions from transportation (R. Zhang & Fujimori, 2020).

Despite ambitious plans to convert cargo transportation to electrified rail, road freight is predicted to continue to expand in absolute terms and remain the highest emitter of CO_2 from all modes of transportation (IEA, 2020). As a result, road freight has enormous potential for emission reduction. Clean alternative fuel sources for transport have become paramount if Europe is to reach its carbon neutrality goal. Electrification of the transport sector, especially road transport electrification is one of the ways to help minimise emissions.

3.2.2 Electrification of transport

In response to the current climate change problem, increased penetration of energy transition technologies in the transportation sector has become critical for the world, in its quest to achieve carbon neutrality. Fortunately, rapid technological advancements are creating new opportunities for the electrification of the transportation sector. In recent years, there has been a global diversification of vehicle propulsion modes, with biofuels, biogas, electricity, and hydrogen (H_2) (Filote et al., 2020). Electrification thus provides numerous opportunities to improve the overall energy efficiency of the transportation sector (Abid et al., 2021; Weiss, Dekker, Moro, Scholz, & Patel, 2015).

Transport electrification can be defined as the use of electricity to power transport including cars, ships, aeroplanes, and railways to mention a few. Though transport electrification has manifested mostly in road and rail transport, there is an opportunity to also electrify sea and air transport to minimise emissions. The road transport mode can be categorised under Passenger light-duty Vehicles (PLDVs), Light-commercial Vehicles (LCVs), HDVs or trucks, and buses etc (IEA, 2021). However, for the purpose of this study, road transport electrification is the main focus, specifically heavy-duty vehicle electrification.

3.2.3 Forms of Electric Vehicles Technology

There are different forms of alternative fuel technologies for transport that have emerged over the years. Alternative fuel technologies for vehicles (AFVs) (Plötz et al., 2019) driven by RES have been developed as a GHG mitigation alternative, especially for passenger cars. These technologies are broadly categorised under these three (3) technologies including

1. EDVs – Electric Driven Vehicles
2. Dynamic roads – Overhead contact line, etc.
3. FCEV - Fuel cell electric vehicles

A fuel cell vehicle (FCV) or fuel cell electric vehicle (FCEV) is an electric vehicle that uses a fuel cell to power its on-board electric motor, sometimes in conjunction with a small battery or supercapacitor (Gönül, Duman, & Güler, 2021). Vehicle fuel cells use compressed hydrogen and oxygen from the air to generate power. Hydrogen is used to power FCEVs (İnci, Büyük, Demir, & İlbey, 2021). They are more fuel-efficient than traditional internal combustion engines and release no tailpipe emissions—only water vapor and warm air (Tanç, Arat, Baltacıoğlu, & Aydın, 2019). However, the FCEVs and the hydrogen infrastructure needed to fuel them are still in their implementation state (Santos, Roso, Malaquias, & Baeta, 2021). On the other hand, Fuels made from renewable resources are known as renewable fuels. Biofuels including vegetable oil as a fuel, ethanol, methanol from clean energy and biomass, etc are all forms of renewable fuels. However, these two technologies internally produce their own energy and do not depend on external systems such as the grid for electricity. For this study, the main focus is on Electric Driven Vehicles (EDV) and dynamic/electric road systems (ERSs) as these technologies are developed to receive electricity from the grid.

Electric Driven Vehicles (EDVs)

The three basic types of EVs are battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and hybrid electric vehicles (HEVs) (Asif & Schmidt, 2021). A BEV is a vehicle that runs entirely on electricity and does not have a gasoline engine. The battery powers the electric motor and onboard electronics (Gönül et al., 2021). A PHEV is a vehicle that has both an electric motor and a gasoline engine (Gönül et al., 2021). It is a combination of the two which poses the benefits of both technologies. The batteries are charged using grid electricity and regenerative brakes (Pirouzi, Aghaei, Niknam, Farahmand, & Korpås, 2018). HEV is a vehicle that has both an electric and a gasoline engine (Gönül et al., 2021). Unlike a PHEV, the HEV battery connected to the electric motor is charged solely by regenerative braking (Gönül et al., 2021). It creates and stores electricity using internal processes, while the PHEVs store electricity by connecting to the grid (Gönül et al., 2021; Pirouzi et al., 2018).

Dynamic/Electric roads

Dynamic or ERS are also another developing form of road transport electrification technology. It is proposed as a supplementary technology to support EVs, especially HDVs. The physical infrastructure for continuous power delivery along the road is comparable to that of overhead wires for trams or railway systems (R. Zhang & Fujimori, 2020). Electrified roads (e-Roads) can provide continuous power while allowing EVs to go around (Soares & Wang, 2022).

Though electric engines are becoming a more essential technology for reducing the carbon footprint of the transportation sector, for example, using electric commercial vehicles (ECVs) for long-haul freight transportation is a difficult undertaking. The battery capacity of ECVs effectively used for urban logistics with driving ranges of 130 to 160 km (Soares & Wang, 2022) are insufficient for long-haul transportation, because of the frequent recharging breaks obstructing on-time delivery (Schwerdfeger, Bock, Boysen, & Briskorn, 2022). Larger batteries, on the other hand, which enable appropriate driving ranges, are so heavy that they significantly decrease the potential payloads of ECVs (Liimatainen, van Vliet, & Aplyn, 2019). These drawbacks have prompted a recent (re-)consideration of the "charge-while-drive technology" for long-distance road travel. Overhead wires, often known as pantographs or trolley poles, are an old established method for transmitting electrical energy to trams, trolleybuses, and trains using roof-mounted current collectors. Catenary trucks, also known as trolley trucks (Mareev, Becker, & Sauer, 2017), have a long history in truck-based freight transportation and are still used effectively in big mining operations (Plötz, Gnann, Jochem, Yilmaz, & Kaschub, 2019).

Electric Trucks

In terms of freight transportation, Moultak et al. (2017) described the use of battery electric trucks (BETs) in two subcategories that rely primarily on either (1) plug-in charging or (2) ERSs. Plug-in charging systems are primarily recommended for light commercial urban deliveries and Medium Duty Trucks (MDTs) for regional deliveries, as well as for refuse trucks. BETs would replace MDTs and Heavy-Duty Trucks (HDTs) on high-demand medium-distance routes, as well as drayage truck routes around ports (Jabłoński & Jabłoński, 2020; Moultak et al., 2017). They also suggested using FCEVs for long-distance HDTs and drayage trucks around ports (Moultak et al., 2017).

Plötz et al. (2019) present electric trucks powered by overhead lines, also known as catenary hybrid trucks (CHT) or trolley trucks (TT). The trucks are operated as hybrid vehicles, with either a conventional engine and an electric motor or an electric motor with a battery range of roughly 50–100 km (Plötz et al., 2019). The purpose of both the conventional engine and the battery is to act as a range extender (allowing operation on highways without overhead lines) and to allow the passing of other vehicles on the highway (Plötz et al., 2019; Teter et al., 2017).

The EU wants to be a major player in the EV market, and most European countries have put together a package of policies to help them revitalise the automotive industry and create more high-tech jobs (R. Zhang & Fujimori, 2020). Renewable targets under RED II encourage fuel switching (IEA, 2020). The EU presented a target of 14% renewable energy in transportation by 2030 (with a 3.5% target for advanced biofuels) with the RED II, an ambitious increase from 8% in 2018 (IEA, 2020). Overall, the renewable transportation target will be progressively met through the promotion of EVs (IEA, 2020).

Additionally, other developing technologies include extended-range electric vehicles (EREVs), fuel cell electric vehicles (FCEVs) are various types of EDV technologies (Cruzat & Valenzuela, 2018). However, the HEVs, EREVs, and PHEVs are recommended for short-term GHG reduction plans, while BEVs and FCEVs are recommended for long-term alternative fuel solutions for zero-emission heavy-duty truck technologies (González Palencia, Nguyen, Araki, & Shiga, 2020; Jabłoński & Jabłoński, 2020; Moultak, Lutsey, & Hall, 2017). Novel technologies including autonomous vehicles (AV) (Holland, Mansur, Muller, & Yates, 2021; Jabłoński & Jabłoński, 2020) as well as new business models such as shared mobility and social practices (Holland, Mansur, Muller, & Yates, 2021; Plötz et al., 2019; Whittle et al., 2019) are also being developed to address these to minimize emissions from transport.

3.2.4 Drivers of road transport electrification

In the late 1800s, the first EVs were introduced (Basma & Rodríguez, 2021). The lack of superior battery technology, the inadequacy of electrical networks, and the start of the cheap oil period all contributed to the rapid development of Internal Combustion Engine Vehicles (Filote et al., 2020). EVs have regained popularity because of the depletion of fossil resources, increased energy dependency, and rising environmental concerns (Filote et al., 2020). According to Abid et al. (2021) in recent years, especially in the past decade, the global EV market has risen at a faster pace. Over the previous decade, EVs have seen steady expansion across all modes of transportation as displayed in figure 6.

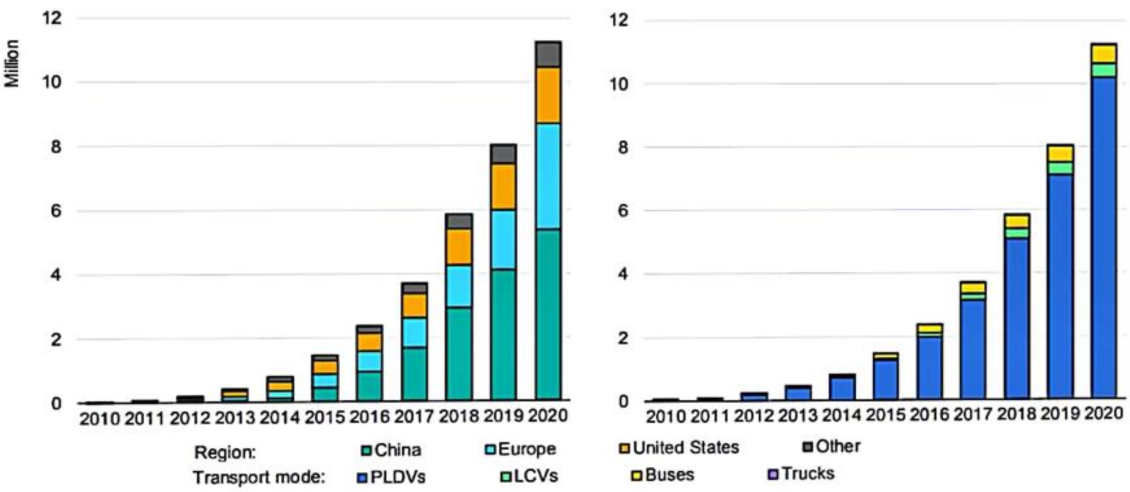

Figure 6 - 2010-2020 global electric vehicle stock by region (left) and mode of transportation (right). Source (IEA, 2021).

According to the IEA (2021) Europe has seen a boom in electric vehicle registrations. In 2020, new electric vehicle registrations in Europe, more than doubled to 1.4 million, representing a 10% market share. Germany registered 395 000 new electric cars in the major market, whereas France registered 185 000. Registrations in the United Kingdom more than doubled to 176 000. In Norway, electric automobiles have a record high sales share of 75%, up almost a third from 2019. Electric vehicle sales surpassed 50% in Iceland, 30% in Sweden, and 25% in the Netherlands.

This was due to two governmental measures. First, the EU's CO_2 emissions rules, which restrict the average CO_2 emissions per kilometre driven for new cars, had a 2020 deadline. Second, many European governments raised EV subsidies as part of stimulus packages to combat the pandemic's effects (IEA, 2021). BEV registrations accounted for 54% of electric car registrations in Europe in 2020, continuing to outnumber plug-in hybrid electric vehicle registrations (PHEVs). However, the number of BEVs registered doubled from the previous year, while the number of PHEVs tripled. The share of BEVs was specifically high in certain countries including the Netherlands (82% of all electric car registrations), Norway (73%), the United Kingdom (62%), and France (60%) (IEA, 2021).

Heavy-duty vehicle electrification is gaining traction, fuelled in part by ambitious legislation around the world requiring truck and bus manufacturers to cut emissions in their new vehicle fleets or establishing unambiguous sales criteria for zero-emission technologies (IEA, 2020). Governments have also begun to make long-term promises to phase out internal combustion engine medium- and heavy-duty trucks entirely (Buysse & Sharpe, 2020). Trucks create 22 % of total CO_2 emissions from road transport, according to the UNFCCC, despite accounting for only 2% of total vehicles on the road.

Since 2009, the EU has promoted the use of renewable energy (including electricity) in the transportation sector, resulting in the implementation of national blending mandates across the EU. The first EU Renewable Energy Directive (RED) (Directive 2009/28/EC) mandates that the EU and member states meet the 10% renewables target in transportation by 2020 (IEA, 2020). EU RED II (2018/2001/EU) maintains (higher) national targets for renewable energy in transportation for 2030 (upon request by the member states) (IEA, 2020). The directive also requires member states to mandate fuel suppliers to supply at least 14 % of the energy consumed in road and rail transportation from renewable sources (IEA, 2020).

3.2.5 Benefits of road transport electrification

Current research clearly demonstrates the overwhelming importance of road transportation electrification (Fernández, 2019; García-Afonso et al.,2021; Holland et al., 2021; Noel et al., 2018; Peng et al., 2018; Plötz et al., 2019; Whittle et al., 2019; R. Zhang & Fujimori, 2020). Road transport electrification creates an avenue for renewable energy integration (Noel et al., 2018; Pirouzi et al., 2018), minimises dependency on fossil fuel (R. Zhang & Fujimori, 2020), reduce emissions (Filote et al., 2020; Plötz et al., 2019; Tian et al., 2022; R. Zhang & Fujimori, 2020) and others. These authors illustrate the impact of road transport electrification in achieving a low-carbon transition. Of course, emission mitigation is one major reason behind all these energy transitions. According to R. Zhang & Fujimori (2020), The development of road transport electrification is a vital part of efforts to meet EU GHG reduction targets and the Paris Agreement's goals of keeping global temperature rises below 2^oC. Increased energy efficiency in transportation, as well as a reduction in smog and noise, are all advantages of electromobility.

According to Peng et al. (2018) electrification with low-carbon electricity is a key strategy for carbon reduction as well as end-use electrification can also reduce air pollutant emissions from demand sectors, which has a positive impact on public health. Plötz et al. (2019) perceive it as an interesting alternative to emission reduction in heavy road transport. Electric-powered low-carbon vehicles provide an alternative to traditional fossil-fuel technologies and transitioning to electricity for road transport has been proposed as a substantial means of reducing direct CO_2 emissions and alleviating the supply-demand imbalance for oil (Weiss et al., 2015; R. Zhang & Fujimori, 2020).

Decarbonization is not the only advantage of transport electrification. Additionally, electrification is regarded as a viable option for lowering road transportation's reliance on oil and its environmental impact (Peng et al., 2018). Thus, it serves as a remedy to the energy resources depletion problem. More so, in terms of road transport there are also driving privileges, subsidies, the economic benefits depending on the region (He et al., 2019), cost savings, advanced performance, noise reduction, and most importantly renewable energy integration (Noel et al., 2018). Despite the benefits of transport electrification, there are also several limitations that are worth considering.

3.2.6 Limitations of transport electrification

EVs are currently confronted with two significant issues: their impact on the grid network and social acceptance. High EV purchase prices, long fuelling times, a lack of suitable charging infrastructure in some countries, and battery replacement are among the most significant challenges for buyers (John Gartner Matthias Spöttle, 2018). Different authors have highlighted several limitations of transport electrification. Transport electrification is characterised by challenges including uncertainty (R. Zhang & Fujimori, 2020), increased mining (Hao et al., 2019), and pressure on the grid (Peng et al., 2018; Plötz et al., 2019). According to R. Zhang and Fujimori (2020) even though EVs reduce transportation-related emissions, detecting the cross-sectoral effects of transport electrification remains difficult, for example, the impact of EV deployment on CO_2 emissions from the power sector and the impact of EV penetration on mitigation costs. R. Zhang and Fujimori (2020) argue that it remains uncertain if EVs will deliver the transition toward a green future. Moreso, if fossil fuel continues as the main source of electricity generation, Fernández (2019) claims that there are some issues with BEVs because their use is inextricably linked to the upstream emissions caused by the generation of the energy required to charge their batteries.

Unfortunately, the huge energy requirement to propel large vehicles and their payload (Hao et al., 2019; Peng et al., 2018; Plötz et al., 2019) is a major barrier in this industry (Hao et al., 2019). According to Hao et al. (2019), extensive-distance coaches and tractor-trailers with long driving ranges face an even greater issue, because the amount of battery capacity required by HDVs is much greater than that of light-duty vehicles (LDVs) - The enormous battery capacity projected adds to the vehicle's weight and expense of the vehicle. According to the above-mentioned authors, HDVs have a much longer life expectancy than batteries, such that a heavy-duty tractor-trailer has an average total mileage of more than 1,200,000 km. During the lifetime of an HDV, battery replacement is predicted, boosting demand for batteries and their raw materials, such as lithium, cobalt, and nickel (Hao et al., 2019).

On the other hand, according to García et al. (2020) EVs are not carbon neutral. EV and battery manufacturing, as well as battery recycling, increase the carbon and material footprint of EVs. EVs and ICEVs are said to have similar material footprints.

This study focuses on the additional electricity demand (Peng et al., 2018; Plötz et al., 2019) as the main consequence of transport electrification. In addition to increasing demand for batteries (Hao et al., 2019), transport electrification necessitates the generation of additional electricity (Peng et al., 2018; Plötz et al., 2019). It exerts pressure on the electricity grid. Additionally, the demand generated is inflexible (Plötz et al., 2019). Green Electricity is another crucial area of this study. "*In order for EVs to attain their full potential to mitigate* *carbon emissions, critical progress is required to decarbonise electricity generation, to integrate electric vehicles in power systems, to build charging infrastructure and to advance sustainable battery manufacturing and their recycling*" (IEA, 2021). The next section discusses green electricity as the other half of the green-to-green paradigm.

3.3 Green electricity

Green electricity basically refers to electricity generated from renewables. Renewable energy is regarded as a key path toward the so-called green economy, because of its potential for climate change mitigation, fossil energy savings, and green job creation, (Gönül et al., 2021; Moreira, 2019). The replacement of fossil fuels with renewables in electricity generation is defined in this study as "electricity greening". For electricity to be green, more renewables must be integrated into the grid at the expense of fossil fuels. This section reviews the integration of RES into the electricity system. The electricity system, power generation, and the grid are discussed in the following subsection.

3.3.1 The electricity system, power generation and the grid

It is crucial to understand the electricity system and its regional variations when reviewing the literature on transportation and green energy integration into the power grid. The electricity system is fundamentally divided into four stages: generation, transmission, distribution, and retail (as displayed in figure 7). Electricity is produced at power plants and flows through a complex system of electricity substations, transformers, and power lines that connect electricity producers and consumers (Hall & Lutsey, 2017). This system is sometimes referred to as the "electricity grid". Most local grids are interconnected for reliability and commercial reasons, forming larger, more dependable networks that improve electricity supply coordination and planning (Energy Information Agency, 2021).

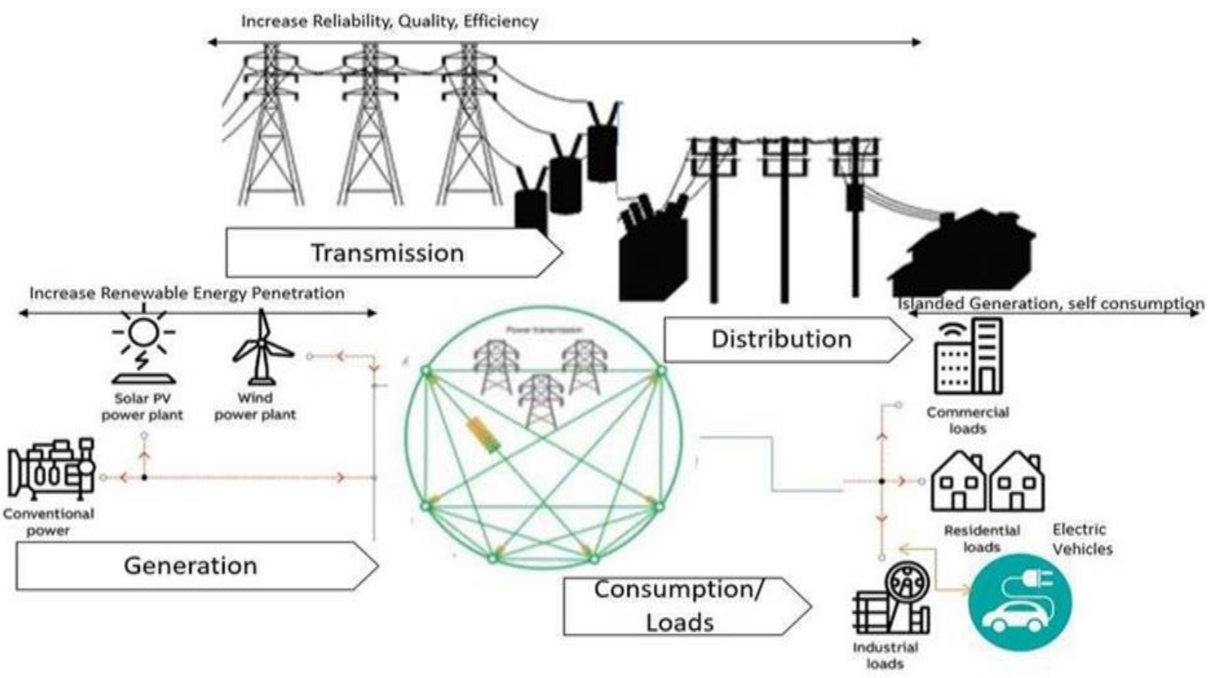

Figure 7 - Basic electricity system (Hall & Lutsey, 2017)

The benefits of electricity to the globe cannot be underestimated. Electricity transmission that is both reliable and inexpensive is critical to modern economies. Simultaneously, the need to address climate change is causing a massive restructuring of electricity infrastructure around the world (Hall & Lutsey, 2017). Electricity is the fastest-growing source of final energy demand, with growth expected to outstrip overall energy consumption over the next 25 years. Electricity today attracts more investment than oil and gas combined, which is important as the generation mix shifts and older infrastructure is replaced (IEA, 2020). In Europe, electricity accounts for around 23% of the total energy consumed, and it originates from both renewables and fossil fuels. However, electricity presents an avenue for renewable energy integration as discussed in the next subsection.

3.3.2 Renewable integration into the Electricity Grid

The integration of renewable energy into the grid looks optimistic. The integration of VRE sources, most especially, has received significant global attention. VRE sources are renewables that generate energy intermittently instead of on-demand (IEA, 2020). They include wind, solar, tidal, and hydroelectric power. According to Gasparatos et al. (2017) increasing the contribution of VRE technologies in power systems, such as wind and SPV, is critical for decarbonizing the power sector while continuing to satisfy rising energy demand. VRE technologies deployment has exploded in recent years, thanks to drastically lower costs and supporting legislation (IEA, 2020). The rising availability of low-cost VRE, the deployment of distributed energy resources, developments in digitization, and increased electrification potential are all driving substantial changes in power systems around the world. These changes necessitate a significant shift in the power system (IEA, 2020). VRE's rising significance is one of the most important global drivers of power system reform (IEA, 2020).

Solar photovoltaics and wind power, in particular, have seen remarkable growth in recent years, owing to regulatory backing and steep cost reductions (C. Wang et al., 2021). With the high expansion of solar photovoltaics and wind in recent years, the energy sector remains the brightest spot for renewables, adding to the already large contribution from hydropower (IEA, 2020). However, according to IEA (2020), electricity accounts for about a fifth of global energy use, so the role of renewables in transportation and heating remains crucial in the energy revolution.

According to IEA (2020), in contrast to all other fuels, renewable energy for electricity generation expanded by about 7% in 2020. Solar and wind technologies have accounted for most of the recent increased renewable energy in the global electricity mix in recent years, and this trend is expected to continue. long-term contracts, priority grid access, and the continuing. This development is attributable to significant cost reductions that have occurred and are expected to occur (Ringkjøb, Haugan, & Solbrekke, 2018), and the technological and infrastructural developments are all supporting robust growth in renewable electricity (IEA, 2020). In Europe, electricity generation from RES is expanding, owing in part to the European Commission's ambitious emission reduction targets.

The EU set a goal of lowering emissions to 80% below 1990 levels in its 2050 Low Carbon Economy roadmap (IEA, 2020). The EU also maintains that all sectors must contribute to this reduction, although the power industry has the greatest potential to reduce emissions. The power sector can almost eliminate its emissions by 2050 by increasing the amount of zero-emitting RES in the energy mix (IEA, 2020). Renewable energy generates more electricity than fossil fuels in the EU, as displayed in figure 8. Electricity accounts for around 23% of the total energy consumed in Europe, and it originates from a variety of sources. RES accounted for 39% of electricity in the EU in 2020, overtaking fossil fuels (36%) as the primary power source for the first time. Furthermore, nuclear power plants provided 25% of the electricity. Wind turbines (14%), hydropower facilities (13%), biofuels (6%), and solar power all contributed the most electricity among renewable sources (5%) (Eurostat, 2022).

The Member States' electricity production sources differ. In Denmark, wind energy produced more than half of the electricity (57%) in 2020, whereas hydropower plants produced more than 60% of the electricity in Austria. In Malta and Cyprus, about 90% of electricity was generated from fossil fuels, while in France, over two-thirds (67%) of electricity was generated by nuclear power plants, followed by 53% in Slovakia (Eurostat, 2022).

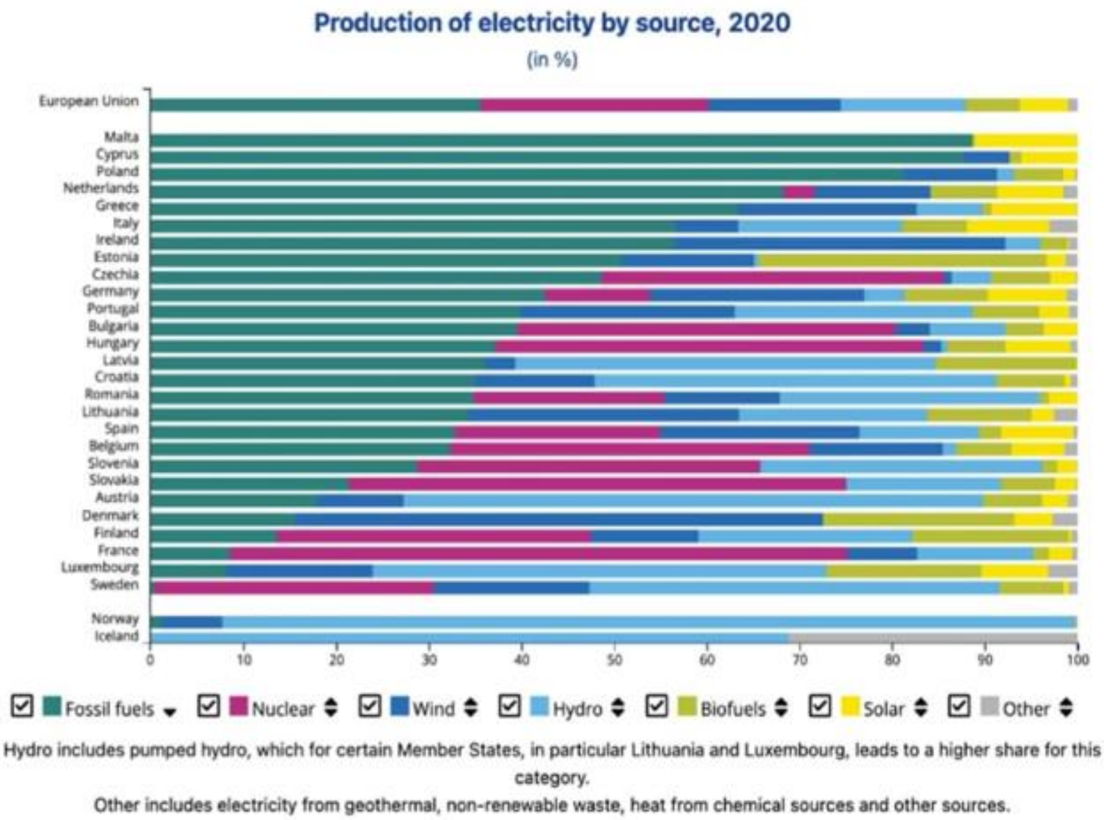

Figure 8 - EU production of electricity by source, 2020. Source (Eurostat, 2022)

However, there are several limitations that are worth considering. These challenges are addressed below.

3.3.3 Limitations/Critics of Green Electricity

Green energy is not free of shortcomings and criticisms. It is characterised by a variety of limitations including variability or intermittency (IEA, 2020; Ringkjøb et al., 2018), uncertainty (Sinsel et al., 2020), misconception (Q. Wang & Wang, 2020), destruction of biodiversity (Moreira, 2019; York & Bell, 2019) and others.

Firstly, COVID-19 has had an impact on the progress of renewable energy. Renewable energy project progress decreased in the first half of 2020 due to supply chain interruptions and construction delays (Sinsel et al., 2020). However, even during full/partial lockdowns, construction work did not halt in many nations, manufacturing activity swiftly ramped up, and logistical issues were mainly overcome with the lifting of cross-border restrictions since mid-May (IEA, 2020). Monthly capacity additions in Europe, the United States, and China have all outperformed estimates in September, indicating a quicker recovery in regions such as Europe, the United States, and China (IEA, 2020).

Furthermore, renewable energy systems such as wind turbines, and hydroelectric facilities cause significant harm to wildlife and nature. IEA (2020) and Moreira (2019) believe that conventional energy (coal, oil, and gas) and renewable energy projects, as well as energy transportation and distribution systems, have negative impacts on biodiversity. People view renewable energy installation as an obstruction of the natural view of the environment. Moreso, the integration of renewable energy into the electricity system could lead to "energy addition" instead of "energy transition". Gasparatos et al. (2017) claim that renewable energy might rather lead to energy "addition" instead of "transition". They argue that, while it is reasonable to expect renewables to provide a growing share of global energy supply, characterising this growth in renewable energy as a "*transition*" is misleading, and that doing so could stymie the implementation of meaningful policies aimed at reducing fossil fuel use.

Moreover, York and Bell (2019) argue that the rising unpredictability of RES presents significant hurdles in the functioning of today's power grids. According to Li et al. (2020), the intrinsic variability of wind and SPV power generation, on the other hand, presents difficulties for power system operators and regulators. Though VRE is a key power system transformation driver, its characteristics interact with the broader power system, posing several system integration challenges which do not manifest overnight, but rather develop over time as VRE penetration rises (Gasparatos et al., 2017). According to IEA (2020), the impact and challenges of VREs are largely determined by their deployment level and the context of the power system, including system size, operational and market design, regulation, and supply and demand fundamentals.

As the number of variable renewables grows, these disparities create a slew of problems for electricity networks (IEA, 2020; Sinsel et al., 2020). Solar and wind, on the other hand, are VRE sources whose outputs vary over time and on several scales. This is especially true for wind, which can range from brief gusts to large-scale patterns that evolve over several years (Ringkjøb et al., 2018). The daily and yearly cycles of solar radiation are well-known components, making it somewhat more predictable. However, due to the quick change in cloud cover, solar radiation on shorter durations might be difficult to estimate. Larger proportions of VRES pose several issues in an electrical infrastructure that demands a balance between generation and consumption (Ringkjøb et al., 2018).

To maintain a stable and reliable grid, solar and wind technologies, as well as innovative system components such as batteries, must be able to deliver the essential grid support services. Both wind turbines and photovoltaic systems can go from generating nominal power to generating nothing at all on an hourly timeline (Gevorgian & O'Neill, 2016; Ringkjøb et al., 2018). According to these authors, it is possible that, with a high VRES penetration, difficult ramping scenarios, times of oversupply, and periods when renewable sources are unable to fulfil demand can occur. Increased system flexibility, such as flexible power plants, energy storage, demand response, and transmission grid extensions, may be required in future power systems with high VRES shares (Ringkjøb et al., 2018).

According to IEA (2020) failure to address these issues could compromise the dependability of electricity systems and the attainment of decarbonization goals. The smart grid is a technology that is considered a system to increase the flexibility of the electricity grid.

3.3.4 Smart Grid Technology

EVs not only assist to reduce tailpipe emissions, but they can also integrate with renewable energy systems to create a green-to-green paradigm, particularly with renewables with intermittent supplies such as solar and wind, etc. A smart grid is an electricity network that monitors and manages the conveyance of power from all generation sources to satisfy the variable electricity demands of end-users using digital and other modern technology (IEA, 2021). Smart grids coordinate the demands and capacities of all generators, grid operators, end-users, and electrical market stakeholders to run the system as efficiently as possible, reducing costs and environmental consequences while increasing system dependability, resilience, and stability (IEA, 2021).

Better monitoring, control, and automation technologies can not only encourage the development of new business models but can also unleash system-wide benefits such as fewer outages, faster reaction times, deferred grid expenditures, and distributed energy resource integration (IEA, 2021).

Smart grids can enable demand flexibility and customer participation in the energy system at the end-user level, such as through demand response, EV charging, and self-produced distributed production and storage (IEA, 2021). Demand flexibility can help the system integrate variable renewables while also speeding up and lowering the cost of electrifying heating, cooling, and industries (IEA, 2021). The deployment of a physical layer of smart-grid infrastructure, supported by smart metres, can assist in unlocking these benefits (IEA, 2021).

Smart charging and demand-side management approaches can improve the efficiency of Electric Vehicle-Renewable Energy Sources integration even more (IEA, 2021). EVs have a lot of potential to help lessen the "*Duck Curve*" issue created by high Photovoltaics penetration during the day, and they can even assist lower grid operating costs by smoothing the demand profile with smart charging strategies.) (IEA, 2020).

This concludes the background details of the study. The following section comprises the empirical review which talks about the several authors, the research problems, the methodologies they used, and the findings they derived.

3.4 Empirical review

An empirical literature is reported below to understand precisely what has been done in relation to the research problem of this study and what was found. The review below shows how different authors addressed transport decarbonization using scenario-building approaches. This part of the literature review outlines the related research covering the topics, authors, objective, methodology, and findings as presented in table 1.

Table 1. Summary of empirical review of transport electrification

TITLE	AUTHORS	OBJECTIVE & METHODOLOGY	FINDINGS
Transport electrification scenarios for decarbonization of the European transport sector by 2050	(Gönül et al., 2021)	This study examines two different electrification scenarios for a transport sector powered entirely by renewable energy in the EU. The first scenario, 'electrification and e-fuels,' envisions electrification using electro fuels and BEVs, whereas the second, 'electrification +,' envisions a deeper level of electrification using electric roads for heavy-duty transport.	The analysis shows that extensive electrification of all sectors benefits the transportation system greatly in terms of improving overall energy efficiency and lowering total annual costs. Ideally, all road transport should be converted to electricity. Where battery electrification is not feasible, options such as ERS offer an energy-efficient alternative to synthetically produced liquid fuels. As it becomes more difficult to electrify aviation and shipping, expensive and inefficient electro-fuels should be prioritized for these industries.

The role of transport electrification in global climate change mitigation scenarios	(Abid et al., 2021)	Scenario simulations to depict the role of transportation electrification in mitigating climate change and how the transportation sector would interact with the energy supply sector	Increased emissions result from transportation electrification without the replacement of fossil-fuel power plants. While transport electrification by itself would not contribute to climate change mitigation, switching to electrified road transport under the sustainable shared socioeconomic pathways allowed for an optimistic outlook for a low-carbon transition even in the absence of a decarbonized power sector. The strict penetration of EVs can also help to reduce the mitigation costs associated with the 2 °C climate stabilization target.
Impact of automated driving systems on road freight transport and electrified propulsion of heavy vehicles	(R. Zhang & Fujimori, 2020)	Using mathematical optimization and vehicle dynamics models, to determine how much ADS facilitates BEHVs and what the limitations are for various transportation scenarios.	In comparison to BEHVs with human drivers, the combination of ADS and electrification resulted in the profitability of BEHVs for a broader range of transportation tasks. The profitability of BEHVs was determined by comparing their total cost of ownership (TCO) to that of conventional combustion-powered heavy vehicles (CHVs)

Road Freight Transport Electrification Potential by Using BEVs in Finland and Switzerland	(Ghandriz, Jacobson, Laine, & Hellgren, 2020)	A geospatial data analysis approach to analyse the potential of large-scale BET adoption in Finland and Switzerland for trucks with GVWs greater than 3.5 t by combining a battery electric vehicle potential (BEVPO) model with datasets from road freight transport surveys.	Trucks with payload capacities of up to 30 t have the greatest electrification potential, with 93 % (55 % tkm) and 89 % (84 % tkm) trip coverage in Finland and Switzerland, respectively, using currently available battery and plug-in charging technology. ERSs would be required to cover 51 % of heavy-duty truck trips (41 % tkm) in Finland. Range-extender technology has the potential to increase trip electrification by 3–10 percentage points (4–12 percentage points of tkm).
The Role of Powertrain Electrification in Achieving Deep Decarbonization in Road Freight Transport	(Jabłoński & Jabłoński, 2020)	A scenario-based approach was used, with a base scenario and three alternative scenarios focusing on powertrain electrification.	Between 2012 and 2050, tank-to-wheel CO_2 emissions are reduced by 42.8 % in the Base scenario due to vehicle stock reduction, improved vehicle fuel consumption, and the implementation of HEVs. Diffusion of FCEVs in regular vehicles and BEVs in compact and mini-sized vehicles results in the greatest tank-to-wheel CO_2 emissions reductions, up to 44.6 % when compared to the 2050 baseline value. Over the entire time horizon, the net cash flow is

			positive, peaking at 6.7 billion USD/year in 2049 and falling to 6.6 billion USD/year by 2050. Powertrain electrification is insufficient to meet any of the CO_2 emission reduction targets for road freight transportation.
Impact of transport electrification on critical metal sustainability with a focus on the heavy-duty segment	(González Palencia et al., 2020)	Using scenario modelling and a simulation model called Transport Impact Model (TIM), this study assesses the lithium resource impacts from the electrification of the heavy-duty segment at the worldwide level.	The findings demonstrate that mass electrification of the heavy-duty segment, on top of the light-duty segment, would significantly increase lithium demand and put further strain on world lithium supply.
Electric vehicles standards, charging infrastructure, and impact on grid integration: A technological review	(Hao et al., 2019)	This document provides a complete overview of the current state of the electric vehicle market, including standards, charging infrastructure, and the impact of EV charging on the grid.	Unified standards for electric vehicles and their charging infrastructure around the world are a must for EVs to gain market traction. The prevalent standards for EV charging and grid integration are thoroughly described so that future researchers will have a clear

understanding of the parameters that must be met.

The above summary shows how researchers have addressed the green road transport electrification agenda in different ways. Most of these researchers address the tail-end of the green-to-green paradigm (transport electrification) and several of them address green electricity as part of the paradigm. However, at this point of the chapter where all the important areas of the study have been discussed, a summary of the various sections is developed below.

3.5 Chapter Summary

Road transport electrification has developed considerably over the past decades; however, trucks have the lowest electrification rate of all vehicle sectors because long-haul trucking needs advanced technologies for high-power charging and/or huge batteries. Also, fuel efficiency measures are not strict enough, other policy or regulatory initiatives, such as Zero-Emission Vehicles mandates, are less ambitious than for light-duty vehicle counterparts, reflecting the relatively slow rate of electrification of the HDVs.

In Europe, electric heavy-duty vehicle registrations increased by 23% to around 450 vehicles in 2020. This is expected to increase significantly by 2030 if Europe is to reach its zero emissions target. To achieve a higher level of heavy-duty vehicle electrification by 2030, there are certain drivers which must be considered, related to factors including government policies, actions of auto manufacturers, technological development, etc. These drivers are presented below.

- If governments speed up their efforts to meet climate objectives, the EV industry might grow dramatically. Ambitious targets should be set for heavy-duty vehicle electrification.
- Europe has to push more investments into truck electrification.
- Also, carbon taxation on fossil fuels has to be intensified to help speed up the electrification of HDVs.
- Truck manufacturers need to intensify their efforts to transition from ICEVs to electric trucks.
- The development of battery technologies is also paramount for heavy-duty vehicle electrification by 2030. Batteries with lighter weights and larger storage capacities are prerequisites.
- Moreso, the charging infrastructure needs to develop alongside EVs to ensure charging security.

However, to achieve the greatest reduction in GHG emissions, EV adoption must be coupled with the decarbonization of electricity generation.

On the strength of technological know-how, supportive laws, and government goals, Europe has established itself as a centre for renewable energy technologies. The continent's goal of reducing greenhouse gas emissions by 55% by 2030 and becoming climate neutral by 2050 necessitates a massive growth in RES. RES accounted for 37.5% of total electricity consumption in Europe in 2020, up from 34.1% in 2019. This is expected to increase considerably by 2030. Wind, hydro, and nuclear provide the majority of renewable electricity, whilst solar energy is growing at a significant pace.

With wind and solar energy development, variability of RES is seen as the major limitation of renewable energy integration. However, several critical drivers have to be considered to facilitate electricity greening in Europe, including government policies, smart grid technology, stricter taxation on emissions, etc. These drivers are presented below.

- The efforts of policymakers are crucial to the development of green electricity in Europe by 2030.
- Europe has to push more investments into green electricity to help minimise the start-up cost of renewable energy installations.
- Also, carbon taxation on fossil fuels has to be intensified

- The development of storage technologies is also paramount to managing variable energy sources such as wind and solar.
- Moreso, smart grid technology and other energy-efficient technologies need to be developed.

However, according to the literature survey, heavy-duty vehicle electrification has the potential to develop and reduce emissions significantly by 2030 if the source of electricity is decarbonized at a significant rate. The next chapter presents the findings of this study.

4. Findings and analysis

The findings generated from the transcribed interviews are analysed and presented in the coming chapter. The analyses of the responses of the experts are broadly categorized under the two shifts heavy-duty transport electrification and electricity greening, the interaction between these two shifts, and lastly the impact of Russia’s invasion on Ukraine. The questions for the interviews were open-ended, which further created the room for the interview participants to discuss different but related topics flexibly. The analysis begins with the background of the experts.

4.1 Background of Experts

As can be seen in the interview guides 1, 2, and 3, (Appendix A; Appendix C; Appendix E) the questions seek to highlight the background of the researcher. All three experts interviewed have significant experience in both road transport electrification and electricity greening.

Respondent 1 (Res1) has been a research scientist for 14 years. He has mostly been working with transport research, but in the later years has worked on the electrification of the transport sector. Specifically, with the interface between the transport system and the energy system, which is the charging infrastructure, and with hydrogen as an energy carrier in transport. He now works with people who are experts on energy systems, electricity grids, and renewables. So, his experience is highly related to electricity greening (Appendix B, page 1).

Respondent 2 (Res2) has been a professor in energy engineering and research leader/research director from 2000 until 2018 and is currently a senior professor. He has experience within processing industries, power plants, etc., but also transport, especially trains, construction equipment and those types of machinery. He also has significant knowledge of electricity greening in relation to transport. Res2 takes an active part in the production of electricity, as well as the use of electricity in batteries (Appendix D, page 1).

Respondent 3 (Res3) is a researcher in energy system analyses. Specifically, on transport and its connection to the grid. He has knowledge about hydrogen, charging infrastructure, and its challenges, and understands how the charging infrastructure could work most efficiently. He has participated in publications regarding the adoption of distributed renewable energy in charging stations. His focus of work has been within Norway, through several research projects, they have been closely connected to the industry and power sector. He is well-positioned to understand the power sector, including the current challenges and research questions (Appendix F, page 1).

However, this background analysis shows that all the three experts interviewed had a significant level of experience and were knowledgeable with regard to green road transport electrification.

4.2 Electricity Greening

Different questions were asked related to how electricity greening will develop in Europe from 2022 to 2030 and the potential drivers that are likely to affect the development. The responses from the experts included: The benefits of electricity greening, the main challenges, the main actors, or stakeholders involved, the likely renewable energy mix, promising countries, the impact of electricity greening, the smart grid technologies, renewable energy production and space utilization, and the possibility of a fully connected European grid.

The benefits of electricity greening

Electricity greening has the potential to help minimize emissions significantly. On the question, "*Do you believe that "Electricity Greening" could help minimise emissions (i.e., GHG emission) in Europe? If yes, how*?" (Appendix A, page 3; Appendix C, page 3). Both Res1 and Res2 agreed that electricity greening could minimize emissions (i.e., GHG emissions) in Europe. They further stated that "…*we can principally replace everything that we're using fossil fuels for with electricity instead*." (Appendix D, page 2). And that **"**… *the main way of achieving this target is to switch into other energy carriers in the transport sector. Whether it is biofuels or hydrogen or battery electric vehicles, by doing this it will help to achieve the target*." (Appendix B, page 10). And concluded that; "... *this will of* *course help reduce greenhouse gas emissions directly, both in the consumption part and the production part*." (Appendix B, page 4).

Main challenges of "Electricity greening" for Europe

Start-up investment cost and local people rejecting the construction of renewables infrastructure in their "backyard", and limited space for renewables infrastructure are the most common bottlenecks hindering electricity greening. On the question of "Which are the main challenges or bottlenecks of "Electricity greening" for Europe?" (Appendix A, page 3; Appendix C, page 3); Res1 pointed out that; *"One obvious thing is the investment cost of investing in renewable energy sources", and "... also the public opinion of nuclear, windmills, and the demand for large areas for solar power and so on."* (Appendix B, page 5). Res2 stated that the biggest obstacle could be the individuals who were against renewable energy systems, like wind power and SPV systems for aesthetic reasons. Stating that "*It's very many people that say: "I like renewables, but I don't want to have it in my backyard". This is a major challenge. I don't know how to overcome it.*" (Appendix D, page 6).

Res2 later discussed the decision-maker dilemma of force or incentive, and the public approval; "*In Sweden, there is a big discussion now if the municipality will not be allowed to have a veto against expansion in their municipalities. For the time being, each municipality or city has arrived to say no, and if you have local people who are very upset about getting wind power in their neighborhoods, then very often the politician says: "okay, then we shouldn't have it". And they say that you can have it somewhere else, but not here. And if this is happening everywhere, we will have no expansion. And I think this is really the biggest threat to this. And the biggest bottleneck.*" (Appendix D, page 7).

Res2 further commented on a possible incentive-based solution; *"The second thing is it should be a benefit for people living in the neighborhood. So at least the municipalities should get benefits from when you are building these big wind power plants, for instance, or if there are big solar power plants and so on."* (Appendix D, page 16). Res2 later commented on the practical difficulties regarding noise levels, etc., with this type of solution, but were generally optimistic (Appendix D, page 17).

Res2 reflected the possibility of an incentive-based solution: "*There is a discussion, if you should give annual income to the people living in that neighborhood. If you did, it would probably overcome most of these big problems. Today, you have only the negative effects but no positive effects. Because the locals don't get anything if they are not a landowner themselves. The landowners are getting some, but not the people living on these lands*." (Appendix D, page 15) "*I think that is the major challenge. Okay. I don't think there are, of course in this regulatory demand you don't pay, or they don't get any benefits from those who are living in the neighborhood, and so on. So that you could say it is a regulatory problem*." (Appendix D, page 16).

Main stakeholders in "Electricity greening in Europe and Scandinavia

The decision makers including the EU, leaders of the countries, the government, parliament, vehicle manufacturers and citizens have a crucial role to play in electricity greening in Europe. On the question of: **"***Which are the main actors or stakeholders to help in "Electricity Greening" in Europe***?**", Res1 stated that "*The most important once are the people in charge. I think politicians make decisions that can change the framework (in terms of economic framework), subsidies, and taxes, and so on*." (Appendix A, page 4; Appendix C, page 4). Res2 also mentioned the decision-makers as the most important stakeholder and added the importance of the EU system as a factor (Appendix D, page 12). So, the decision makers control many of the economic factors, and this is a strong deciding aspect in investment of renewables, the price for electricity or other energy sources, and the continuation of funding of initiatives in terms of taxes and/or subsidies. Res1 states therefore "*So, I think these are the main stakeholders*." (Appendix B, page 8). Res1 and Res2 mentioned the industry and production side is mentioned as a key stakeholder (Appendix B, page 8; Appendix D, page 12) Res2 added that the industry is positive to the change and drive the change along, but because of the potential loss in competitiveness they need the stakeholders to make the drive possible by enabling them (Appendix D, page 17). Res2 reflected on who the decision-makers really are, stating that the decision makers are the elected prime ministers from the different countries (Appendix D, page 12). They are elected, so they are listening to the voters. We as individuals have a major importance, but indirectly, so to say, through the politicians. The industrial companies, the same thing there in the way that we are as the customers to the industry companies (Appendix D, page 12).

“So, the stakeholders are: we as individuals…” (Appendix D, page 12).

Res2 mentioned an example of such a redefining drive. The vehicle company who started to create change, a change which people followed… “*And that was Tesla, an American company with a great entrepreneur, who was doing something that made everyone have to do this.”* (Appendix D, page 12). When asked about who the key stakeholders in Sweden were, Res1, Res2 and Res3 agreed that it would be similar to the stakeholders in Europe with the government, parliament, and the enabled industries (Appendix B, page 11; Appendix D, page 17)

Renewable energy mix for Europe by 2030

One the question of *Which renewable energy sources do you think are most-likely to constitute the renewable energy mix for the European- Scandinavian region in their quest to green their electricity grids? and why?”* (Appendix A, page 3; Appendix C, page 3), the experts stated that firstly it is a complicated situation, since… “*It is more of a political question than a technical or also economical question*.” (Appendix B, page 4). And further claim that… “*... a mix of nuclear energy, solar, wind, hydro, maybe more tailored to the topography of each country or the public opinion*” (Appendix B, page 4). But also adding; *“...but there is also the price of solar panels, technological development, battery development, there are a lot of uncertainties for several technologies. So, yeah. I guess the answer will be a mix. That will be most likely*.” (Appendix B, page 5). Res2 answered that hydro, wind power, SPV systems, Nuclear, CHP. And further stated that: “*But it* [solar] *will never be as important as wind power, probably although it is becoming higher and higher volumes, but probably the wind power in Europe will be the most important after hydropower.*” (Appendix D, page 4).

On the question about the recent EU taxonomy inclusion of nuclear energy Res2 agreed on the inclusion, explaining that since the period we must solve the climate crisis is short and the problem of nuclear waste may not be prioritized when CO_2 is the most addressed problem (Appendix D, page 5).

In the case of Sweden, the researchers stated that it was a complex answer with several aspects that needed to be considered, such as the negative effects on nature, risk to the population, and economical aspects. A few predictions were given, (1) Hydropower would not be expanded in the next ten years, because it is difficult to do from an environmental perspective (Appendix D, page 4). (2) Nuclear would not be expanded for 20 - 25 years since the current capacity was sufficient (Appendix D, page 4). (3) Wind power would be expanded if companies are not stopped and blocked by local peoples (Appendix D, page 4). (4) SPV systems are widely used in Sweden already, but a continuing expansion is expected (Appendix D, page 4). (5) CHP plants are not expected to expand but are described as crucial in the mission to replace the oil in products like plastic (Appendix D, page 4). Res3 added that the Nordic countries already have a tradition for renewables, so its large acceptance/consensus for renewable projects (Appendix F, page 13).

Which European country will likely lead to "Electricity greening" by 2030?

On the question of "*Which of the European countries do you think stand the greater chance of leading the "Electricity Greening" in Europe by 2030? and why?"* (Appendix A, page 4; Appendix C, page 4), Res1 stated that countries like Germany, France, and the UK maybe. The big countries. That they could be good examples for the others and push for other countries that try to follow them. Res1 pointed out that this would be because of the size and making large improvements like removing coal plants (Appendix B, page 9).

Res2 stated that countries like Norway and Sweden could be leading countries. Mainly because of hydroelectricity, and also the nuclear energy used in Sweden. Res2 also mentioned a large amount of wind power in Sweden. Roughly 27 terawatt-hours (2021) according to Res2. And had installed *"…7000 megawatts installed wind power capacity, or something like that. Which is more than Denmark*" (Appendix D, page 13).

The power grid: Smart grid technology and supportive systems

On the question of how the grid will develop till 2030, Res3 stated that it is forecasted that there will be increasing demand for electricity. Therefore, the grid may need expanding/improvement. But, building out the grid will take time and has a significant lead time. With "Dumb grid" system is designed for the peak hour of an extreme day, and its purpose is to handle that, and the rest of the time it is much lower loads. With better utilization and better capacity through smart grid technology, it will allow us to use the existing grid more efficiently, it will offset/delay some of the need for the grid development. The smart grid system allows for better use of the existing grid. Then the lead time will not be such a huge barrier (Appendix F, page 13). Res3 stated that it "…*will need to build more grids, but through the support of a smarter system, we can make the transition smoother and cheaper."* (Appendix F, page 13).

On the question "*Could the implementation of a smart grid system make it unnecessary to upgrade the grid?*", Res3 stated that it is the direct motivation for the smart grid system. To use it more efficiently. Res3 further thought that smart grid technology is a very broad area where technology already is advancing and scaling up. This is needed when more renewables are coming (Appendix F, page 9). A future bottleneck would be that it would not be a fast enough development of the grid. So, a grid smarter would is a more efficient way to get access to more energy. If the grid would be utilized better then the grid could wait 10 years of building new lines and systems (Appendix F, page 12).

Renewable energy production and space utilization: SPV and Wind power

Res3 stated that space utilization is an increasing problem, and therefore, solutions where land is more valuable need to be explored. Related to this issue Res3 commented that in the Nordic countries with vast lands it is less complicated than in mainland Europe where population density is higher. Res3 stated that: "*I think it is forecasted that in Europe, the future will be offshore wind.*" There are limitations of how many windmills are possible to put up, but it is a very natural step for European countries with shorelines. For countries without a shoreline, such as Switzerland, Austria, or Czech, Res3 stated that a solution would not be as obvious, but it was a very large potential in Europe for SPV systems. There are frontrunners with a lot of SPV systems, like Germany, Netherlands, so SPV would have low or no impact on land or the visual, so this could be an opportunity on industry roofs or other un-utilized flat areas (Appendix F, page 14). Res3 further stated that SPV systems alone would not necessarily be the golden solution but could complement future systems and their energy mix (Appendix F, page 14).

Renewable energy production: Handling of large demand

On the question if a large demand for energy in a specific area could be handled by renewable energies, without the baseload of for example nuclear energy, Res3 stated that: "*we have the energy system that produces electricity to follow a load, so there is a challenge of having a large share of non-dispatchable production, and the question is how you're going to manage that*" (Appendix F, page 12). A separate question is with or without nuclear or hydro. Res3 had confidence that we will solve how a large share of renewable energy is implemented. Even without nuclear energy, it would be a solution. And a possibility for hydrogen over time, for those who don't want to have nuclear power (Appendix F, page 12).

Factors that should be considered when addressing "Electricity greening"

On the question regarding "*Which other factors should be considered when addressing or pursuing "Electricity Greening" for Europe*?" (Appendix A, page 4; Appendix C, page 4). Res1 referred to previously stated factors, while Res2 had more factors.

The importance of financial support functions. Here subsidizing is mentioned as a driver of projects and as the usual support function used. But, also mentioned stories of projects where companies stop after the economic support is used up, and much of the effect is lost. So, Res2 brought up CO_2 taxation, the cost of CO_2, as a promising tool (Appendix D, page 10). "*If you have a high tax on CO_2, it will improve the possibility of building these alternatives*." (Appendix D, page 10). Res2 also insisted that the support activities would need to be different and complement the possibilities and abilities of that country and region since there are very different conditions. An example mentioned was biomass. Sweden is a country with a lot of biomasses, while Belgium does not have the same amount of biomass (Appendix D, page 10). Res2 mentions it is also a competition of interests, and therefore a political problem and question of public opinion. Examples mentioned are the question of nuclear energy and the use of natural gas but follows up with the complexity of a system like this and the simple core of this – all kinds of CO_2 emissions should be put a penalty on one way or the other (Appendix D, page 10). Res2 mentions; "*And I think the politicians are giving very strange signals sometimes. And the reason is in Sweden we have an election in September. So,* *everyone wants to be very positive to as many voters as possible. So right now, the negative decisions are just blooming*." (Appendix 4, page 10).

The possibility of a fully connected European grid

On the question if it were possible for Europe to have an integrated electricity grid that could supply the whole of Europe, (Appendix D, page 22) Res2 responded that there are limitations in the power grid transmission lines. These are the bottlenecks. Because Northern Europe (Sweden, Finland, Norway, Denmark, Northern Germany) have good transmission lines and have a lot of renewables. Northern Germany is part of the North-Europe grid, and the lines from northern Germany to Southern Germany are very poor lines. It is said that they need five big transmission lines to be built from northern Germany and Southern Germany. Since France has good grids toward Southern Germany and Italy. The connection between France and Spain is poor, and very poor between Spain and Portugal. And in Portugal, 100% of the electrical power comes from wind power when it is windy. And this could be transported, but they have no way to export the wind power (no transmission lines to Spain, or very little. There must be built a number of these new lines. So, for a fully integrated net in Europe, there are limitations (Appendix D, page 22).

4.3 Heavy duty vehicle electrification

Different questions were asked which related to how heavy-duty vehicle electrification will develop in the European-Scandinavian region from 2022 to 2030 and the potential drivers that are likely to affect the development. The responses from the experts included: The main challenges of heavy-duty vehicle electrification, the main actors or stakeholders involved, electrification models, charging infrastructure, battery technology etc.

Main challenges of "heavy-duty vehicles electrification"

On the question of "*Which are the main challenges or bottlenecks of "heavy duty vehicle electrification" for Europe*?" (Appendix A, page 3; Appendix C, page 3); Res2 pointed out that because of in-land production of vehicles, the import cost is higher than in other countries like Norway where importing is cheaper because of no inland-production of vehicles (Appendix D, page 14). In countries with inland production of vehicles, they would have a barrier of import, since in-land produced vehicles are cheaper than imported EVs with a taxation added (Appendix D, page 14). A barrier mentioned is the lack of charging infrastructure "*…you want to transport yourself longer distances, there are too few charging stations, and as the electric vehicles are increasing, this is becoming a larger and larger problem*." (Appendix D, page 14), and pointed out that this is not only a problem in the Nordic countries, but also the rest of Europe (Appendix D, page 14).

Electrification models

On the question about the view on the dominance of road transport electrification, Res3 responded that there had recently been launched the first serial production of BEVs. Although, charging initiatives like "electric road", both overhead catenary lines (OCL) and inductive charging, are technically still in the testing phase, and Res3 hasn't seen a real push towards commercialization (Appendix F, page 2). Res3 speculated if it were because of immature technology, or the need for a certain type of investment business model (Appendix F, page 2). There is a need for a clearer advancement of BEVs also in more heavy-duty segments.

On the question: *"How do you see this development till 2030?*" (Appendix E, page 13), Res3 responded that BEVs will be dominating and increasing. There will not be an easy road, there will be more challenges with charging infrastructure. "*I think there will also be a lot of issues with a supply chain around batteries because the future growth is expected to be immense, and it's not always hard to scale efficiently into such big dimensions."* (Appendix F, page 4). Res3 pointed out that the work focus has been on trucks, other technologies would have a role when scaling up, and there could be special cases where hydrogen could be used (Appendix F, page 4).

BEV or FCEV – which technology do you think will be implemented?

On the question of the potential technology to be implemented, Res3 stated that BEVs would most probably be the technology. Res3 further stated that this would make sense in Norway with very green electricity production and a very solid grid compared with other countries. So, it is hard to see the disadvantages of BEVs. But Res3 stated that there is a strong community around the fuel-cell electrical trucks and pointed at an example with ASKO in Trondheim. As one of the first to have FCEVs running. But pointed out that it would be an extreme/special situation where BEVs would have a hard time competing towards 2030 with much better battery and range (Appendix F, page 6).

On battery technology, Res3 thought that BEV will be the dominant technology. Since everything is based on factors like reduced cost and the scaling of production (Appendix F, page 9). Res3 stated that a whole spectrum of applications where you want to have batteries. So, battery technology is very crucial, stated Res3 (Appendix F, page 10). Res3 further elaborated that smart grid systems will be important for Greening the Grid, and that there would be huge potential growth in battery technology, and grid support as smart grid technology (Appendix F, page 10).

Hybrid solutions

On the question of a possible hybrid of BEV and FCEV, Res3 stated this would be a very interesting field of research that still needs research. But for the foreseeable future, BEVs will have this flexibility and ease of access to charge, so they have a stronghold. Battery charging (BEVs) is the one that is advancing fastest and has the strongest hold now (Appendix F, page 5).

Production-related issues

On possible barriers like production-related issues, like a production stop in Taiwan, Res3 stated that a lot of things are driven by economics. If there are initiatives and a market for it, then the technology will come if there are possibilities to make money. But maybe there would be a need to build fabric and industry somewhere else (Appendix F, page 4).

Special cases of BEVs

Res3 stated that battery performance, the topography, and how you're running the vehicles would be essential. And further commented that each country would probably have special segments for assignments (Appendix F, page 7). An example would be assignments like snow clearing in the mountains. This is a special case, and the trucks would need to be special. Res3 stated this would mean a demand for charging infrastructure/megawatt charger in less used areas, and Res3 did not think that would be the reality in 2030, because the bulk part of trucks is driven in predictable patterns and reasonable distances. (Appendix F, page 5).

The battery's reaction to low temperature and arctic climates

On the question if "*…the battery of BEVs because of the harsh climate in Norway, north of Norway, north of Sweden and maybe Finland, or Austria or Germany, where it's quite cold in the winter. How would the BEVs react to this?"* (Appendix F, page 7).

Res3 thought the assumption could be an experience from personal BEVs that could have shorter range in wintertime. Res3 thought the effect would be less significant for trucks than for cars for three reasons. Firstly, Res3 stated that the winter range is quite good for the first serial-produced BEVs. And since the transport companies want a truck that they can rely on, manufacturers will calculate range versus the battery size more closely and look more closely at the variabilities than with a personal BEV (Appendix F, page 7). Secondly, Res3 stated that in the winter, a lot of energy in person BEVs or battery electric buses are used for heating for the benefit of the passenger. In BEV the limited size of the cabin does not need as much energy for heating and more energy is needed to move the truck forward. So, the cold would not mean as much for a BEV (Appendix F, page 7). Thirdly, Res3 mentioned energy management. New trucks have smart energy thermal management of the battery system, and this improves the situation of heating and potential reduced range (Appendix F, page 7).

Charging solutions for logistics hubs with BEVs

Res3 mentioned the example of custom-suited charging systems for companies who could charge at their home-based. Then relevant factors and questions. If the local grid had the capacity: How much power will be needed? The cheapest way to charge: Charging at smaller power outlets during the night since you own the infrastructure, and because fast chargers will be a third-party infrastructure, Res3 thought that it would be more feasible/economical by owning the charging system. But if there are 50 trucks at the logistics hub with the need to change this, could create barriers. Then the demand would require an investment to create a smart charging system (Appendix F, page 11).

Charging infrastructure - System and the need for planning

Res3 mentioned an example related to the need for a charging system and planning. If a truck is driving a certain distance to deliver goods with one planned stop along the way to do the charging. Then realizes; "*I need to add some more charging". Let's say we need 30% more time because we need one more charge, so it is an expense. But it is still too simple to say: "okay, as long as we have enough charging everything is going to be okay*" (Appendix F, page 8). Res3 said it would be a bit more complicated and complex picture and a need for a logistical and costs match (Appendix F, page 8). Res3 stated that it is up to the decision-maker and the logistical planners to make the system of charging points work. The charging stations need to be strategically placed, and the companies need to trust in technology that can deliver their business (Appendix F, page 8).

One standard of charging and charging systems

On the question if an organization like "CharIn", which is working towards standardization, would be crucial Res3 responded: "*Yes, of course, that is very crucial for an efficient scale-up*. "(Appendix F, page 6). Res3 stated the need for new standards for these larger-scale chargers, and that the current standard has the capacity for up to 350 kilowatts. So, for the trucks that need a larger charging effect, larger charging power, and power outtake, there is no standard yet. Res3 thought that this would need to be a global/large region standard.

(Appendix F, page 10). Res3 further stated the importance of a good working charging system and better charging technology for the development of electrification. The question is of course how good/efficient it would be, stated Res3 (Appendix F, page 10).

Potential threats or bottlenecks in the infrastructure expansion

On the question of which potential threats or bottlenecks there would be for such an infrastructure expansion, Res3 mentioned some potential threats. Firstly, if there is no consensus of one standard (charging effect/power) for fast charging (Appendix F, page 11).

Secondly, if there would be a limitation in space utilization and charger location for transport. Urban areas were mentioned as a potential location who would have challenges here (Appendix F, page 11). Thirdly, the capacity of the grid and the transmission lines. Res3 thought this would not be a problem if supporting systems like smart grid systems would be used. Using such a support system could delay the need for improvement on the grid by 10 years.

As Res2 commented, this could lead to a need for better cables, at a local level, to handle the demand of power (Appendix D, page 18).

Res3 states that the lead time for building out the infrastructure of the grid would be substantial, and therefore systems as smart grid systems could smooth the need for development regarding increased demand by transport electrification (Appendix F, page 13). Res3 responded that the development was closely connected to the policy side and questions like; how much we need, and how will the government support smart grid systems and charging infrastructure. Res3 thought that the policies could play a big role to pick up good enough speed and advances on that part (Appendix F, page 15).

4.4 The interrelation between heavy duty vehicle electrification and electricity greening

Effect of heavy-duty electrification on electricity grid

On the question of how the Swedish grid would be affected by the electrification of heavy road freight vehicles (Appendix A, page 5; Appendix C, page 5), Res1 and Res2 brought up it would be difficult to say and would depend on how the charging situation was handled. That issues from large demand could lead to not enough electricity coming through even though there is enough energy produced (Appendix B, page 13; Appendix D, page 18). Res2 later followed up that a smart regime when it comes to vehicle charging would be a possible solution. Both researchers (Res1 and Res2) agreed that there would be a gradual increase in FCEV and BEV, and as long as the grid was invested in to cover the expansion this would not necessarily be a problem (Appendix B, page 13; Appendix D, page 18). And that there is a strong possibility that a hybrid solution would be a future alternative, the combination of hydrogen in FCEV and batteries would be an option (Appendix D, page 8).

Capacity of the grids to handle the demand

On the question: «*Research shows that transport electrification could increase electricity demand. Do you think the Swedish electricity grid can meet this demand?*" (Appendix A, page 5; Appendix C, page 5).

Res1 stated that Sweden had come a long way by participating in several pilot projects on charging infrastructure and electric roads. And that maybe these experiences could smooth out the request for power by the transport sector (Appendix B, page 13). Res2 stated that generally, it would have the capacity for the transport sector. Res2 followed it up by addressing that there could be local limitations with regard to the grid capacity. There would be a need to expand the local grid in some places since there would be a need for cables with larger diameters to handle a larger amount of power, so there would not be overheating (Appendix D, page 18). The transmission grid would need upgrading where there already are industries demanding large amounts of power. Res2 stated that: *"If you come to the Stockholm or Mälardalen region, Västerås, Uppsala, Örebro, and* *so on where we have a lot of industries, we have limitations in power coming into this region."* (Appendix D, page 18).

Potential effects of "electricity greening" on heavy-duty vehicle electrification

On the question of "*What effects do you think greening the grids could have on electrification (I.e., transport electrification) in Europe*?" (Appendix A, page 4; Appendix C, page 4). Res1 stated "*I think that the economical part is higher. So, it could be an indirect effect... if greening the grid would mean cheaper electricity prices, it would be a higher motivation to choose electric vehicles. But I don't think it is a very high direct effect between these two."* (Appendix B, page 6). Res2 stated that from the Swedish perspective, there is quite a lot of trading between southern Sweden and Poland, Germany, and Denmark. So, low wind production results in the price going up, and then other types of energy like natural gas and other sources are used to produce electricity in those countries (Appendix D, page 7) [Transfer capacity]. So, a higher transfer capacity will result in other countries buying as much energy as possible when there is a need for it. And because the energy companies could get a better price by sending the energy to Europe, the cost will also increase for the Nordic countries (Appendix D, page 7). But if there is a lower or no transfer capacity this will decrease the cost in the energy-producing countries. So, from a national perspective, it would be a price positive effect, but for Europe, it would be a price negative effect. Besides economics, it would be an environmental positive effect for Europe to have a cheap renewable alternative when it comes to an energy source (Appendix D, pages 7-8).

On the related question, "[what] *Are the potential positive/negative impacts of the greening of the grid on transport electrification (heavy road freight vehicles) in Europe?"* (Appendix A, page 4; Appendix C, page 4) referring to the EU goal of at least 50% renewable in the electricity energy mix by 2030, Res1 and Res2 responded that there would not be a substantial negative impact from transport electrification (Appendix B, page 7; Appendix D, page 8).

Then commented on uncertain technological elements such as "…*availability of vehicles and batteries and, so on, of course then the relation between a green grid and an electrified* *vehicle/transport park, also heavy road vehicles*" (Appendix B, page 7). Res1 pointed out crucial aspects as (1) a reliable supply of electric trucks for the suppliers and (2) a stable grid for stable charging. The stability of the grid was again commented on with regards to the transition period from non-renewable to renewable energy (Appendix B, page 8).

Res2 had many dimensions to the answer, so it is split up thematically to give a better overview for the reader. Firstly, Res2 directed the answer towards the cooperation between the original equipment manufacturers (OEMs) to push the infrastructure initiative in parts of Europe. "*... Volvo AB, Scania, MAN, and Daimler, are the four major manufacturers of heavy vehicles in Europe. They have agreed with a joint company to build infrastructure in Europe, at least Western Southern Europe, perhaps the whole EU 27. So, and this is said to be both electrical fast charging those type of things as well as hydrogen stations and filling up and so on.*" (Appendix D, page 8). Secondly, Res2 addressed the different engine technology possibilities, especially regarding hydrogen (FCEVs) and BEV: *"So, if you look at Volvo AB, they say for long distance transport, they believe very much in hydrogen, because the batteries will be too big, too heavy, but for short term communication, regional communication then electrical vehicles will be very important for transport of heavy materials and so on"* (Appendix D, page 8). Thirdly, Res2 addressed OCL and stated: *«So, it would be quite feasible, when it comes to long term transport, we need to expand the capacity of these train lines"* (Appendix D, page 8). Fourthly, Res2 addressed the transport and energy possibility with biomass and the resource competition: *«Of course, if you have this, there will be a competition between different types of transport systems. That can be a negative thing, to some extent. If you want to use biomass, there is a limited resource of biomass. We have a lot. Sweden is the country having the most biomass in Europe. And of course, we're looking very much on that. But the question is, should it be used for packing paper? Should it be used as a replacement for plastics? What should it be used for? So, there is a competition on those types of resources"* (Appendix D, page 9).

The electricity grid: large demand in one location

On the question of the capacity of the electricity grids in Europe to handle increased demand as a result of heavy-duty vehicle electrification. Res3 pointed out that currently there are not many trucks. It would depend on how fast the electrification of vehicles would develop since the charging demand of one new vehicle would not demand that much more. If the development is gradual, then in the short term it would not be a barrier with demand for new vehicles and the grid. In the long term, it would not be a problem if the demand is forecasted, and the grid is developed to meet the demand. If the demand is not met then the demand would be a barrier to the future (Appendix F, page 11).

The effect of the Russian invasion of Ukraine

In this next section, questions are referring to the Russian invasion of Ukraine, and how this will affect the two paradigm shifts in Europe. The introduction of the question is cited from interview guide 1 and interview guide 2 found in Appendix A, page 5; Appendix C, page 5.

"*Because of the situation in Ukraine, we need to address this. The energy mix in some European countries (Germany, Italy, etc) is currently heavily influenced by Russian Energy (coal, gas, and oil), and because of the possible unreliability, some countries are looking towards other energy policies. Because of the possible shift of energy policies, we would hope to get your opinion on…*

(1) How could this affect Electricity Greening in Europe?

(Appendix A, page 5; Appendix C, page 5).

Res1 stated that a possible effect would be that large countries like Germany would possibly re-open closed coal plants (Appendix B, page 14). Res1 follow with that this could be an opportunity to invest in alternative energy sources like renewables. But that this would depend on how the different countries would react to possible shortages in gas, coal, and oil. But in whole saw this as "*…a good opportunity to green the grid, if they do it and in the correct way"* (Appendix B, page 14). Res1 pointed out that it is not to benefit from the war, but to try to turn it towards something positive when the public is invested in the change. (Appendix B, page 14). Res2 stated on Europe that through public support and the enabling of the decision-makers we could push towards replacing most of the fossil fuels that is used today (Appendix D, page 21) "*Both by reducing the energy use the heating, demand, those type of things. And when we transfer to electrical* *vehicles and so on, this would also dramatically reduce the need. What we still need is oil for industrial use as a raw material. "(*Appendix D, page 21). Res2 stated that Russia could be a provider of forest material (wood, wood products, biomass), and mentioned that was worth considering. "*And that would have a very much better impact on the world. So, to say. It's still Russia, but it would be much more positive."* (Appendix D, page 21).

5. Discussion

This chapter discusses the findings analysed and presented in chapter 4. The findings from the expert interviews are compared to the findings of the literature survey to determine the agreement and disagreements between the two data collection approaches. The discussion of the findings is categorized under the research questions as presented below.

5.1 Heavy-duty vehicle electrification

On the issue of how heavy-duty vehicle electrification is likely to develop in Europe from 2022 to 2030. Heavy-duty vehicle electrification will develop significantly from 2022 to 2030. This confirms the findings from the literature survey that heavy-duty vehicle electrification will develop at a considerable level from 2022 to 2030 in Europe.

According to the literature survey, the key benefit of vehicle electrification is the decarbonization of road transport. The heavy-duty vehicle sector has the potential to reduce emissions in the European Union (EU) significantly more than the EU's "*Fit for 55*" package and 2030 climate target plan currently anticipated. Because vehicle stock renewal periods are long, and changes require time. Even with very positive growth patterns for new registrations, electrification, for example, will take some time to produce major effects.

According to the International Energy Agency, the transportation sector generates 24 % of direct CO_2 emissions from fuel burning, accounting for a considerable share of worldwide GHG emissions. The majority of the world's people support the Paris Agreement, which aims to keep global warming far below 2 degrees Celsius, preferably 1.5 degrees Celsius, relative to pre-industrial levels. To reach this goal, commercial vehicles, particularly trucks, will need to be electrified as soon as possible.

According to the findings, BEVs will be dominating and will be increasing among other models. There will not be an easy road, there will be more challenges with charging infrastructure. Norway, with very green electricity production and a very solid grid compared with other countries, has a greater chance. Cost reduction and the scaling of production will be the considerable factors. The smart grid systems will be important for charging EVs and there would be huge potential growth in battery technology, and grid support as smart grid technology. However, this is a very interesting field of research that still needs more research. But for the foreseeable future, BEVs will have this flexibility and ease of access to charge, so they have a stronghold. Battery charging (BEVs) is the one that is advancing fastest and has the strongest hold now. The potential drivers that are likely to influence the development of heavy-duty vehicle electrification are discussed below.

5.2 Which are the potential drivers that are likely to influence the development of European heavy-duty vehicle electrification from 2022 to 2030?

The experts pointed out some factors which may influence the development of the European HDVs electrification by 2030, with some confirming the findings of the literature survey. These drivers are discussed in this section.

5.2.1 Decision-makers

The stakeholders are identified as the key drivers by the researchers. The decision-maker is identified as a substantial stakeholder and driver, in Europe and Scandinavia. They have the capacity to control incentives (Subsidizing, CO_2 taxation systems, etc.) and also reduced taxation on EVs. In-land producing countries like Sweden do not import EVs because in-land produced vehicles are more affordable. This confirms the findings of the literature survey that if governments speed up their efforts to meet climate objectives, the EV industry might grow dramatically. Ambitious targets should be set for heavy-duty vehicle electrification. Again, Europe has to push more investments into truck electrification. Also, carbon taxation on fossil fuels has to be intensified to help speed up the electrification of HDVs.

5.2.2 Truck manufacturers

The Truck manufacturing industry is identified as a stakeholder and a driver, in Europe Both findings agree that truck manufacturers in Europe including Scania, Volvo, etc. have a crucial role to play in switching from fossil fuel engines to EVs. The Truck manufacturers need to intensify their efforts to transition from ICEVs to electric trucks.

5.2.3 Battery technology and intermittent supply of energy

According to the findings of the literature survey, the development of battery technologies is also paramount for heavy-duty vehicle electrification by 2030. Batteries with lighter weights and larger storage capacities are prerequisites. The cost of EVs will continue to fall as battery technology and mass manufacturing improve.

According to the findings of the experts, the maturity of technology and the ability to scale up to the market is identified as a driver. Battery technology will be used in a spectrum of things. Very crucial in several sectors, and a huge growth is expected. There needs to trust in battery technology by the customer/companies. The experts stated that elements like the topography of the area and how the vehicle is running would affect the battery. On the question of article climates and the assumption of reduced battery capacity in colder climates, the experts commented that different factors apply to HEV than EV. The cabin is smaller, so less energy is used for heating. New BEV trucks have Smart Energy Thermal management. The manufacturer(s) look closer to variabilities because the HEV will have a higher utilization percentage than EV. Concluded by stating that the winter range for the first serial produced BEV is good.

5.2.4 Charging infrastructure

The charging infrastructure is a very crucial driver and needs to develop alongside EVs to ensure charging security. According to the literature review, drivers associate the comfort of EVs with the availability of charging facilities. This means that they fear running out of power in the middle of a trip with no accessible charging facility.

The experts pointed out the importance of a good working charging system and better charging technology for the development of electrification (Appendix F, page 10). As well as a stable grid for stable charging (Appendix B, page 7). When asked about grid limitations with large charging demand in one area the expert responded the transition to BEV would happen gradually, and as long as the grid was improved and invested in this would not be a problem. Further stated that supportive systems such as Smart Grid Systems would be crucial to delay and smooth the demand for investment since the lead-time of such improvements.

5.2.5 The consensus of a standard

This is an important driver pointed out by the experts which are not present in the literature review of this study. There is a need to build a standard consensus for charging facilities, electric vehicle technologies, and resources.

Charging

The experts pointed to the consensus that one standard would be very crucial. Flexibility and ease of access to charging are crucial (Appendix F, page 5). The bulk part of trucks is driven in predictable patterns and reasonable distances (Appendix F, page 5). So, a charging system must be heavily invested in through logistical strategic match and cost match. Megawatt chargers via organizations like “CharIn” is an example of such an initiative. The experts pointed out the possibility of a custom-suited charging system for companies with day-to-day operations. Companies would rely on the cheapest possibility for charging to stay competitive in the market. So, a consensus on a standard would support a cheaper charging possibility from a public charger and the possibility of scaled-up technology which again would have a lower investment cost.

Electric Vehicle technologies

It is very crucial to a consensus on technology, according to the experts. The experts stated that any switch of energy carrier would make a GHG improvement. Alternative energy carriers like Biofuel, BEV, or FCEV would help reduce emissions from transport. It is very crucial to have a consensus on technology, according to the experts. The experts believed BEVs would be the technology till 2030, and battery technology through BEV would help reduce cost via scaling up the technology. FCEV would come later when mature, and a hybrid solution would be possible. Critical with a reliable supply (Appendix B, page 7).

Resources

There will be a competition between different types of transport systems. Competition for those types of resources can negatively affect (Appendix D, page 9). There is a limitation in space utilization and charger location for transport. So, a consensus on a standard would decrease negative competition for resources as crucial space. On the question of production-related issues, the experts thought as long as there was a demand there would be a supply. That possibly new production facilities would be built by the industry.

However, the findings from both expert interviews and literature review confirm that to achieve the greatest reduction in GHG emissions, EV adoption must be coupled with the decarbonization of electricity generation.

5.3 Electricity greening

Electricity greening is expected to grow significantly in Europe by 2030. According to the findings of the literature review, on the strength of technological know-how, supportive laws, and government goals, Europe has established itself as a center for renewable energy technologies. The continent's goal of reducing greenhouse gas emissions by 55% by 2030 and becoming climate neutral by 2050 necessitates a massive growth in RES. According to the findings of the interviews, Norway and Sweden among other European countries are expected to lead the "electricity greening agenda" since almost all sources of their electricity supply is from renewables. Germany, France and the UK are also expected to make significant progress in switching to renewables by 2030. VRE such as wind energy and solar energy are two renewables that will be mostly developed in Europe.

According to findings from the expert interviews, wind power in Europe will be the most important renewable hydropower for Sweden, hydropower would not be expanded in the next ten years, because it is difficult to do from an environmental perspective. Nuclear would not be expanded for 20 - 25 years since the current capacity was sufficient. Wind power will be expanded if companies are not stopped and blocked by local people. SPV systems are widely used in Sweden already, but a continuing expansion is expected" (Appendix D, page 4). and CHP plants are not expected to expand but are described as crucial in the mission to replace the oil in products like plastic.

5.4 Which potential drivers are likely to influence electricity greening in Europe from 2022 to 2030?

The experts pointed out some factors which may influence electricity greening in the Europe by 2030, with some confirming the findings of the literature survey. These drivers include the decision-maker and public opinion, Financial and technological support systems, and investment in the grid and energy mix, etc.

5.4.1 The decision-maker and public opinion

Just as it is a crucial driver for heavy-duty vehicle electrification, the decision-maker is identified as a substantial stakeholder and driver for electricity greening in Europe.

According to the findings of the literature review, the efforts of policymakers are crucial to the development of green electricity in Europe by 2030. According to the findings of the experts' interviews, for the decision-maker, there is one enabler, and that is public opinion, according to the experts. So, trust in the decision-maker is a driver. The experts stated that, with regards to the energy mix, it was often more of a political question than an economical question. The expert further stated that it would be critical to have it tailored to the topography of each country or the public opinion. So, the decision-maker and the public opinion and traditions of that country is a driving element. The recent change in the EU taxonomy. When asked about the recent change with the inclusion of nuclear energy the experts agreed. Also stated that the crucial time window the climate change needed to be handled in, nuclear energy made sense as an energy alternative to coal, oil, or natural gas.

5.4.2 Financial and technological support systems

As pointed out in the findings of the literature review, Europe has to push more investments into green electricity to help minimize the start-up cost of renewable energy installations. Also, carbon taxation on fossil fuels has to be intensified.

However, the experts confirmed the importance of technological and financial support systems. These are used as tools for the decision-maker. The technological tool is the possibility of better utilization of the grid through smart grid systems. This would "buy" time and delay the demand for grid investments/improvement. The financial tools are (1) subsidization of green energy, (2) penalty-based CO_2 taxation, and (3) incentive-based solutions (Passive income/compensation) for the affected citizens close to RE plants. The experts have mentioned that it is too easy to stop investment in RE plants by the local citizens. These citizens are the voters on who the decision-makers rely. The experts mentioned the possibility of compensation as a passive income for the affected citizens, and not just the landowner.

5.4.3 Infrastructural development

The expert interviewed pointed out one possible driver which is a fully connected European grid that could help enable electricity sharing in Europe. There is connection and energy trading between Southern Sweden, Finland, Poland, Norway, Denmark, and Northern Germany, and these countries have good transmission lines and have a lot of renewables. Northern Germany is part of the North-Europe grid, but the lines from northern Germany to Southern Germany are very poor transmission lines. France has good grids towards Southern Germany and Italy. The connection between France and Spain is poor and very poor between Spain and Portugal.

In Portugal, 100% of the electrical power comes from wind power when it is windy. This energy could be exported, but they have no way to export the wind power (no transmission lines to Spain, or very few.) So, for a fully connected European grid system that can benefit from a large renewable energy mix there must be built new lines between Spain and France, and Spain and Portugal, and also transmission lines to be built from northern Germany and Southern Germany.

5.4.4 Increase in transfer capacity

Scandinavia has hydropower and Portugal has wind. Some countries have higher renewable energy production than others. This could possibly mean a cheap renewable alternative for Europe (Appendix D, pages 7-8). For the energy-producing country, low renewable energy production results in an increase in the price of energy since there is less energy produced. For Europe, which in this example, is the importer of energy this would mean that other cheaper types of energy are used to produce electricity (Appendix D, page 7). For the energy exporter higher transfer capacity results in import countries buying as much energy as possible because it is the cheaper alternative. The price in the exporting country will increase since energy companies could get a better price in Europe. So higher transfer capacity would mean a cost increase for the Nordic countries (Appendix D, page 7).

For the energy exporter lower or no transfer capacity would decrease the cost in the energy-producing countries (Appendix D, page 7). For the energy importing country, this would result in importing other energy sources, which for the example's sake, could be non-renewable. The climate crisis do not see borders. So, a large transfer capacity in Europe has an environmental positive effect. So, the increase in transfer capacity combined with a fully integrated European transmission grid could mean a better utilization of the energy mix and an environmentally positive impact.

On the strength of technological know-how, supportive laws, and government goals, Europe has established itself as a center for renewable energy technologies. The continent's goal of reducing greenhouse gas emissions by 55% by 2030 and becoming climate neutral by 2050 necessitates a massive growth in RES. RES accounted for 37.5% of total electricity consumption in Europe in 2020, up from 34.1% in 2019. This is expected to increase considerably by 2030. Wind, hydro, and nuclear provide the majority of renewable electricity, whilst solar energy is growing at a significant pace.

With wind and solar energy development, variability of RES is seen as the major limitation of renewable energy integration. However, there are several critical drivers that have to be considered to facilitate electricity greening in Europe, including government policies, smart grid technology, stricter taxation on emissions, etc. These drivers are presented below.

The efforts of policymakers are crucial to the development of green electricity in Europe by 2030. Europe has to push more investments into green electricity to help minimize the start-up cost of renewable energy installations. Also, carbon taxation on fossil fuels has to be intensified.

The development of storage technologies is also paramount to managing variable energy sources such as wind and solar. Moreso, smart grid technology and other energy-efficient technologies need to be developed.

5.5 The interrelation between road transport electrification and electricity greening

As already established in the literature, road transport electrification will continue to depend on green electricity to be able to realize its full emission reduction potential. According to the literature survey, heavy-duty vehicle electrification has the potential to develop and reduce emissions significantly by 2030 if the source of electricity is decarbonized at a significant rate. Both findings claim that it's vital to remember that electrification of the transportation sector must be accompanied by grid integration of renewables; otherwise, EVs will be counterproductive, increasing emissions rather than decreasing them. Moreso, there are some similarities in the drivers identified and discussed above. Both the findings of the expert interviews and literature review stated these drivers for both heavy-duty vehicle electrification and electricity greening, including the decision-maker, consensus on technology and standards, and technological and infrastructural development.

However, the interrelation between road transport electrification and electricity greening is paramount if Europe is to achieve its 2030 zero emissions targets.

5.6 The effect of the Russian invasion of Ukraine

Public opinion has changed on a large scale after Russia in 2022 invaded Ukraine. Many things can be said about the atrocities of war. This study seeks to identify the effect the invasion has on electrification of transport, and electricity greening in Europe.

However, according to the findings of the expert interviews, the Russian invasion of Ukraine is a driving force and could make Europe replace most of the fossil fuels it uses today and be independent of Russia in the long term. Not only Russian, but also other authoritarian regimes. Both by reducing the need for energy use, as the heating and production to mention some. However, in the short term, it could cause affected countries such as Germany to reopen its coal plants, which could increase emissions.

5.7 Chapter Summary

Both the two shifts: heavy-duty electrification and electricity greening will develop significantly in the European-Scandinavian region from 2022 to 2030. The drivers that are likely to influence these developments include the decision-maker, consensus on technology and standards, technological and infrastructural development, etc. However, technical shortcomings exist that will demand more research and improvement in the coming years. To stay up with the global competition, knowledge generation must be accelerated, particularly in the transition of technology into reliable and cost-effective items. To attain market success and competitiveness, these prerequisites must be met.

6. Conclusion

This chapter includes a summary of the research as well as the conclusion regarding the research objective(s) and the managerial implications of the findings. In addition, the chapter discusses the study's limitations and suggests future research topics.

6.1 Research summary

The study seeks to determine the potential drivers that are likely to influence the growth of both green electricity and heavy-duty vehicle electrification in Europe-Scandinavia from now (2022) till 2030. By identifying the drivers, it can help to predict how Green Road transport electrification within the period from now (2022) till 2030 will evolve, and which drivers need considerable attention in Europe and Scandinavia when trying to achieve the 2030 goals for the transport sector and energy sector.
The study used a survey method consisting of expert interviews and literature review to acquire perspectives on the research problem which seek to identify drivers and how these affect the development of heavy-duty vehicle electrification and electricity greening by 2030.

The findings of the study show that both the two shifts: heavy-duty electrification and electricity greening will develop significantly in the European-Scandinavian region from 2022 to 2030. The drivers that are likely to influence these developments include the decision-maker, consensus on technology and standards, technological and infrastructural development, etc. However, technical shortcomings exist that will demand more research and improvement in the coming years. To stay up with the global competition, knowledge generation must be accelerated, particularly in the transition of technology into reliable and cost-effective items. To attain market success and competitiveness, these prerequisites must be met.

The findings of this study could serve as a basis for further research specifically for creating plausible scenarios for the development of heavy-duty vehicle electrification and electricity greening in Europe-Scandinavia by 2030.

6.2 Managerial implications

It is expected that the findings of this study will help the auto manufacturers and governments, or policymakers understand the future of transport electrification, electricity greening, and the need to pursue a “green to green paradigm”. The study sheds light on the factors that could affect the development of both transport electrification and electricity greening by 2030. This study further provides insights into the bottlenecks of electricity greening and how these limitations could be minimized going forward. The drivers identified in this study are expected to aid policymakers in their sustainable energy development planning.

6.3 Limitation of the study

Any research project entails several challenges that the researcher may experience while conducting the study. This does not imply that the report is invalid, but it did face some difficulties during the design and data collection processes. The following are the study's limitations:

Firstly, time constraint was a major limitation. The timeframe of this master's thesis prevented us from evaluating additional elements which might have been significant to this study. This study presents a wider and more interesting scope that required extra time to accomplish. Secondly, the experts not showing significant interest in the study was a limitation. We planned to have seven expert interviews but ended up with three instead. The effect of this was offset by the literature survey which provided us with relatively significant secondary data.

6.4 Suggestions for further research

This section shows the area(s) that provide prospects for further investigation so that other researchers and readers can evaluate the quality and future value of this work. This research seeks to identify if the benefits of heavy-duty vehicle electrification could be affected by the limitations in the provision of green electricity in Europe by 2030, could be the benchmark in other continents and at different time scopes such as 2040 or 2050. This study could serve as a basis for further research specifically for creating plausible scenarios for the development of heavy-duty vehicle electrification and electricity greening in Europe-Scandinavia by 2030.

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Appendix

A. Interview guide 1

Interview guide for the exploratory interviews - Electricity greening

Guide for exploratory interviews

(The following information is to be read by the interviewer to the respondent before the core interview starts, and/or shared with the respondent in written form before the interview)

> Start recording

The purpose of this interview

This interview is one of a series of interviews with a focus on the electrification of Heavy goods road vehicles, and the greening of the energy grid. It will focus on Europe with Sweden as a special case. Our goal is to use the information provided and these interviews to develop a set of scenarios that scope till 2030.

Definitions of keywords

- By "Electricity greening" we mean replacing the sources of electricity production with renewables (including nuclear energy).
- By "Heavy road freight vehicles" we refer to goods vehicles with a gross vehicle weight rate (GVWR) above 3 500 kg, designed, exclusively or primarily, to carry goods; including road tractors and agricultural tractors which are permitted to use roads open to public traffic.
- And lastly, "Zero-tailpipe-emission transport electrification" is the concise name for both transport electrification (road transport) and electricity greening.

Procedure and anonymity

This interview will be recorded in an audio file and a written version (transcript) will subsequently be produced based on this audio file. The transcript will be e-mailed to you for verification and corrections. After the final version of the transcript is agreed upon by the interviewer and the respondent, the audio file will be deleted. The transcript will be used in the project as background for developing the project, as input and reference for academic publications, and as an attachment to our Master's thesis. The transcript will not contain the name of the respondent or the name of the company he or she represents, however, the background information about the respondent and the company will be included in the transcript and when making references to the interview in research reports and papers. When reviewing the transcript, the respondent should also make sure the way the respondent and the focal firm are described, is acceptable.

Start of core interview*

*In the interview we asked for the contact information of the researcher, this is taken out.

<u>The interviewer states:</u> "This is a semi-structured interview. This means that we do have a "checklist" of topics and questions that we want to cover, but also that you as a respondent should feel free to bring any other relevant information to the table at any time."

Structure of interview questions

The questions have been structured into three categories as listed below:

1. Clarification of the expertise and job role of the expert
2. General perspective on "Electricity Greening" in the European setting
3. Specific perspective on "Electricity Greening" in the Swedish setting

Under these categories, there are main and sub-questions. The main questions present the objectives of this interview, whilst the sub-questions provide a checklist to serve as a guide, they need not be followed strictly.

Clarification of the expertise and job role of the expert

1) Could you please describe your field of work, and in particular explain how it is related to "Electricity Greening"?

2) Could you please describe your role, and your background related to "Electricity Greening"?

3) Do you take an active part in an aspect of "Electricity Greening"?

4) To what extent are you informed about "Electricity Greening"?

General perspective on transport electrification in the European setting

Based on your experience, what is/are your perspectives on "Electricity Greening" in the European setting?

5) Do you believe that "Electricity Greening" could help minimize emissions (i.e. GHG emission) in Europe? If yes, how?

6) Which renewable energy sources do you think are most-likely to constitute the renewable energy mix for Europe in their quest to green their electricity grids? and why?

7) Which are the main benefits/potentials of "Electricity Greening" for Europe?

8) Which are the main challenges or bottlenecks of "Electricity Greening" for Europe?

9) Which are the potential consequences of "Electricity Greening" for Europe?

10) What effects do you think greening the grids could have on electrification (I.e. transport electrification) in Europe?

11) The European Union has agreed on the goal that "Renewables should constitute at least 50% of the electricity generation mix by 2030"(IEA, 2020: European Union 2020. Energy Policy Review. Page 127). What do you think…

a) *Are the potential positive impacts of the greening of the grid on transport electrification (heavy road freight vehicles) in Europe?*

b) *Are the negative impacts of the greening of the grid on the transport electrification (heavy road freight vehicles) in Europe?*

c) *Could greening of the grid jeopardize the benefits of transport electrification (heavy road freight vehicles)? If yes, how?*

12) Which other factors should be considered when addressing or persuing "Electricity Greening" for Europe?

13) Which are the main actors or stakeholders to help in "Electricity Greening" in Europe?

14) Which of the European countries do you think to stand the greater chance of leading the "Electricity Greening" in Europe by 2030? and why?

Specific perspective on transport electrification in the Swedish setting

Considering the energy and transport system of Sweden, which are your perspectives on "Electricity Greening" in Sweden:

15) The Swedish government has a target to reduce transport emissions by 70% by 2030 (Swedish Climate Policy Framework).

    a) Do you believe that "Electricity Greening" could help Sweden minimize the country's transport emissions (i.e GHG emissions)? If yes, how?

    b) How do you think "Electricity Greening" could help achieve this target?

16) What are the most critical factors for the progress of "Electricity Greening" in Sweden?

17) Which of these renewables (hydro, nuclear, solar, wind others) would be the best option(s) for Sweden, and why?

18) Which are the key stakeholders (i.e Government, electricity sector, other stakeholders), and what is/are their roles in the "Electricity Greening" in Sweden?

19) Which are the strength and weaknesses of Sweden in their quest to "Electricity Greening"?

20) What are the potential challenges or bottlenecks for Sweden in their quest to "Electricity Greening"?

Heavy road freight vehicles electrification in Sweden

21) To what extent do you think the electricity grid of Sweden will be affected by the heavy road freight vehicles electrification?

22) Research shows that transport electrification could increase electricity demand. Do you think the Swedish electricity grid has the capacity to meet this demand?

23) Does the Swedish electricity grid pose any challenge to the electrification of heavy road freight vehicles? why yes?/ why not?

Because of the situation in Ukraine, we need to address this. The energy mix in some European countries (Germany, Italy, etc) is currently heavily influenced by Russian Energy (coal, gas, and oil), and because of the possible unreliability, some countries are looking towards other energy policies. Because of the possible shift of energy policies, we would hope to get your opinion on…

24) How could this affect the Electricity Greening in Europe?

25) How could this affect the Electricity Greening in Sweden?

(> Stop recording)

B. Interview transcription 1 – Respondent no 1

Research field/ Research background: Energy, Energy systems and renewable energy

Date: 15.03

Duration: 55:25

Interview guide: A – Interview guide 1

--- Start of interview ---

Interviewer:

We are going to divide up the interview, with who are going to ask the questions. But I will start. Are you properly provided with by the structure of the interview, are you compliant in participating in this interview, and things like that?

Researcher:

Yes. Yes, I'm fine with that.

Interviewer:

Beautiful. If the definitions of the key words, I guess you have read through them, and the scope are clear. If there isn't any questions about 'procedure and anonymity' we can just start with the first questions. This is by the way our first interview, so we'll be glad to have some feedback so we can be better prepared for the next interview. We will fill in the information and then you will get a chance to confirm that it is correct when you get the transcript So, this is a semi structured interview, so we have checklist of topics and questions that we need to cover. But if you as a respondent you should feel free to bring up any relevant information or... anything that you would feel would give anything/something to the thesis. So, this interview is categorized in three parts. First, we will ask you a couple of questions about your expertise and role, and then about the European perspective on electricity greening, and then the Swedish perspective. You might have noticed that we switched the perspective from Germany till Sweden. And that's because we really struggled with getting in touch with Deutsch researchers. Therefore, we picked Sweden. But we are still keeping the European perspective, and we are keeping up with changes that the war may have created, and the energy crisis that is happening there. So, we are looking at the European perspective and the Scandinavian perspective. And that would still be exciting, we hope

So, could you describe you field of work, and in particular explain how it is related to ‘Electricity greening’?

Researcher:
Yeh. Eh I can do that. I work as a research scientist at SINTEF ENERGY Research, and I have been at SINTEF for 14 years. And of those years I have mostly been working with transport research, but in the later years the electrification of the transport sector has become more and more important, so I work quite a lot with that. And then specifically with the interface between the transport system and the energy system, which is the charging infrastructure. But I have also worked a bit with hydrogen as an energy carrier in transport as well. I recently switched department, within SINTEF, and now I work within a department called ‘Energy systems. So, I work a bit more with people who are experts on energy system, Electricity grid and renewables. And this is highly related to ‘Electricity greening’, I guess. Because of the role that the transport sector has on the future. Especially if the transport sector is electrified or has a larger share of hydrogen. This will have a large impact on the electricity production, the grid, and how it is operated since there will be a more unpredictable energy demand then what we have today. So, this will take a toll on the electricity grid as a whole, but how the electricity is produced will affect the “greenness” of the transport sector.

Interviewer:
I think you checked of plenty of questions there. So I’ll just run through them.

Researcher:
heh, I might.

Interviewer:
No worries, that’s a good thing.

Interviewer:
“Could you please describe your role, and your background related to ‘Electricity greening’?”. I think maybe that question is sufficiently done. Ehm…

Researcher:

I can say something about my role, because being a research scientist we don't have an active part in the decisions and so on. We mainly provide knowledge, advice, and so on, and do particular assignments for the people who are actually in charge, who do take decisions with both the grid and also incentives for the transport sector ect.

Interviewer:

Nice. Do you have any comment on the last two questions? Do you take an active part in an aspect of electricity greening? And to what extent are you informed about electricity greening? I feel that you have answered them a bit before, but do you have a additional comments or anything to add?

Researcher:

I think that this is the first time I have heard about the term Electricity Greening, so it's a bit new to me. But I understand what it means based on your definition. But it is an important foundation for everything we do. So, I mentioned the transport sector and how the production of electricity will affect how green the transport will be, and battery electrical vehicles and so one. Because if the electricity is produced in a coal plant the whole life cycle calculation because different, when comparing to hydro power for example. I guess that's how we take an active part because it is a important context of everything we do.

Interviewer:

My college will continue with some of the questions. We try to divide up the questions. So, I'll just scroll down to the questions, and mute myself.

Interviewer:

I'll take over from here, and I'm going to ask the questions about the general perspective on transport electrification in the European setting. So based on your experience, what is you perspectives on 'Electricity greening' in Europe.

So, the first question is, do you believe that 'Electricity greening' could help minimize emissions (i.e GHG emissions) in Europe. If you answer is yes, how would this be possible?

Researcher:

I think that my answer is Yes, and ill try to explain why. Because this is a quite a complex question or a complex system when you talk about the European setting. Because each country is different in terms of how they produce electricity. We have for example Germany that has actively reduced the number of coal plants and also have reduced the number of nuclear plants and relied on Russian gas maybe too much. Then we have France who that have a lot of nuclear power, and all the way up to Norway where almost all production is green in terms of renewables. Regarding transport, Its like I mentioned, that the source of the power is quite important when we look at the greenhouse gas emissions. And I think we need to separate the actual consumption of energy in the vehicle and the production of energy. It doesn’t necessarily contribute in the right direction. There is a large push towards a electrification of the transport sector, and in general this will help the transport sector become more efficient, because the efficiency of electrical motors compared to the combustion engines. But then there is the question of; if the energy is produced by non-renewables, one could argue what’s the point? But looking into the future, I guess everyone is planning to build more renewables. More solar, more wind power, more hydro. So, yeh. I think everything is going in that direction. And this will of course help reduce greenhouse gas emissions directly, both in transport consumption part and also the production part.

Interviewer:

Okay, that’s nice. But..

Researcher:

I think I might answered many of these questions now but yeh.

Interviewer:

Probably yeah. If necessarily we will skip some of the questions. Ehm but we will like to know the energy mix. Do you know of energy sources that collectively that will constitute the renewable energy mix if they are going to green their grids? Which RE sources do you think will stand the greater change of dominating the energy mix in the future?

Researcher:

Its really not easy to answer this question because really nobody knows. Its more of a political question than a technical or also economical. As I mentioned with Germany and

France, and the public opinion towards nuclear, for example, which is highly different large opposition in Germany and not as large in France. But I thnk that there is not a single one tech that would be the winner, but I think there will be a mix of everything that would be the most likely. So, a mix of nuclear energy, solar, wind, hydro, maybe more tailored to the theography of each country or the public opinion. And then there is other factors like the war going on in Ukraine. I noticed that you had some questions about that later but there is also the price of solar panels, tech development, battery development, there a lot of uncertainties for several technologies. So, yeah. I guess the answer it will be a mix. That will be most likely.

Interviewer:
Okay, in understand. We know that greening the grid will help reduce emissions, but we want to know what Europe has to gain by greening its grids?

Researcher:
I guess that the main benefit is the greenhouse gas reduction. Of course, there is some other benefits. Especially talking about the grid quality. But I have to mention that this is not my field of expertise. But when looking at the stability of the green with regard to voltage quality, stability, probability of blackouts and so on. Then it is feasible to have a mix of different sources, and not rely for example only solar. But u have a combination of several energy sources. This might help increase the quality of the grid as well. I think that this is only speculation from my side.

Interviewer:
Okay. So, we also want to know what challenges that Europe might face. Are there any bottlenecks of greening the grid in Europe?

Researcher:
One obvious thing is investment cost of investing in renewable energy sources. Which it is a cost, but also the public opinion of nuclear, windmills and also the demand for large areas for solar power and so on. And also that other sources that is green might be cheaper.

Interviewer:

We can not see the investment cost in financial times(?). We also want to know if there are consequences of greening the grid, if we can separate from the challenges that we just mentioned, are there any implications that Europe stand to face by greening their grids?

Researcher:

No sure if I can contribute with anything. But there might financial impact on the work marked. More jobs for people working with these energy sources. But then again I am not sure if this will create more workplaces or less when switching from energy source to another. But it could be.

Interviewer: Okay

Researcher:

I am not sure that is what you meant by consequences, or maybe you have some other examples?

Interviewer:

I think that we are okay with what you just said, yeah. So, I will carry on to the next question. We are heading towards transport electrification in relation to electrification greening in Europe. So, this is basically a generally question asking if greening the grid in Europe will influence transport electrification, or electrification in general specifically transport electrification in Europe. What do you think are the effects?

Researcher:

Do you mean if greening the grid will impact the pace of the electrification?

Interviewer:

Yeah.

Researcher:

I'm not sure if there is a connection there. Of course, if you green the, or if you have a green energy source then it might be that people think that by buying an electrical vehicle it will be green, then if it got power from a coal plant. But I'm not sure if that this is the reason why people choose electrical vehicles. Some people will have this as motivation but when considering the population as whole I don’t think that this is the most important part for choosing electric vehicles. I think that the economical part is higher. So, it could be a indirect effect... if greening the grid would mean cheaper electricity prices, it would be a higher motivation to choose electric vehicles. But I don’t think it is a very high direct effect between these two.

Interviewer:
Alright. We have some..yup. We want to know the European union has agreed on the goal that “Renewables should constitute at least 50% of the electricity generation mix by 2030”. We want to know that you think in terms of the positive impact of greening the heavy road freight vehicles. I think you touch upon that, but we want to know if there are any other ideas also. We want to know what/ if it have any negative impact on it. Yeh, that is what we want to know.

Researcher:
yeh. If I can take the question b first (*Are there negative impact of the greening of the grid on the transport electrification (heavy road freight transport) in Europe?)* I can’t see an negative impact from transport electrification. But the positive is ehm... I’m not really sure if there are any more in general, as I answered on the last question but for heavy road freight vehicle is a more uncertain segment related to other things like availability to vehicles and batteries and, so on, of course then the relation between a green grid and an electrified vehicle/transport park, also heavy road vehicles. Yeh. I am not sure if I have anything to add, but maybe you could sort of rephase the first question.

Interviewer: Probably I will go into my details. We know that the renewable energy sources like solar specifically is seasonal, so we don’t have it all the time so there is fluctuation regarding supply for the renewable energy. So, we kind of anticipated that if we are planning to green our grids we are not going to have a smooth supply of this energy that have a negative impact on the... cause we know that electrifying the transport will increase the amount for electricity, if we though of that correctly. So, if demand increase from the consumption side, and the supply site is “not stable” because of the challenges that we face in renewable energy that we know now, that it have any negative impacts?

Researcher:

Okay. Of course. If the supply is unstable, it will be hard to convince people to buy electric trucks. Ehm if we assume that the grid will be unstable, or the power source will be unstable so that might be a negative impact but then we can investigate how likely this it is that it would happen. If the European government will accept that the grid is unstable and what they will do to compensate for this. There will be a transition period that is important. On the way from today's power system / power network system to our future green grid there will be a transition period were the number of renewables increase, and non-renewables decrease, and im not sure if we can assume that this will be a stable or non-stable, or if we can expect a non-stable grid because of this. Because I think that it will be an extreme situation if we only rely on solar. Then something needs to happen. I do not think it will be very likely that that will happen.

Interviewer:

Okay. We would like to know at this point, in terms of Europe is greening its grid are there any important factors worth considering?

Researcher:

hmm other factors... I think we have mentioned quite a few. But... Yeh I am not sure if anything else is worth mentioning regarding this... yeh.

Interviewer: Then we should move on to the next question then. We want to know which are the main stakeholder, or who are the main actors in greening the grid in Europe? If there is any.

Researcher:

The most important once are the people in charge. I think the politicians that take decisions that can change the framework (in terms of economic framework), subsidies, and taxes, and so on. When it comes to the point the economical factors are the most important, that is what people take decisions by. Whether it might be the once that build powerplants, invest in renewables, and set the prices for electricity or other energy sources, then the economical factors are important. A lot of these are decided by the politicians in terms of taxes and/or subsidies. So, I think these are the main stakeholders. But there are also others of course like the industry, as I mentioned. But also the.. well the industry and the production side, but also the demand side. But also, the other demand groups like transportation for example.

Interviewer:
When you say the industry, I guess that you mean the electricity sector?’

Researcher:
Yes. That what I meant.

Interviewer:
Okay. So, the last question here will be ‘which of the European countries do you think to stand the greater chance of leading the ‘Electricity greening’ in Europe by 2030? If you have any assumption or what do you think about that?

Researchers:
It really depends on what you mean by leading. But if you look at the energy production in Norway, also all energy production is already renewable. It won’t be the one who take lead because of its special geography but I think that the large countries have a large change of lead this; like Germany, France, and the UK maybe. The big countries. If they can get this to work, they can of course be good example for the others and also be a good push for other countries that try to follow them. So, I think that they will be the best candidate for this. Because of their size, or the potential they have in actually reducing the number of coal plants for example.

Interviewer:
Okay. Thank you. At this point my college will take the reminder of the questions.

Interviewer:
Okay, here we go. Now we have the specific perspective on transport electrification in the Swedish setting. So, considering the energy and transport systems of Sweden, which are your perspective on “Electricity greening” in Sweden. The Swedish government has set a target to reduce transport emissions by 70% by 2030. Do you believe the “Electricity greening” could help Sweden minimize the country’s transport emissions (i.e. GHG

emissions)? It’s pretty much the same questions as the European questions from earlier just in the Swedish perspective. If yes, how?

Researcher:

I guess that the same answers and mechanisms applies for Sweden as for Europe. Then again, I am not really an expert on Sweden, but I think they are close enough to relate to the problems in Sweden to the problems in Norway. But it depends on the transport sector, and the number of electric vehicles. If there is a large transition to electric vehicles, then ofc the produced energy is green it will help reduce the amount of transport emissions. But then again it is difficult to look at it isolated in a Swedish context because of the European power market and the interactions regarding electricity. Yeh it could be yes, but It depends on how the neighbouring countries produce electricity and the amount of electric vehicles in that country.

Interviewer:

How do you think “Electricity greening” could help achieve this target?

Researcher:

The target of reducing transport emissions? Well, again, I think that the main way of achieving this target is to switch into other energy carriers in transport sector. Whether it is biofuels or hydrogen or battery electric vehicles, by doing this it will help to achieve the target. But it might not be very, very good for searching to battery electric vehicles if all the power is produced by non-renewables. So, then electricity grading Well, of course, to achieve this

Interviewer:

Alright, on to next one, what are the most critical factors for the progress of electricity grading in Sweden?

Researcher:

I'm not sure if I can give a good answer for this. Because I don't know enough about the about the power system and Sweden to really give a good answer on this. I'm sorry.

Interviewer:

That's an honest answer. And it's better to answer like that way, then to give poor speculations, I guess we'll turn to the next question.

Which are the these which of these renewable energy (Hydro, nuclear, solar, wind etc) would be best will be the best option for Sweden? And why? I think you get maybe related to Norway, or maybe Scandinavia and as a whole. Yeah, do you have any speculations there? Or?

Researcher:

Yeah, it depends on what you mean by best, but in terms of negative consequences, its negative consequences with all. But if you look at the way the nature is affected, for example, then it might not be best to invest in windmill parks that demand large areas or parks, or even hydro, because they will affect the nature.

If you look at the risks for the population, then nuclear might not be the best. Because there is a small risk of incidents at nuclear plants. And then there's other aspects like the economical, which is the cheapest, the most expensive. So, it's, it's kind of difficult to give one answer to what's the best. I think it's a very complex question. We have several aspects. So, it's difficult to really single out one specific (renewable energy source).

Interviewer:

Yeah, yeah. Yeah. Which are the key stakeholders, and what are the roles in the electricity greening in Sweden?

Researcher:

Yeah, I think that this will be the same as for Europe. The politicians are of course quite relevant as an answer to this question, as representatives for the public opinion. I think that I would probably answer the same for Sweden as for Europe

Interviewer:

That is reasonable. Which are strengths and weaknesses of Sweden in this quest to electricity greening?

Researcher:

Yeah. Again, I'm not sure if I have a good answer for this.

It might be that I have a tradition for renewables already, for hydro and nuclear, and they have some experience with it, and can use this in the future as well. I'm not sure if I have anything else to say on this.

Interviewer:

That's, that's fine. Maybe it's a bit of the same question. But what are the possible challenges and bottlenecks for Sweden in this quest?

Researcher:

Yeah. I guess this is quite similar to the other questions about Sweden and know what to talk about, but it's a way of finding out what the best for Sweden in terms of financial investments, public opinion, and so one. I guess these are the most important challenges in general, but also for Sweden.

Interviewer:

Yeah. So, you could say that different countries, even though it's in Scandinavia or in Europe, will kind of have the same challenges with introducing new energy as a whole?

Researcher:

Not necessarily. There might be there is a different political situation in Sweden, it might affect this. But not sure if the differences are that large that will be like a special situation for the Nordics. But if we relate to Norway, for example, then there's a higher level of trust Norway and the Scandinavian countries to to the government, so that but this is more like benefit, not challenge. Like it's more like a facilitator.

Interviewer:

Nice. Now we'll just move on to a couple of questions about heavy road freight vehicles electrification, and then some questions about the current energy crisis and the ongoing war. And that's about it.

So, to what extent extent do you think the electricity grid of Sweden will be affected by the heavy road freight vehicle electrification?

Researcher:

So, if we assume that that the whole vehicle park / transport park will be electrified, then I guess there will be a substantial demand for electricity. I guess that the ratio between energy demand and transport and energy demand in total is roughly the same in Norway and Sweden. So, it's it, I guess it will be a significant higher number, but it's very difficult to say how the grid will be affected.

It depends on how the charging situation will be handled for example. And it might not be that the total energy demand is the restricting issue, but more like the demand for power or the situation where everyone will charge at the same time, and that you don't have enough power in the grid, even though we have enough energy. So, this might require some heavy investment in grid in order to supply power for everyone charging their vehicles.

Interviewer:

Okay, so the peaking of when we use energy at the same time will kind of be the challenge. But smart systems, technologies like that could possibly help maybe?

Researcher:

Yeh. It could be more controlled or smart regime for charging vehicles. I guess this needs to be in place if all the vehicles will suddenly switch to battery electric vehicles. Because the amount of power needed this is too high to handle in the current grid. It's not distributed over the day.

Interviewer:

That's moves smoothly along to the next question that I think you might have already responded to. But do you think Sweden has the capacity to meet this demand?

Researcher:

Yeah, us there's a special situation in Sweden because they have come a long way in terms of building electric roads. They have, for example, several pilot projects around Sweden, where they put the charging infrastructure in the Road infrastructure. So, you can have dynamic charging, to charge when you drive. And this, this might be a way to smooth out the request for power from the transport sector. So that might be a special situation for Sweden.

Interviewer:

Does Swedish electricity grid post any challenges to the electrification of Heavy Road freight vehicles?

Researcher:

Yeah, I, um, I don't have any detail knowledge about Swedish grid. But my guess is that the main challenge is bottlenecks in terms of charging points and transformation stations, and that they are not many enough of them and not equipped to handle a large power peaks. But that's just estimated guess from my side.

Interviewer:

That that's still good. We're going to fill in with some Swedish researcher knowledge on the same topic later. So, we can move on to the most relevant thing. Personally, I think this is really exciting, but yes, because of the situation in Europe we need to address this. The energy mix in some European countries (Germany, Italy and others) are currently heavily influenced by Russian energy (coal, gas and oil) and because of the possible reliability, some countries are looking forward to other energy policies, and because of the possible shift of energy policies, we hoped to get your opinion on how this could affect the electricity greening in Europe?

Researcher:

Yeah, good to affect this in many ways. If for example the large countries like Germany, that has closed down a lot of coal plants, now will start to reopen them then this will affect it in a negative way.

But if they on the other hand, see this as a opportunity/possibility to invest in renewables then this will have a positive effect. So, it I guess it depends on how countries will react to shortage in gas, coal and oil. So, I guess it's, it's a good opportunity to green the grid, if they do it and in the correct way.

I guess that this, this is the same in Europe, as in Sweden. I'm not sure if I can specify anything for Sweden, but it should be a good opportunity to start or do this transition with the public opinion in our/their backs. So yeah, by sort of not using the war as in their advantage but using the opportunity.

Because if if there was no shortage in natural gas, then I guess it will be hard to convince the public opinion to invest in renewables. Now, I haven't an extra motivation to do this. So, in that sense, it might be positive, but of course, there's nothing positive about the war itself.

Interviewer:
Yeah. That's completely true. Yeah, I can agree there. But as we talked about earlier, the public opinion and getting the political forces and economical forces on their side regarding investments, building large projects. I think maybe there is an opportunity now. Because I think nobody wants to rely on Russia right now..maybe. Um, do you have anything else that we could have done with our planned questions? Do you have any reflections and things to add to the topic of the interview?

Researcher:
I can't think of anything from top of my head, but no, I think we've been through all the relevant issues.

Interviewer:
Yeah. Nice, I then I think we can stop the transcription there. Thank you!

--- End of interview ---

C. Interview guide 2

Interview guide for the exploratory interviews

Electricity greening

Guide for exploratory interviews

(The following information is to be read by the interviewer to the respondent before the core interview starts, and/or shared with the respondent in written form before the interview)

> Start recording

The purpose of this interview

This interview is one of a series of interviews with a focus on the electrification of Heavy goods road vehicles, and the greening of the energy grid. It will focus on Europe with Sweden as a special case. Our goal is to use the information provided and these interviews to develop a set of scenarios that scope till 2030.

Definitions of keywords

- By "Electricity greening" we mean replacing the sources of electricity production with renewables (including nuclear energy).
- By "Heavy road freight vehicles" we refer to goods vehicles with a gross vehicle weight rate (GVWR) above 3 500 kg, designed, exclusively or primarily, to carry goods; including road tractors and agricultural tractors which are permitted to use roads open to public traffic.
- And lastly, "Zero-tailpipe-emission transport electrification" is the concise name for both transport electrification (road transport) and electricity greening.

Procedure and anonymity

This interview will be recorded in an audio file and a written version (transcript) will subsequently be produced based on this audio file. The transcript will be e-mailed to you for verification and corrections. After the final version of the transcript is agreed upon by the interviewer and the respondent, the audio file will be deleted. The transcript will be used in the project as background for developing the project, as input and reference for academic publications, and as an attachment to our Master's thesis. The transcript will not contain the name of the respondent or the name of the company he or she represents, however, the background information about the respondent and the company will be included in the transcript and when making references to the interview in research reports and papers. When reviewing the transcript, the respondent should also make sure the way the respondent and the focal firm are described, is acceptable.

Start of core interview*

*In the interview we asked for the contact information of the researcher, this is taken out.

The interviewer states

This is a semi-structured interview. This means that we do have a "checklist" of topics and questions that we want to cover, but also that you as a respondent should feel free to bring any other relevant information to the table at any time.

Structure of interview questions

The questions have been structured into three categories as listed below:

1. Clarification of the expertise and job role of the expert
2. General perspective on "Electricity Greening" in the European setting
3. Specific perspective on "Electricity Greening" in the Swedish setting

Under these categories, there are main and sub-questions. The main questions present the objectives of this interview, whilst the sub-questions provide a checklist to serve as a guide, they need not be followed strictly.

Clarification of the expertise and job role of the expert

1) Could you please describe your field of work, and in particular explain how it is related to “Electricity Greening”?

2) Could you please describe your role, and your background related to “Electricity Greening”?

3) Do you take an active part in an aspect of “Electricity Greening”?

4) To what extent are you informed about “Electricity Greening”?

General perspective on transport electrification in the European setting

Based on your experience, what is/are your perspectives on “Electricity Greening” in the European setting?

5) Do you believe that “Electricity Greening” could help minimize emissions (i.e. GHG emission) in Europe? If yes, how?

6) Which renewable energy sources do you think are most-likely to constitute the renewable energy mix for Europe in their quest to green their electricity grids? and why?

7) Which are the main benefits/potentials of “Electricity Greening” for Europe?

8) Which are the main challenges or bottlenecks of “Electricity Greening” for Europe?

9) Which are the potential consequences of “Electricity Greening” for Europe?

10) What effects do you think greening the grids could have on electrification (I.e. transport electrification) in Europe?

11) The European Union has agreed on the goal that “Renewables should constitute at least 50% of the electricity generation mix by 2030”(IEA, 2020: European Union 2020. Energy Policy Review. Page 127). What do you think…

a) Are the potential positive impacts of the greening of the grid on transport electrification (heavy road freight vehicles) in Europe?

b) Are the negative impacts of the greening of the grid on the transport electrification (heavy road freight vehicles) in Europe?

c) Could greening of the grid jeopardize the benefits of transport electrification (heavy road freight vehicles)? If yes, how?

12) Which other factors should be considered when addressing or persuing “Electricity Greening” for Europe?

13) Which are the main actors or stakeholders to help in “Electricity Greening” in Europe

14) Which of the European countries do you think to stand the greater chance of leading the “Electricity Greening” in Europe by 2030? and why?

Specific perspective on transport electrification in the Swedish setting

Considering the energy and transport system of Sweden, which are your perspectives on “Electricity Greening” in Sweden:

15) The Swedish government has a target to reduce transport emissions by 70% by 2030 (Swedish Climate Policy Framework).

    a) Do you believe that “Electricity Greening” could help Sweden minimize the country's transport emissions (i.e GHG emissions)? If yes, how?

    b) How do you think “Electricity Greening” could help achieve this target?

16) What are the most critical factors for the progress of “Electricity Greening” in Sweden?

17) Which of these renewables (hydro, nuclear, solar, wind others) would be the best option(s) for Sweden, and why?

18) Which are the key stakeholders (i.e Government, electricity sector, other stakeholders), and what is/are their roles in the “Electricity Greening” in Sweden?

19) Which are the strength and weaknesses of Sweden in their quest to “Electricity Greening”?

20) What are the potential challenges or bottlenecks for Sweden in their quest to “Electricity Greening”?

Heavy road freight vehicles electrification in Sweden

21) To what extent do you think the electricity grid of Sweden will be affected by the heavy road freight vehicles electrification?

22) Research shows that transport electrification could increase electricity demand. Do you think the Swedish electricity grid has the capacity to meet this demand?

23) Does the Swedish electricity grid pose any challenge to the electrification of heavy road freight vehicles? why yes?/ why not?

Because of the situation in Ukraine, we need to address this. The energy mix in some European countries (Germany, Italy, etc) is currently heavily influenced by Russian Energy (coal, gas, and oil), and because of the possible unreliability, some countries are looking towards other energy policies. Because of the possible shift of energy policies, we would hope to get your opinion on…

24) How could this affect the Electricity Greening in Europe?

25) How could this affect the Electricity Greening in Sweden?

(> Stop recording)

D. Interview transcription 2 – Respondent no 2

Research field/ Research background: Energy, power generation, and transport

Date: 30.03.2022

Duration: 1:16:08

Interview guide: C. Interview guide 2

--- Start of interview ---

Interviewer:

Firstly, we need that you give us your permission to use this information, we're going to anonymize it. And we're going to get the recording transcribed and then send it back, so you can look through it. Then delete some, or add some, and the usual procedure. but we just need that you say it is okay at the start of the interview.

Researcher:

Yeah, it is okay

Interviewer:

Okay, thank you. Yes, as you might have seen, the structure of the interview is: First we're going to look at your role and your job as expert, and then the general perspective of electricity greening in the European setting, and then electricity greening in the Swedish setting. And this is a semi structured interview with a open ended questions. So, the questions is pretty general. So, if you want to elaborate or answer questions from us during the interview, that would be really great. So, then we might just start. Could you describe your field of work? And in particular, how it's related to electricity grading?

Researcher:

Yes. So, what I can say is, I'm a professor in energy engineering. And as far as I have understood here, I've been working with a quite broad field with relation to anything from processing industries, power plants, those types of things, but also transport very much around trains and construction equipment and those type of machineries. Which is why we are coming into this electricity greening quite a lot in relation to transport, but also when it comes to the power supply in different ways. I have been Research Leader, or research director, for this activity within Malardalen University since year 2000, until 2018, when another lady took over this role, so now I am what is called a senior professor. Which is when you're passing 65 years old.

Interviewer:

I think he might have answered question one and question two. So, then we'll just move on to question three. Do you take an active part in the aspects of electricity?

Researcher:

Yes, very much. Both when it comes to the production of electricity, but very much also the use of this electricity like in battery. In the trains, and construction equipment and heavy transport. Those are the areas where we have been mostly working with this.

Interviewer:

That's awesome. Then I feel that you might have taken question four as well. So, then we can just move on to question five. This is the general perspective of electricity greening. Based on your experience, what is your perspective on electricity greening in the European setting? Do you believe that electricity greening could help minimize emissions in Europe? And if yes, how?

Researcher:

Yes, I will say that, absolutely, yes. Electricity greening will be very important. And we can principally replace everything that we're using fossil fuels for with electricity instead. But historically in Sweden, we had roughly around 350 terawatt hours of oil per year, year 1970. Then the decision was taken to try to get rid of oil and instead go for electricity. So that was a big program for nuclear power. And it led to that today we have 130 terawatt hours. 1/3 of the oil is still there, which is primarily used for transportation, a little also for industry, but mostly for transportation. So, we went from having all the industries and all the households and the buildings and so on, were using oil before for heating and electric production so on. And now we have almost zero on that side. What we can see is, you have a possibility to do similar type of things. In France, they have done it, they have a nuclear power that too. So, this is very positive alternative, when it comes to Norway and Sweden, we both have a lot of hydropower, which was built already before this. So, what we can foresee is that the hydropower from Scandinavia will be used also in the rest of Europe. Just as a balancing power, when we're getting more and more wind power. Today, I will say that we have almost a surplus of wind power in northern Germany, and, and perhaps even Denmark. But it's not windy all the time. So, we need this balancing capability. When it comes to other countries, further to the south, we know that we have a lot of wind power in Portugal and Spain, and also is coming in quite a lot in Italy. And we can see that solar power is also coming a lot in those southern regions, especially in Germany, we have a lot of solar power, which is complementing especially during the summer half of the year. So, I will say yes, we will definitely have much more electricity, and it will reduce the emissions dramatically. When it comes to vehicles. If you have a car, and you drive it with diesel, or gasoline, you have roughly somewhere between 6- and 10-kilowatt hour per 10 kilometer. If you do the same thing with electrical vehicle, it will be somewhere between 1.5-to-2-kilowatt hour or 10 kilometres. So, it's only 1/3. So, if we have a lot of electrical vehicles, we will reduce the total amount of terawatt hours of energy. Because it's so much more efficient. If we're starting using hydrogen, instead of direct electricity, you're losing quite a lot of this advantage because you have much more losses in production and in storage and in use later on. But you're still using fuel cells and so on, with hydrogen. That is an alternative where you can store the energy in a relatively easy way. When I say relatively, it's not so easy to store hydrogen, but it is principally it is easy at least. And then you will have a balancing system between if it's windy or non-windy, the hydrogen can be stored. You are producing a lot when it's windy, and then you can use it and store it for a relatively long time periods. So, I think that will be a combination of battery electricity and use of the low-cost direct electricity use, but also the balancing with using hydrogen. And that is also what EU is driving very much now. And we can see that if we're using electricity, we can or hydrogen we can use hydrogen also for reduction of oxides in metal ores. So, if you have iron oxide, for instance, you can take away the oxygen either with coal, and then it produces CO_2, or you use hydrogen and then it produces steam which is then water. The drawback with that system is that if we have one coal and kilowatt hour coal, you will need roughly 2.7 kilowatt hours of hydrogen or energy as hydrogen to do the same work for the reduction. So, if we have 1/3 of the energy needed for transferring into electrical vehicles, you have the opposite when it comes to transfer from coal to hydrogen in like steel manufacturing or in iron ore reduction, those type of things where it's like three times more instead. But still, those systems will be used together. And as you know, both in Norway and Sweden we have a lot of metal ore production to produce metals. So, we're using today a lot of hydropower it will be much more wind power of course, but we also see the same thing in northern Germany.

Ultra-metal, the biggest steel company in the world. They also go for this process we use a hydrogen instead, close to Hamburg, and then they have a huge amount of wind power in northern part of Germany. So they are going for that So, what we can say yes, the greening, it is going to minimize emissions. When we go for the vehicles, it will be dramatic decrease of the total energy demanded, but it will be, of course, much more minerals needed, and metals needed to produce batteries. I think that was a long answer, but it was answering probably some of the other questions later on as well.

Interviewer:

Yeah, I'm really blown away, you know really much about this. So cool. I think we maybe overlapped a couple of questions. If you feel that you have already answered then can you say so, and then we have the transcript from earlier, and we can use that. So, let's move on to Question six. Which renewable energy sources do you think are most likely to constitute the renewable energy mix for Europe in their quest to green their electricity grids, and why?

Researcher:

The most important, that we already are using a lot, especially in Sweden, and Norway is hydropower. That is actually very important for this, but it's all really there. The second thing that is second most important will be the wind power. And that will be huge wind power plants, like in Dogger bank, outside Scotland, you will have it in the North Sea, along the shores and so on. Also, in in Sweden, we're discussing a lot in northern part of the mountain areas. The biggest problem when it comes to the wind power is that a lot of people are seeing those plants. And they are very negative, because they don't want to have any difference compared to what they are used to. So there is a resistance that is mostly aesthetic. Not so technical, but aesthetic, which is hindering the expansion of wind power, but I still think we will have much more wind power, because it is economical. And even if wind is not continuous, it is relatively even over the year, a bit more during the winter, even or spring and autumn, especially when it comes to solar power, we will have a lot of solar power coming in. But it will never be as important as wind power, probably although it is becoming higher and higher volumes, but probably the wind power in Europe will be the most important after hydropower. When it comes to nuclear power, some countries will have nuclear power, like France, Finland, in Sweden that is a big discussion if we should have it or not. A political discussion we will have at least until 2040-45, the existing nuclear power plants question is, will it be economical to build it after that? One thing you didn't have on your list is CHP combined heat and power using biomass and waste. This is actually very important in many countries, like Germany, Sweden and many other countries, where you're utilizing the waste and biomass, and then you have it both for heat and power and in the future can also use it combined with pyrolysis that is an area where we're quite a lot with so gasification to produce hydrogen and CH_4, pyrolysis to produce replacement for fossil oil, that is liquid products. So, there will be a number of those types of things that will come in as well.

Interviewer:

I have one question. Recently nuclear energy was added to the EU taxonomy of green energy. Do you agree in this change, or do they have any comment on this change in classification from non-renewable to renewable?

Researcher:

Yeah, I can say that, when it comes to nuclear power. There is a lot of fake news around it, I would say. In reality, if you look at nuclear power, you have uranium 235, which we are normally using, which is point 0.7% of the uranium and the rest is uranium 238. What we know is that this uranium 235 is degrading if you put it that way is giving away energy when it's being split (fission power). And this is happening anyhow. This is not relating to if you take it out. If you concentrate it then you can utilize this fission power, so to say, here. Which means that it is not a renewable thing, but is sunshine a renewable thing? No, of course, the sun is also degrading all the time, but with fusion processes. So, the nuclear power is very similar to Sunshine. And if sunshine is considered being renewable, then you could say that, then, of course, in the same way in the nuclear power is. Principally they are not, but they're working in the same way, when it comes to the storage of the nuclear fuel after it's been used there are natural things in Gabon, were they ever seen for roughly 600 million years ago, you had natural reactors. At that time all uranium, or there were roughly 5% uranium 235 in the natural uranium at that time. And you can see how this is degraded or given away becoming 238 later on, and you can see that it has not been any major problems with the nucleotides that are coming out of this polluting and this the surrounding and so on, it has not been a big effect on that. So, I will say that nuclear power is very much something that is psychological much more than technical, mostly. Then, of course, there can be effects like Fukushima, where you had this huge wave falling in that, and you have Ukraine (Chernobyl) but those are in relation to very many other things. minor things. So, to my opinion, yes, of course, nuclear power should be part of this greening.

Interviewer:

Okay. I agree, that within the time perspective which we need to react to counter climate change, I think is very much a renewable source.

Researcher:

Yes, I think the biggest problem is the CO_2 emission and you don't have much CO_2 emission from that (nuclear energy). So, it is in the same category as the other renewables, I would say.

Interviewer:

Yeah, totally agree. We can move on to Question seven. Which are the main benefits of potential electricity greening of Europe. You might have commented on this in question five, but if you want to add something you can.

Researcher:

I think one thing that is very important is to reduce CO_2 emissions, and in that way, reduce the global warming impact. The second thing is to become independent of like Russia and other other countries with very authoritarian regimes, it would feel very nice not to be dependent on those. So I think these two are the major things. So, we can be independent of import of fossil fuels from those countries we don't really appreciate, and at the same time we're doing something good for the environment.

Interviewer:

I think it's only positive benefits. There, you see a lot of the countries in Europe are reacting to the Russia crisis, and then moving forward with the new policies that were meant to take 20 years, suddenly taking two or five years. So, I think yes, as long as the people and the decision makers have the possibility to do it, they can do it. Yeah. Really interesting to see the change now.

Researcher:

Yes, I will say that the biggest obstacle today, to meet these types of things is persons who have aesthetical things against expansion of wind power and solar power and things like that. It's very many people that say: "I like renewables, but I don't want to have it in my backyard". This is a major challenge. And this is I don't know how to overcome it. In Sweden, there is a big discussion now if the municipality will not be allowed to have a veto against expansion in their municipalities. For the time being, each municipality or city has arrived to say no, and if you have local people who are very upset about getting wind power in their neighbourhoods, then very often the politician says: "okay, then we shouldn't have it". And they say that you can have it somewhere else, but not here. And if this is happening everywhere, we will have no expansion. And I think this is the really the biggest threat to this. And the biggest bottleneck.

Interviewer:

Yeah, I totally agree. I think there is a bit of hypocrisy going on there.

Researcher:

Yes, yes.

Interviewer:

Which are the potential consequences of electricity greening in Europe, then again, referring to question five, where you elaborated a lot, but...

Researcher:

I think we have answered that already. Yeah.

Interviewer:

Good. Let's move on. What effects do you think greening the grids would have on electrification? Especially transport electrification in Europe?

Researcher:

Yeah, I would say that we have two things, one positive and one negative, if you're looking from a national perspective. If we look from the Swedish perspective, there is quite a lot of trading between southern Sweden and Poland, Germany, Denmark, which means that when there is low wind production, the price goes up, you're using other types of energy like natural gas, and things like that, to produce electricity in those countries. And then if we have a higher transfer capacity, it means that they will buy as much as possible from hydropower and other types of things from Sweden and Norway, but this in turn will mean that if they get much better paid to send it down there the power companies will also increase the cost for us. So, if we don't have this transmission line externally, it will reduce the price in southern Sweden. So, this is both positive and negative is very good for Europe, if we have a high transmission capacity of cheap renewable electricity from Sweden and Norway primarily, but from national perspective, it may be a negative effect with respect to the pricing.

Interviewer:
I agree. Let’s move on to Question 11. The European Union has agreed on the goal that renewable should constitute at least 50% of the electricity generation mix by 2030. This should be said though, this was a goal before the war. So, we have some questions about that. What are the potential positive impacts of the greening of the grid on transport electrification in Europe?

Researcher:
I can just say that there is Volvo AB, Scania, MAN, and Daimler, they are the four major manufacturers on heavy vehicles in in Europe. They have made an agreement a joint company to build infrastructure in Europe, at least Western Southern Europe, perhaps the whole EU 27. So, and this is said to be both electrical fast charging those type of things as well as hydrogen stations and filling up and so on. So, if you look at Volvo AB, they say for long distance transport, they believe very much in hydrogen, because the batteries will be too big, too heavy, but for short term communication, regional communication then electrical vehicles will be very important for transport of heavy materials and so on. When it comes to long transport, we also have this with the trains. And if you look at the train, you have a lot of electrified lines, the big lines are electrified, but the shorter lines in like Germany and UK and so on, they are still using diesel engines. And what we were looking a lot on is having batteries too. You can charge them if you're transporting on the big lines where you have the catenary, but when it comes to this, we have normal diesel, you can use a battery for those distances, which are normally perhaps 50 kilometres, that range. So, it would be quite feasible, when it comes to long term transport, we need to expand the

capacity of these train lines. And if you have the fast train, we're talking about to communicate people, we probably need to have parallel lines for transport of goods. Because the goods are going much slower, and today we have a competition between transporting the goods and transport in the people. So, but I think transport, using those type of things will be very important. When it comes to shipping, the shipping is important already, but today they're using fossil fuels totally. So, what we can see is for sea is to use other types of renewables like bio liquids. A fuel that are produced from biomass to use for the transport, I think that will also be very important. You're asking about negative impacts. Of course, if you have this, there will be a competition between different types of transport systems. That can be a negative thing, to some extent. If you want to use biomass, there is a limited resource of biomass. We have a lot. Sweden is the country having most biomass in Europe. And of course, we're looking very much on that. But the question is, should it be used for packing paper? Should it be used as a replacement of plastics? What should it be used for? So, there is a competition on those types of resources. Perhaps they should not be burned in the first case, but they could be burned when they have been reused a number of times. I could see that. Yeah, but as a benefit of transport electrification, I don't really see that. It's not the greening in that can give that. The greening will come anyhow. It is more of how we make these wind power plants and solar power plants and so on. Because you need to have large scale. In Sweden, there is right now a big discussion. They want to build a big solar power plant in southern part of Sweden. And there is, of course, a huge opposition from people living around there, they don't want to have it in their backyard. When it comes to farming, we have a product here in Västerås, where we are having vertical PV cells, where you have PV on both sides. And we have been doing this with a farmer (Pilot project). And what we can see is we don't get any negative impact on the production of the field; we actually have the same production level with these PV cells out in the farmland as we would have without it. And the reason is that you get a little less sunshine while you have shadow. On the other hand, you also get less drying effect, which means that drying is very often during summer a bigger issue than too little sun. So, I think you can see there are possibilities to do things in the field here, but there are also limitations are very often the limitations are more aesthetical.

Interviewer:

I can Imagine. Just stop me if you just pushed on to question 12 now, but which other factors should be considered when addressing or pursuing electricity greening for Europe.

Researcher:

There is always a discussion should you have different type of support functions to support this. And the support functions are very often you're giving subsidies to build, you have had huge systems like this for solar power in Italy and Spain. And when they built as much as was subsidized, the whole thing stopped. They didn't expand any anything more. So, the question is, how do we get financially sustainable system so that it will be of interest long term, and I will say that is CO_2 tax, the cost for CO_2 emissions. That is very important. If you have a high tax on CO_2, it will improve the possibility to build these alternatives. But exactly how you should do that you have a national possibility to have different types of support activities, or subsidies or things like that. It is not really a common, which could be natural because we have very different conditions. In Sweden, we have a lot of biomass. So in Brussels, they don't have a lot of biomass.. So they are not so positive to buy them to use(?). In countries having a lot of biomass., they say that, of course by biomass. should have very positive effects from these perspectives. Why those who don't have it they really don't care, and they are very many people. So, you have also political, would you say, a competition between different interests. Which is driving. Of course, this with a nuclear France having a very strong nuclear basis, they are very positive to nuclear power and don't want to have any limits on that. In Germany, they have very strong natural gas uses and in Italy as well. So, they are very hesitant to block the natural gas from like Russia, while we have almost nothing in Sweden and you have you have nothing in Norway. But there are some countries having a lot. So, this is complicating things. But the driving force should be that all kinds of this CO_2 emissions should be put penalty on it in one way or the other. And it needs to be significant penalties. Right now, with the natural gas price goes up. The diesel price has gone up as well, and especially diesel. And then the politicians say that, okay, we have to subsidize this, we are giving money to people, because if they haven't stabilized the economy themselves, we have to do it for them, which is giving the totally wrong signals. If you have varying thing, the price is going up and down. And you're earning a lot of money on having it when it is at low price levels, then you don't want to bind it over the whole year, because it will be a bit higher. But then when the price goes up, then they have to pay that because they didn't have this, like security with a fixed price that you have to pay for. And I think the politicians are giving very strange signals sometimes. And the reason is in Sweden that we have an election in September. So, everyone wants to be very positive to as many voters as possible. So right now, the negative decisions are just blooming up.

Interviewer:

Maybe the solution is to change the political system? haha

Researcher:

Yeah, what we know is after the election, then they have four years for running so then they can take the bad decisions or the toughest decisions.

Interviewer:

I wrote down a question. You mentioned that Sweden had a lot of access to biofuel, and that could be feasible in Sweden, but other countries don't. Do you think that there is going to be regional differences, or differences country to country in technologies, going forward?

Researcher:

In reality, yes. Where you have more sunshine PV cells will be more interesting. When it comes to electrical vehicles, of course, if you're having a lot of fossil fuels, you don't earn very much and having an electrical vehicle. But in Sweden, Norway, and those countries, it is very favourable to have electrical vehicles because we are limiting the emissions by that. So that will be different alternatives. And it will be regional differences. And exactly how to handle that, yeah, that is a tricky thing for the European community to handle. But even more than other countries. I know in like India; they have very different systems in different sub countries / regions in India. And some of those are very negative. So, you have in Southern India, for instance, they are giving the electricity for free to farmers. So, they have no reason to reduce the spending, where they can save energy, because they don't have it for free, which is a very negative system. But on the other hand, yeah, they are having it because people are poor and have a difficulty, and then you can say that it would probably be better to have another system. At the same time, they have also green electricity certificates system in some other sub countries / regions in India. So, I was in a panel in India, in Delhi in 2010. And then in this panel was also the energy minister in India. And I was asking because we had green electricity certificates in Sweden and I was asking if they're having it in India, and he said, we just introduced it a month ago. So, he was very proud. But that was just for some parts of India and other parts, they don't have it at all. And I think this is a tricky thing. If you come to China, you can see in China, they have a department and a group for renewable energy. I met one of the directors of that board, I've forgotten where, and he was so fascinated of fracking. Because this was when the fracking was coming up a lot in the US.

And said: "we should go for fracking". I said: "That is fossil, but you should work with renewables?" He said: "yeah, by fracking that is the thing." So, the politicians and a different interest and so on. When you have those who should try one thing or not really doing it, then you have a problem. Xi Jinping, his predecessor was very positive to renewables. And I don't know Xi Jinping and how he is, but I know that he's very fascinated by batteries and now he's going for hydrogen, the hydrogen society. And then you can say that, okay, this will lead the whole of China, but in reality, it means that they will do a number of demonstrations and they will support that. But then when it comes to really implementing that is more up to the local cities and regions to do, and the influence from the top is significantly less than even in a country like China.

Interviewer:

Thank you for answering. Which are the main stakeholders to help in electricity greening in Europe?

Researcher:

I would say that the biggest system is the political system, the EU system, that will be very important. The second biggest one that is actually the industrial companies, because the industrial companies, they are very positive to this and driving this, but they drive along what are the general rules and the regulations and so on. Because you don't want to be losing competitiveness because others are not doing these types of things. So, I will say these two are the most important, but then we can say the political system. What is the political system? Yes, it's ministers, the Prime Ministers from the different countries and the prime ministers of the different countries. They are elected, because we have a democratic system. So, they are listening to the voters. So, it's very important what the voters as persons are saying. We as individuals have a major importance, but indirectly, so to say, through the politicians. The industrial companies, the same thing there in the way that we are the customers, to the industry companies. So, if we are prepared to buy the things that are good, either in our role as individuals as residentials or when we are sitting in other countries that are buying, those roles are also very important. So, the stakeholders is: we as individuals through the political systems, especially the EU, Norway is not part of the EU, but Norway's the country that is best on following the rules, so the super EU country, ha-ha. And the industries, we have a very strong force in industries to drive for this. And then we're going to say, who was starting this activity with getting the industry to fall in, especially the vehicle industry. And that was

Tesla, an American company with a great entrepreneur, who really was doing something that made everyone having to do this. And the first country that has really been scaling up the electricity on a large scale, that is China, they are so much before us. I have a guest professorship at a university in Beijing in North China electric power University, and already 10 years ago, they (Students/professors etc) could lend electrical vehicles at the university to a very good price. And if they wanted to buy an electrical vehicle, it was much lower price than if you bought a diesel or something like that. So, they had a very strong driving force for this. In all big cities, they made a ban on fossil fuels for mopeds, you're not allowed to have anything else than electrical mopeds in the big cities. And then you had like 20 million of those 10 years ago. The buses there, I've seen figures that are 400,000 electrical buses in China. So, they have really been driving this. And the question is, how do we get to these levels? Yeah, it's a bit slower in the democratic system. But on the other hand, when we are turning things, we can go very far.

Interviewer:
Which of the European countries do you think out stand the greater chance of leading the electricity greening in Europe by 2030? And in the case why?

Researcher:
Stand the greater chance of leading? Yeah, I will say that Sweden has a great chance, aside of Norway. Sweden is still its EU country. Norway is not. Sweden and Norway are the two I would say leading countries on this in Europe.

Interviewer:
Because of the hydro power?

Researcher:
Yes, very much hydro power, and in Sweden also nuclear.
Interviewer:
Okay. Yeah, that's, that's true.

Researcher:
You know, Sweden has a lot of wind power today. We have in the range of, I think, it is 7000 megawatts installed wind power capacity, or something like that. Which is more than

Denmark. So, it is we have roughly 27 terawatt hours where wind power was produced last year. Denmark has 30 terawatt hours of total use per year. And we have almost that only wind power. And that is yes, we have another 45-terawatt hour in nuclear power, and we have some 65 terawatt hours in hydropower. So, in relation to the others, it is still low but in absolute figures is very high.

Interviewer:
Quite surprised that you are beating Denmark in the amount of wind power. That's quite impressive.

Researcher:
Yeah, so it is already three years ago, we were passing Denmark on wind power, and it's expanding still in Sweden, much more than in Denmark. The expansion stopped in Denmark.

Interviewer (1):
Now my colleague will take over the Swedish perspective.

Interviewer (2):
Thank you very much for your views on the European setting. I believe that you've said much about Sweden already, so if we ask a question that already feel you have answered you could just skip it.

Researcher:
I can say that, if you look from Swedish perspective, we can say that the major challenge so far (today) is transportation and heavy industry. Those two we have almost zero when it comes to energy field (electricity and heat). We have almost zero, it's only renewable or nuclear there. But when it comes to transportation, I think the biggest obstacle right now for electrical vehicles is that it is still quite expensive to buy this car. Firstly, you have a much better system in Norway where you have normally very much higher tax on imported cars, we don't have it because we have our own production. So, it is quite expensive to buy an electric vehicle. And the second is, is a significant problem with charging, you don't have enough charging positions (Charging infrastructure). And this is really a disaster. You can't buy an electrical vehicle if you're living in a city, because we’re should you charge it? If you

want to transport yourself longer distances, there are too few charging stations, and as the electric vehicles are increasing, this is becoming a larger and larger problem.

Interviewer:

Okay, so do you believe Greening the Grid could help Sweden minimizes transports emission?

Researcher:

Yes, in transport? Absolutely. That is the major challenge we have roughly 85 terawatt hours out of 130 terawatt hours are fossil and is for transportation. So, it is 2/3 in reality. Official figures are saying 1/3, but I don't know how they are counting because in reality is two thirds. When it comes to the industry, there are big programs now by LKAB, SSAB and some other big companies who wants to replace roughly 15 terawatt hours of coal, which is almost all the coal within until 2035-2040, stuff like that. But the limitation is they need much more electrical power. And you have in Sweden, we have a lot of locals in northern Sweden, Sapmi. In southern Sweden, a lot of people are living wherever, who are very negative to have wind power in their neighbourhoods. And they don't want to discuss possible solutions. How can we solve this together? It's impossible. And then they say "no, and you can't build these huge plants". So, it we have the biggest problem in Sweden now is the obstacles with people giving a veto. They say no. And they have the right, so far, to do it. And the government cannot override them.

Interviewer:

I think it's very important to consider the local people. Factor for the progress of electricity greening, which are the other factors that we also need to consider for the Sweden perspective?

Researcher:

I can say one comment on how we can overcome this. There is a discussion, if you should give annual income to the people living in that neighbourhood. If you did, so, it would probably overcome most of these big problems. Today, you have only the negative effects but no positive effects. Because the locals don't get anything if they are not a landowner themselves. The landowners are getting some, but not the people living at these lands.

Interviewer:

Yeah, I think that those very thoughtful. So, which are the other factors that we have to also consider in Sweden, aside the local people?

Researcher:

I think that is the major challenge. Okay. I don't think there are in reality are, of course in this regulatory demand you don't pay or they don't get any benefits those are living in the neighbourhood, so on. So that you could say is a regulatory problem. These are the two major problems.

Interviewer:

Sweden’s energy system is quite an interesting system. So, for each of these renewables, you know, Sweden have a lot hydro power and nuclear power, and now they're adding wind power. So, which of these do you think is going to stand a greater chance for the next 10 years, that by 2030?

Researcher:

By the next 10 years, you can say that they will not expand hydropower. There is a big issue right now about how to improve from an environmental perspective when you're upgrading hydropower plants, because they are starting to get old, when it comes to nuclear power, there will be no expansion, you will have what we have for another 20-25 years, the existing reactors will still be there. When it comes to wind power, it will expand if the companies are allowed to build and not stopped and blocked by local peoples. When it comes to solar power, we're having quite a lot of solar power on the roof topping all over Sweden, and I think that will expand. But it's still the wind power that will give the biggest input. We have CHP plants - combined heat and power plants - in Sweden, they will keep roughly what they have today, but they will probably be more important in the process of replacing oil. Generally, perhaps not so much in the energy field, but more for other purposes as fuels for plastic production, for replacements, plastic production using wood and things like that.

Interviewer:

Okay, so which key stakeholders in Sweden do you think can help in this electricity greening?

Researcher:

I will say that the government, of course has a very strong role, because it's the parliament who are making the rules. And they have to change these rules in one way or the other. And I think those two things. First, it should not be possible to so not so easily. It's too easy to say no. The second thing is it should be a benefit for people living in the neighbourhood. So at least the municipalities should get benefits from when you are building these big wind power plants, for instance, or if there are big solar power plants and so on. But of course, it's also how do you do this? Limit the noise levels? You have regulatory demand? Where can these be placed? I think they are quite good as they are, for the time being, you shouldn't have this with... you have noise limits, you're not allowed to have above a certain level, at a certain distance. When it comes to shadows, you're not allowed to have more shadowing than eight hours per year, while you're living, it's a number of those rules that I think are quite okay. What you have to look for is when you place the wind power plants avoid having it where you have the birds moving (active areas and fly paths), avoid having it where the reindeers are moving. So, you should consider these types of things when you build these plants and not say "yes" or "no", but say "Okay, we tried to compromise in one way or the other to make it good for everyone". It is possible. I think the key stakeholder in this case, it is the government/decisionmakers. When it comes to the government, they are setting rules, when it comes to the companies who want to build this, they think it (incentives) is good enough. The economic incentives are good enough. So, they want to do it. So, it's not the industrial side. Those also want to build or operate. The limiting factor is the regulatory demands or the regulatory system. Yes, that is absolutely the most important thing. In relation to the municipalities, and the municipalities then in relation to those people living close to these areas where you have the wind power plants.

Interviewer:

So, can you specify a bit about the strengths and weaknesses of Sweden in the electricity greening?

Researcher:

Yeah. A strength is that there is a very positive attitude to renewables, we already have a lot of electricity in the country. The weakness is that people are not agreeing on where to place things. I will say that is the biggest weakness. It's too easy to stop. This is too difficult to get approval.

Interviewer:

That there is also the potential challenge or the bottleneck?

Researcher:

Yes, yes, absolutely. And I will say that you have a similar situation in other EU countries. It is not only Sweden, but of course, if you go to Germany as a lot of discussions in the same way there.

Interviewer:

So, you want to take a look at the heavy road freight vehicle electrification in Sweden. So, to what extent do you think the electricity grid of Sweden will be affected by heavy road freight vehicles electrification?

Researcher:

We will have it within 10 years, I'm quite sure, it will only be electrical vehicles used in one way or the other. It's much shorter turnover for heavy vehicles, you don't use them for 18 years as you can do for a personal car, you use them for perhaps five years or something like that. But the question is, will it be totally battery driven or will be with hydrogen fuel cells, they are still electrical vehicles, but with the different technologies. Maybe there will be some kind of combinations of those that you have an electrical vehicle, but both with a battery to some extent and then you have also quite a fuel cell and hydrogen for the long distance. Some kind of hybrid technology.

Interviewer:

So, I think research shows that transport electrification could increase electricity demand. So, do you think the Swedish electricity grid has the capacity to meet this demand?

Researcher:

I think so, generally, it has a capacity for it for the transport sector. I mean, that there may be locally there are limitations. If you want to have five fast charging vehicles standing aside of each other everywhere, that might be a problem, because the cables are not made for that. So, you will have to expand not the transmission grid, but the local grid here and there for these purposes. In many places, you will have enough of it, but you need to have a coarser cable (larger diameter), because otherwise they will be overheated if you take out too much power. So, the transmission grid, yes, we have that and probably also regional to some extent at least for the vehicles, but on the local level, there may be demand to improve and expand, which is also happening. Another problem is that if we want to have heavy industries in the cities? If you come to the Stockholm or Mälardalen region, Västerås, Uppsala, Örebro, and so on where we have a lot of industries, we have limitations in power coming into this region. So, when we were building a battery factory, the plan was to do it in Västerås, but we couldn't get the power supply from the grid system. They could get energy/power in northern Sweden, so the plant was built in Skellefteå, because there they had a surplus with hydropower and another type of things. They are planning to expand on the wind power also a lot. So, when it comes to transport sector, generally we have at least on the transmission and reading level, but a limitation on the local level. If you want to have fast charging several in parallel, on a lot of different positions.

Interviewer:
Okay. I'll go for a last question. But then I like to cite an example to clarify this question. Ghana, the country that I come from, we cannot currently have Heavy Duty transports electrification, no passenger transport electrification because we have shortages in our electricity. So, when we go for transport electrification is going to kind of put a lot of demand on our grid. And then the shortages are going to increase. So that is why we are not opting for that. So do Sweden see transport electrification in that way, or?

Researcher:
I have actually been to Ghana a few times, because of a friend of mine. He has built the private university in Accra and is married to the Queen of the shanty people in Kumasi as well. And we have been discussing building electrical power plants in Ghana, then using biomass, so we were looking for the possibility with the elephant grass, for instance, you have huge amount of elephant grass out in the prairies, if you put it that way. That is causing a lot of forest fires and so on. And if you could get a system where people are collecting this and giving it to this powerplant, and then you can produce electricity and at the same time you can decrease the risk for the fires. We have been discussing that. But you have the cost to alter, and the electrical power and the hydropower coming out there. You could probably increase a bit electrical power even more in this river system, I could guess. But it's still your need to transmit it. And I would say that in many countries in Africa, you're having the

problem that you have the power production needed, you have the transmission lines, but you don't take the power from the transmission line down to the local level. People are seeing this line going in the sky with a lot of power, but they don't get it themselves.

Interviewer:

Okay. So that I think, probably Sweden doesn't have the same case as Ghana.

Researcher:

Yeah, no, they're quite different cases. And, of course, you have for good and bad, the electricity... you don't need electricity for heating purposes, but you might need it for cooling purposes. And summertime, PV systems are usually very economical. So, for us, we have a problem in the winter times with the PV systems. But it should be much simpler to use them in in Ghana and expand on that side. So, it would be another alternative, probably, but then the distribution and so on the grid level. My experience from 15 years back was that it was always a problem to get power even to the computers and the mobile phone system and so on. So perhaps it is better now. Not sure.

Interviewer:

It is better now. Yeah. Okay, then I will leave the other last two questions to my colleague.

Interviewer:

These days there are the invasion of Ukraine by Russia, so we need to address this. Because the energy mix in some European countries, Countries like Germany, or Italy, are heavily influenced by Russian energy in coal, gas and oil, and because of the unreliability of Russia, some countries might feel the need to change the energy policies, so we hope we can get your opinion on this. So, how could this affect the electricity greening in Europe?

Researcher:

I will say that this with the coal and gas and oil, if we want to be independent on the Russian, but not only Russian but also from Arabic countries and so on perhaps even Nigeria. This is a driving force, and we could replace most of the fossil fuels that we use in today. Both by reducing the energy use the heating, demand, those type of things. And when we transfer to electrical vehicles and so on, this would also dramatically reduce the need. What we still need is oil for industrial use as a raw material. And then we have another thing that is quite interesting. And that is, Sweden is the country in EU having the biggest forests or forest materials. But in our neighbourhood, we have Russia, which has huge amounts of forest material. And I would much more like to see that Russia is supplying us with wood and wood products, then with oil and gas. I think that is worth to consider. Because if we are shutting down all this with the oil and we don't want to buy it, they are earning very much on this. They are still they are having a lot of food they are producing and exporting a lot of food, they could export very much more on wood and wood products. And that would have a very much better impact on the world. So, to say. It's still Russia, but it would be much more positive.

Interviewer:

Yeah, I agree. Pretty much the same question, but with Sweden in focus. So how could the invasion of Ukraine affect the electricity greening in Sweden?

Researcher:

I will say that just to have the transport sector, it will not impact the electricity system so much. It is a relatively small amount. I was telling this that for each if we say that we have 85 terawatt hours of fossil fuel for transport sector, we will need something around 25 terawatt hours for the whole transport sector in the future. And 25 terawatt hours in relation to 160 that we are producing electricity today is a relatively small amount. If we look at the heavy industry, we are having like 15 terawatt hours only for LK AB. (Coal) today, and we will demand 45 roughly three times as much. So just to replace the coal in LK AB, will demand almost twice as much as the electricity demand for the whole transport sector in the future, so it's much more efficient with the vehicles that we can see. So, this is the first thing we should go for from an environmental perspective. To reduce the global warming. But then of course Sweden is the biggest producer of iron in Europe. 90% of all the iron in Europe is produced in Sweden. So, when it comes to that part, if we can reuse that and use cheap electricity instead, even if it's not the most efficient, we can say that if you're having a hydrogen system, the hydrogen is a very good balancing thing if you have hydrogen also for vehicles and other purposes, if you have big storage is on different positions. It is a good balancing thing aside of the hydropower. We are talking about a total of perhaps 90 terawatt hours extra in Sweden electricity, compared to what we're having today. And of this, two thirds will be for the heavy industry and 1/3 they are talking about for the vehicles.

Interviewer:

I think that was our last question. Do you have anything to add on what you have spoken about so far?

Researcher:

No, I think you have got my points.

Interviewer:

Okay, I think I have this question in mind based on sheets. If you could spare a little bit more time. I would like to know; will it be possible for Europe to have an integrated electricity grid that could supply the whole of Europe? Is that possible? I don't know. I just think about something like that. Is that possible? And then the next question is with regards to moving the world moving to renewables, what is going to happen to fossil fuels, and the fossil fuel production companies and then countries, what is going to happen to them?

Researcher:

Yeah, I take the first question first. The limitations in this power grid, so to say, is there a transmission lines that are bottlenecks, if you look at Northern Europe, and when I say no, then it's Sweden, Finland, Norway, Denmark, Northern Germany. So northern Germany is part of northern Europe, there, we have quite good transmission lines, and we have a lot of renewables. If you then go down to, to Germany, you have very poor lines from northern Germany to Southern Germany. So, they say that they need five big transmission lines to be built from northern Germany and Southern Germany. Instead, in southern Germany, you have a better grid to France. So, France has good grids towards Southern Germany and Italy. If you come down further down, you have poor communication between France and Spain, and you're very poor between Spain and Portugal. So, you have limitations. In Portugal, you can have up to 100% of the electrical power is coming wind power, you have it now and then. But the bad thing is when it's very windy, they have no way to export the wind power, because there are no transmission lines to Spain that could use that. Or very little. So, you can say that you have to build a number of these new lines. The second thing is then if you have this transmission line, how do you pay for if you're transmitting power from one region to the other, because you have always losses. And there you have negotiations and agreements on the business conditions, who is paying for this? If you're just transmitting power, like Norway is transmitting quite a lot of electric power through Sweden, and down to Denmark and to Poland and Germany. So, then you have an agreement in some way on that, if this would be very much bigger and many countries involved, it is a tricky thing to develop the regulatory system for it. Economical financial system. In Sweden, for the power company side, it might be very good to send the power down to a country where you have a limitation, and the price goes up. But this will affect that we will have a deficiency here (Sweden), and perhaps even in Norway in the future, because it's more economical to transport and transmit this, how do we handle that? So, it will be if we have a good transmission system will also mean that we probably will get different pricing mechanism and the pricing mechanism when it's windy, you will have a very low electricity price. And when it's not wind and when it's calm the price will go up everywhere. Even in in countries like Sweden and Norway probably. Yeah.

Interviewer:

Okay. Okay. So, the second question, what happens to oil producing companies and countries?

Researcher:

You have Russia, Poland, Germany, in Germany, they are moving away from coal already in, in Russia, sorry, in Poland, they are discussing a lot now, to build new nuclear power plants to replace the coal. The question is, can they afford it? Who is putting in the money for that? Will it be EU? If it will be you these new rules will be very important. They are expanding a lot of wind power. If you come to countries like Russia. They don't have a very, very big push towards renewable status as far as I know. If they are selling coal and gas and oil and so on and earning money on it, they will look for possibility to sell it to China, but they will have a problem with the income there. But on the other hand, they have a lot of food. They have a lot of forest products they could expand. So, hopefully we will see that they are transmitting more into other types of business. But then they need to have entrepreneurs who are interested in doing that. Yeah. With a very authoritarian system it might be problems

Interviewer:

Thank you very much!

---- End of interview ---

E. Interview guide 3

Charging infrastructure and grid capacity

Guide for exploratory interviews

(The following information is to be read by the interviewer to the respondent before the core interview starts, and/or shared with the respondent in written form before the interview)

> Start recording

The purpose of this interview

This interview is one of a series of interviews with a focus on the forms of transport electrification (*Heavy road freight vehicles*). Our goal is to use the information provided and these interviews to develop a set of scenarios that scope till 2030. The scope of our study trends to be wide since we seek to address a green to green paradigm, however, based on your field of experience, you can contribute your knowledge towards a specific part of this study. "Every specific detail is crucial to complete this puzzle"

Definitions of keywords

- By "*Electricity greening*" we mean replacing the sources of electricity production with renewables (including nuclear energy).
- By "*Heavy road freight vehicles*" we refer to goods vehicles with a gross vehicle weight rate (GVWR) above 3 500 kg, designed, exclusively or primarily, to carry goods; including road tractors and agricultural tractors which are permitted to use roads open to public traffic.
- "*Zero-tailpipe-emission vehicles"(Green road transport)* refer to vehicles that do not emit any carbon dioxide from the exhaust pipe.
- "*Green to green paradigm"* is the concise name for both transport electrification (road transport) and electricity greening.

Procedure and anonymity

This interview will be recorded in an audio file and a written version (transcript) will subsequently be produced based on this audio file. The transcript will be e-mailed to you for verification and corrections. After the final version of the transcript is agreed upon by the interviewer and the respondent, the audio file will be deleted. The transcript will be used in the project as background for developing the project, as input and reference for academic publications, and as an attachment to our Master's thesis. The transcript will not contain the name of the respondent or the name of the company he or she represents, however, the background information about the respondent and the company will be included in the transcript and when making references to the interview in research reports and papers. When reviewing the transcript, the respondent should also make sure the way the respondent and the focal firm are described, is acceptable.

Start of core interview*

*Here we have asked the researcher about contact information, this part is taken out.

Interview form:

The interviewer states: "This is a semi-structured interview. This means that we do have a "checklist" of topics and questions that we want to cover, but also that you as a respondent should feel free to bring any other relevant information to the table at any time."

Structure of interview questions:

The questions have been structured into three categories as listed below:

1. Clarification of the expertise and job role of the expert
2. Perspective on transport electrification (European setting)
3. Perspective on transport electrification (Norwegian setting)

Under these categories, there are main and sub-questions. The main questions present the objectives of this interview, whilst the sub-questions provide a checklist to serve as a guide, they need not be followed strictly.

Clarification of the expertise and job role of the expert

1) Could you please describe your field of work, and in particular explain how it is related to charging infrastructure and grid capacity?

2) To what extent are you informed about advancements in charging infrastructure and grid capacity in Norway and Europe?

Perspective on transport electrification technology

3) Research shows that "road transport electrification" is the fastest developing form of "Green Road transport" (Zero-tailpipe-emission vehicles) technology among technologies such as hydrogen vehicles, biofuels-powered vehicles, liquid nitrogen vehicles, etc.

a. *What is your view on this dominance?*
b. *What do you think are the reasons behind this dominance?*
c. *How do you see this development till 2030?*

4) Research shows that the electrification of heavy-duty vehicles could be done through the following:

- Electric road systems (ERSs)
- Battery electric trucks (plug-in charging trucks (PCT))
- Fuel cell electric trucks
- Others

a. *What is your general perspective on these technologies?*
b. *How do you think these technologies will develop till 2030?*
c. *How do you see the role of these technologies in the development of* heavy road freight electrification *till 2030?*
d. *Which of these technologies do you believe will be mostly implemented in Norway till 2030 and why?*

Perspective on charging infrastructure and grid capacity in the Norwegian and European perspectives

5) Research shows that the following supporting technologies play a crucial role in the development of heavy road freight electrification:

- Battery technology
- Smart grid systems
- Charging infrastructure
- Others

a. *What is your perspective on these technologies?*
b. *How do you think each of these technologies will develop till 2030?*
c. *Which are the potential threats to these technologies?*
d. *How do you see the role of these technologies in the development of (1)* heavy road freight electrification *till 2030?*
e. *How do you see the role of these technologies in the development of (2) greening of the grid?*

6) With regards to the Charging infrastructure:

   a) *Is the development of the charging infrastructure crucial for transport electrification and exploitation of renewable energy?*

   b) *Which models of the charging technology will be implemented in the Norwegean setting till 2030?*

   c) *What are the potential threats or bottlenecks of charging infrastructure expansion?*

   d) *Who are the main stakeholders in the development of charging infrastructure in Europe and Norway, and what are their roles?*

   e) *There is a push toward combined charging systems (CCS) as a global standard by the organization CharIn. Do you believe in this initiative by the large Original Equipment Manufacturers (OEMs)?*

   f) *Would the implementation of Megawatt Charging systems (MCS) for transport electrical vehicles, lower the charging time and increase the pace of transport electrification?*

7) Scaling of technology is one factor that is crucial in introducing new technology to the market, making it a safe investment and providing security in a tested technology.

   a) *Does this apply to charging infrastructure?*

   b) *Is the technology mature enough / efficient enough to make large implementations? If no, which factors are the current bottlenecks?*

   c) *How do you think the technology will develop till 2030?*

8) Siemens has that in its eMobility-white paper that if huge numbers of vehicles suddenly ran on electricity alone and made use of quick-charge facilities, that would put huge stress on our power networks.

   a) *Do you agree with this statement in the Norwegian setting?*

   b) Do you believe that the existing grid is ready for this transformation? If yes, how? If not, why not?

   c) *Is the development of the grid crucial for transport electrification and exploitation of renewable energy?*

   d) *How do you think the grid will develop till 2030?*

   e) *What are the potential threats or bottlenecks of grid expansion?*

   f) *Who are the main stakeholders in the development of charging infrastructure in Europe and Norway, and what are their roles?*

Stop recording …

THANK YOU FOR YOUR CONTRIBUTION

F. Interview transcription 3 – Respondent no 3

Research field/ Research background: Charging infrastructure and transport

Date: 22.04.2022

Duration: 49:47

Interview guide: E. Interview guide 3

--- Start of interview ---

Interviewer:

Could you acknowledge that you have read the information, and you're okay with doing this interview?

Researcher:

Yes. Yes.

Interviewer:

Thank you. Yes. Firstly, we're going to have a clarifying bit about the expertise and role of the expert. So, could you describe your field of work and in particular explain how it is related to charging infrastructure and grid capacity?

Researcher:

I am working as a researcher at the Institute for Energy Technology or IFE. And we are working in energy system analyses where I have been working specifically on transport and its connection to the grid. Both through using hydrogen as well as charging and understanding the challenges. By trying to put some numbers on the challenges, or for example, how the infrastructure could work most efficiently. Including having participated in publications regarding the adoption of distributed renewable energy in charging stations.

Interviewer:

To what extent are informed about advances in charging infrastructure and grid capacity in Norway and Europe?

Researcher:

Our main focus of work has been within Norway, where we have through several research projects closely connected to the industry and power sector, we are well-positioned to understand what is there, including the current challenges and research questions. My picture of Europe is more general.

Interviewer:

We have some questions about transport electrification technology. This is just to connect the relevant pieces of charging technology to transport somehow and what strain it could have on the grid. So, if this is not a field that you will not know of just say so and we can skip the question or you can speculate, whatever you are comfortable with. So, research shows that road transport electrification is the fastest developing form of Green Road transport technology among technologies such as hydrogen vehicles, fuel-powered vehicles, liquid nitrogen vehicles, etc. So, what's your view on this dominance, if we could call it that, of road transport electrification?

Researcher:

I think it's a fair observation that electrical vehicles are dominating the transition. But it also depends on what you mean with road transport electrification. Because it depends on what you put in that definition, and what kind of technology you are considering, we can be very clear that battery-electric passenger vehicles are dominating and have had very fast development both within buses as well as very recent strong development in trucks. Recently was launched the first serial production of battery electric trucks. While the road transport electrification can also mean charging, charging both with lines above the road or have inductive charging below the road, which are technically still, let's say, in the testing phase and I have not seen any real push to commercialization of it. Maybe it is immature technology, or you need to have maybe some certain type of investment business model that has not been realized yet. What more can I say about road transport electrification, can also be argued can be with hydrogen because the vehicle is driven by an electrical motor which then needs to be defined as, at least for passenger vehicles for lighter vehicles, we see the battery technology taking over. For heavy-duty transport, there has been a strong push forward. But as I said previously, there is a clearer advancement of battery electric vehicles also in more heavy-duty segments.

Interviewer:

Nice. So, what you could say regarding dynamic roads and overhead charging is that one of the issues is the upscaling (scale to market) to give it fair costs or bringing it to the markets?

Researcher:

I think, as a part of scaling up I think it shouldn't be a bit simpler technology than battery electric vehicles, especially if you have these overhead lines. But you have, let's say, you will need to have a certain volume, you need to have someone who is investing - how are you going to pay for it? who is going to pay and who's going to be using that infrastructure? So, you need to invest a lot in the infrastructure itself. While for battery electric vehicles, you can have one company deciding, "I like battery electric vehicles, I will always have these 350-kilowatt charging points for a truck in my logistics center, so I can buy it myself", while it is much more complex for overhead lines. While for inductive charging (Dynamics roads), I think there is still some more immature technology, which needs to be further developed before commercialization. It's my understanding or my feeling about it without working directly with it.

Interviewer:

Okay. So, with overhead charging (OCL), it's more up to the state or the government to do the investment, but on the battery technology, part is possible for the private industry to bring it up to the market?

Researcher:

Yes, that is my best understanding.

Interviewer:

How do you see this development going forward to 2030?

Researcher:

So, if we look forwards it will be always some level of guessing. So, we do some modelling of it and try to understand the dynamics. My best view is that the battery electric vehicles will be dominating and will be increasing. There will be for sure not going to be an easy road for just that specific technology, you will have I think at some point, you will have more challenges with, let's say, there could be challenges with charging infrastructure, I think there will be also a lot of issues with a supply chain around batteries because the future growth is expected to be immense, and it's not always hard to scale efficiently into such big dimensions. And I think my work has been focused a lot on trucks, there I also can see that other technologies will have a role. When it's scaling, there might be some special cases where hydrogen can be used. Biofuel power vehicles already are being used. The question is how much more it can grow, and in which niches it will continue to be applied. Liquid nitrogen vehicles It's the first time I hear about it. So, I'm a bit curious. Yes. Can I ask, are these questions more on a European level?

Interviewer:
It's some sort on a general level, yes. But our statistics on our secondary sources is mainly built on pilot projects in Norway and Europe, and Norwegian European statistics - but also EU directives. Since Norway is a country that isn't part of the EU, but we are still one of the better ones to follow the EU directives, were kind of going under the same umbrella. So, it's my understanding, it's pretty much the same. Or to some degree, of course, it's a generalization. But yeah, we're looking into it from quite a general perspective. But there are some recent developments. Now, in Taiwan, there's a blockade because of the COVID lockdown. So, crucial technology isn't reaching the supply chain. It is stopping there. I assume that some of the technologies are used for battery production, or the production of transport electric vehicles. How do you think a blockade of that sort of similar blockade can erupt the development of these technologies?

Researcher:
I need to admit that in this case, I will be more speculating because this is this kind of scenario, and I have not looked into the details. But my view is that a lot of things are driven by economics. Like, will this be a cheaper way to transport goods or a cheaper way to transport persons? If there are initiatives and a market for it, then I think the technology will come, and As mentioned previously, there will be bumps in the road. Like you have mineral sourcing for batteries. So, for example, you have this crucial supply chain in some country that might be stopping up, at least in the short term. The development, I think it's a reasonable idea that you will stop up or slow down rather said, but I'm very doubtful to say that there is this one reason in the supply chain that will stop it because maybe it will slow it down. So, maybe you need to build fabric and industry somewhere else. But I think it's going to kind of be sold as long as there are possibilities to make money.

Interviewer:

I agree, I think the economic forces will kind of always find a way. Let's go on to more specific charging ways. Research shows that the electrification of heavy-duty vehicles can be done through the following look: (1) Electric Road systems (induction charging), (2) overhead charging (OCL), (3) Plug-in charging, or (4) fuel cell electric vehicles (FCEV). What are your general perspectives on these different subject technologists?

Researcher:

I think we answered previously that I see that battery charging is the one that is advancing fastest, and has the strongest hold at the moment, while others might have a role.

Interviewer:

What do you think about hybrid solutions? Where there are different types of charging methods combined? Is that beneficial? Or would large battery packages destroy the benefits? Is that kind of combined solution feasible?

Researcher:

I think this is a very interesting field of research where we don't have all the answers. In general, for sure, you will have to put some size of the battery in the solution. In both electrical road systems or on fuel cell electric trucks, you will always have a battery, the question is the size, or should it be charged independently? How do you design it? Maybe there is some golden combination? I think it will be location-specific, and I think for the foreseeable future, battery electric vehicles (BEVs) will have this flexibility and ease of access to charge, so they have a stronghold.

Interviewer:

How do you think these technologies will develop further going into 2030?

Researcher:

I think we have answered it.

Interviewer:

Organizations like CharIn, are trying to make one standard of charging and charging systems - do think this would be the way of going forward in trying to get one standard?

Researcher:

Yes, of course, that is very crucial for an efficient scale-up.

Interviewer:

I think we maybe have covered it earlier as it is addressing some of the same things. But in the specific Norway perspective, which of these technologies (BEVs, FCEV) do you think will be implemented? Battery electric trucks, as you mentioned earlier?

Researcher:

Yes, I'm quite sure. I can motivate it because I think Norway has already very green electricity production and has a very solid grid compared with other countries. So, let's say, it's hard to see the disadvantages. We can also mention that there is a strong community around the fuel-cell electrical trucks. We have examples, ASKO Trondheim was maybe one of the first having FCEVs running, or one of the first in the world, I think it's fair to say. To have the FCEVs ordered and running, and there is still an interest in it. And there are some cases and maybe some more extreme cases in Norway, where you will need to... Or maybe not only Norway, in all the countries there will be extreme/special cases where you need to think, well, maybe these BEVs will have a hard time to compete even towards 2030 with much better battery and range, like when you have too much uncertainty. So, you need to think about more specific applications and where they will be relevant to other technologies.

Interviewer:

Okay, so each solution/case needs to be customized based on the climate and the topography of that country?

Researcher:

Yes. topography and also how you're running the vehicles. For example, in Norway, I think it's a fair question. Like, if you get stuck in a mountain for several hours where you have these vehicles clearing the roads in the mountains, nonstop. Sometimes, like how you're going to have a fast charging there? There might be some special specific case, in which you see that it might work or you have trucks who need to be very super flexible or sometimes need to drive extreme distances. And I think that will be like that in every country so you have these special segments where you think, "Okay, this will not be easy with BEVs no matter how fast we charge the battery", because then you need to have a megawatt charger everywhere, which will not be the reality 2030. Because the bulk part of trucks are driven in predictable patterns and reasonable distances. My best guess it will be BEVs.

Interviewer:

I know that one uncertainty that the customers of the distribution companies are feeling is that, like if you use your phone out in the cold the battery will die quicker, and I think they transferred this assumption to the battery of BEVs because of the harsh climate in Norway, north of Norway, north of Sweden and maybe Finland, or Austria or Germany, where it's quite cold in the winter. How would the BEVs react to this?

Researcher:

I think there is an experience from private cars like you have shorter range wintertime. I am less concerned because I think that effect is smaller for trucks because of maybe two reasons. There are already BEVs that have been delivered where the manufacturer has stated that the winter range is quite good for the first serial produced BEVs. It can be said that a private BEV, probably will never need those 400 kilometers or very seldom do they need those 400 kilometers of range. So, it doesn't matter that on average, it has only maybe 350 kilometers in range. Even on a good day with not so efficient driving, it's not so important to them. While commercial trucks: they (companies) want a truck which they can rely on always so the truck manufacturers will have a different idea about what range they put in the datasheet versus the battery size and take more into account these variabilities. That is one thing. The other thing is a car has very large room/space which you need to heat up. In the winter, it's a larger energy demand relative to the total energy demand of the vehicle. In the truck, you'll have much more energy needed to move the truck forward than to heat this more limited size of the cabin. Buses are a different case because they again have a big area you need to heat up, which is a big energy demand in wintertime. And the third is energy management you have all these new trucks are coming with Smart Energy thermal management of the battery system, which improves a lot the situation of reduced range in a truck compared with, for example, the first Nissan LEAF cars.

Interviewer:

So, as long as there's a good network of megawatts charges, that is not going to be a problem as long as the infrastructure is sound?

Researcher:

For example, for a truck driving a certain distance you need to deliver your goods, and you have planned one stop along the way to do the charging. I think sometimes maybe it can be okay. Okay, now it's I need to add some more charging. So, I added it somewhere. But I think in most cases, it will be, let's say we need 30% more time because we need one more charging, or 20% or 10% more later, so it is an expense. But I think it is too simple to say "okay, as long as we have enough charging everything is gonna be okay". You need to see that logistics match and the costs match. So, it's a bit more complicated and complex picture, then only have enough chargers to feel that it is safe enough to use.

Interviewer:

Okay, so it has to be strategically placed?

Researcher:

Yes, it needs to be strategically placed. And maybe you need to have the trust in technology that it will be able to deliver the service which you are planning for, which is your business. Not like "Oops, now I need to charge half an hour".

Interviewer:

So, it is more up to the logistical planners to make this kind of system work?

Researcher:

Yes, exactly. So, for sure you need to have megawatt chargers. But they cannot say, "Okay, we just put one more megawatt charger here and there".

Interviewer:

I understand. The next question: It is shown that supporting technologies can play a crucial role in the development of heavy road electrical vehicles, like (1) battery technology, (2) smart grid systems or (3) charging infrastructures. Again, if you feel like you have covered this then you just go on, but what are your perspectives on these technologies?

Researcher:

On (1) Battery technology, I think that (BEVs) will be the dominant way, as I foresee it, at the moment it will be the dominant technology, since everything is based on reduced costs, scaling up of production facilities, so it is crucial. On (2) smart grid systems? Yes, for sure, it will be crucial to have cheap enough electricity. It will help a lot to speed up the process. It will maybe not have fast enough deployment, because if you use a grid smarter it is a faster/more efficient way to get access to more energy, and then you could wait 10 years of building new lines and systems. And (3) charging infrastructure, of course. This is of course the technology side. All of this is very closely connected to that policy side. How much? How the government support that you can easily make improvements? Maybe not for battery technology, but smart grid systems and for charging infrastructure. If/When do you have the access to land and the permits that you need? I think that could play a big role and is an easy way for the public policy to pick up good enough speed and advances on that part.

Interviewer:

Could the implementation of a smart grid system make it unnecessary to upgrade the grid?

Researcher:

I think it is one of the main aspects why we are discussing smart grid systems. It is to have a smaller grid and to use it more efficiently. That is kind of the direct motivation for the smart grid system.

Interviewer:

Yeah. I think it may be a covered battery technology already. How do you think these technologies will develop until 2030?

Researcher:

I think smart grid systems, it is a very broad area where we have some technology already advancing and scaling up, and others are coming. It will be a very interesting and needed development especially when more renewables come, which we for sure have in Europe over time. Within charging infrastructure, I hope we will soon see a new standard for these larger-scale chargers. Because the current standard (broadly developed or deployed CCS) is all only up to 350 kilowatts in my best understanding, and for the trucks who will need larger charging effect, larger charging power, and power outtake - and for that, there is not a standard yet. And I think there are a lot of challenges to be solved to make a good general working system. So, better-charging technology will be very important it will develop, and I'm very sure that it will develop - the question is how good/efficient it will be.

Interviewer:

Could you say something about how these technologies possibly could help the development of greening of the grid? Since renewable energies could vary in the production of energy (peaking) and therefore put greater strain on the grid?

Researcher:

Here battery technology is very crucial. And here we also come into one of the challenges of battery technology, because you have a whole spectrum of applications where you want to have batteries - and there is a huge potential growth including the grid support. I think smart grid systems will be important for Greening the Grid for sure. Charging infrastructure will maybe play a minor role in my opinion.

Interviewer:

We may have responded to this one, how crucial the development is? What will be the Norwegian new way of doing it? With charging technology?

Researcher:

I think the solution which will be developed, I think it's going to be adopted on an international level, just as private car charging.

Interviewer:

So, there is going to be a global or a large regional standard and not specific country standards?

Researcher:

Yes.

Interviewer:

What do you see as the potential threats or bottlenecks in the infrastructure expansion?

Researcher:

Yes, I think we have, as I previously mentioned, for trucks, we have a small question mark around the new standard (in charging effect/power) that needs to cover the effects that the power outtake needs for fast enough charging. If we talk about fast chargers, we'll have also a question specifically for fast chargers, there will be a land issue. Where should such chargers be located, especially in urban areas where you don't have so much space? And you have a lot of trucks passing that need to have space to charge up? This would need land. I find it very interesting how these charging solutions will be solved around logistic hubs, which is a question? How much power will be needed? Because it will be typically the cheapest way to charge, by charging over longer times at smaller power outlets during the night. And it is your infrastructure because these fast chargers will be a third-party infrastructure. It will be more feasible/economic for you to have your charger. But if you have maybe 50 trucks in your logistics center where everyone needs to charge, then it would demand investment to create a smart charging system there. The third may be also quite important, it is the lead time for building out the infrastructure of the grid, which will be seen as a bottleneck.

Interviewer:

I read a report from Siemens about challenges regarding plug-in charges, and it pointed out two possible issues, (1) space utilization - there's already little space in the existing truck stops, and if large amounts of trucks are going to charge there is going to be a need for expansion at truck stops where there already is little space. So, this is one issue. The (2) other issue is if there are let's say 20 trucks charging from the same area at the same time with plug-in megawatt chargers. This would create a power demand for one specific area. Would the local grid or the grid be able to handle this if there were such great demand for power in one specific area?

Researcher:

I think for the moment we don't have any electric trucks, and probably for the next years. It depends on how fast that will develop. If it can adjust gradually, since the effect of the new demand per new truck is not that large. Then we will have very nice development, and then I don't think it's going to be such a barrier over a shorter period. Over a longer period, we need to find a good match between grid development and the increasing demand. But I don't find it a real problem with the grid. Because we have industries, which use a lot of power and that's not a problem. I think building out the grid to support the charging infrastructure, I don't think it's going to be a problem. And it will probably not like be like from one day to another, you won't need this huge effect in one location. That's not going to happen. But the question is, will it be able to have smooth enough forecasted demand so that the grid will be built fast enough so that it doesn't become a bottleneck? Because one day you will have this problem with the grid because this, and that might be a barrier.

Interviewer:
Let’s try to connect that energy production with renewable energy. If there's a large demand for energy in that specific area, do you think renewable energies system, I assume that there is going to be a need for our combined systems of different technologies to cover the demand and weather variations and stuff like that, but I do think renewable energies without the baseload of fore example nuclear energy could handle that?

Researcher:
I think it is two separate and not well-connected questions. Because you have the energy system that produces electricity to follow a load, and there is a challenge of having a large share of non-dispatchable production and how you're going to manage that, that is a question. But we need to solve it somehow, and I think there is a separate question if it should be with or without nuclear or hydro, and how is it going to happen. I think that is a problem that's going to be solved, and a smaller share of that energy will need to be used for charging infrastructure. I have a lot of confidence that we will solve how a large share of renewable energy is implemented. Even without nuclear, I think we can solve it one way or another. For example, if there will be a clear value for hydrogen over time, for those who don't want to have nuclear.

Interviewer:
Yeah. I think thanks to you for the clarification of the question and the valuable input. The next question. How would the grid develop till 2030? I think you said that it doesn't need grid development if we correctly utilize smart grid systems?

Researcher:
I think we can offset/delay some of the grid development. The idea of a smart grid system is that a dumb grid will be designed for the peak hour of an extreme day, maybe for just one

hour, like its purpose is to handle that. The rest time you have much lower loads. So, with a smarter grid system, you just increase the capacity factor and the utilization rate of the existing infrastructure. So, maybe smart grid systems will allow us to use the existing grid more efficiently. What is forecasted and what we expect is that you will need to have we will use much more electricity, and you will need to build out the grid. But building out the grid will take time, so maybe the smart grid system will allow/give the grid expansion some lead time. So that lead time will not be such a huge barrier. And this could help that the coming investment in the grid might be smaller and more efficient because of better utilization through a smart grid system. We will need to build more grids, but through the support of a smarter system, we can make the transition smoother and cheaper.

Interviewer:
I have a question about the implementation of renewable technologies. We talked to a Swedish researcher, and he told us that there is a discussion in Sweden is the communes were not going to be able to veto the outbuild of for example windmills or solar panels. This is because people support the climate initiative, but they don't want windmills in their place. What do you think about this implementation strategy?

Researcher:
That is a sensitive question, and it can very fast backfire. Also in Sweden, they have built out the wind to a different scale than in Norway, and it has been much larger acceptance there. So, I think these things you cannot take too easily or be too arrogant about sustainable production.

Interviewer:
I just flew over Denmark, on my way home from the holidays, and I saw that they had a lot of offshore windmills. 500 meters out on the shore., because they have pretty shallow shores on the sand, they could do that solution by the coastline. What do you think of this alternative or solution?

Researcher:
I think it is forecasted that in Europe, the future will be offshore wind. Because Sweden, Norway and Finland are kinds of an exception in the European setting, because they have so vast lands, and therefore you can put windmills in a lot of places. But let's say if you go

to Central Europe then the land is much more valuable. So, because of the population density, you have much more interest in land and have a limited potential for how many windmills you can put up. So, therefore it will be natural to move them offshore, and offshore it is also more resources/interest in expansion. So, it's very natural the next step for Europe. They are moving in that direction.

Interviewer:
Yeah, so space utilization is a more complicated issue in mainland Europe. But what about countries in Europe without a shoreline?

Researcher:
For countries like Switzerland, Austria or Czech it is not obvious. I think in Europe, there will be more focus and I think there's a very large potential in Europe, for PV systems (Photovoltaic systems / solar-powered energy systems). We have some frontrunners, like Germany and also the Netherlands, with a lot of PV systems. Which does not necessarily need to compete so strongly regarding the land or the visual impact, because you can have it on industry roofs (or other un-utilized flat areas) to a much larger extent than what we have today. It will be a development, but I don't think that PV systems alone are the golden solution. It will complement future systems and their energy mix.

Interviewer:
Yeah, I agree. I'd say that our time is running out. Do you have anything to add as the last thing? I think you have two minutes left before it's 10? o'clock.

Researcher:
As a final, as a final remark. I've been especially working with the trucks and how they can decarbonize the sector. And one part, which you get very humble about is the complexity. There is such a diversity in how you use vehicles. In which applications, how they look like, how they are designed. So, it is difficult to generalize too hard. Because you will have lots of different users and cases which you need to consider.

Interviewer:

I agree. The more I read, I understand the complexity of renewable energy production with the grid and everything and transport electrification and the complexities there with battery technology, charging infrastructure and the policies of these decision-makers.

Researcher:

Yes. To try not to swallow too much, because it's too easy. And, but it's an I think we also need to be humble. And there are a lot of unanswered questions.

Interviewer:

Yeah. Sure, that we need to address that in the introduction, in a large way. I appreciate that you had the opportunity to do this.

Researcher:

It was my pleasure. And I think you did very professional work, so it was a nice experience.

Interviewer:

Thank you. I will end the recording now.

--- End of interview ---