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Smart Charging and Innovation in EV Batteries Driving European E-Mobility.

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Abstract

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The substantial growth in the EV market has reached a tipping point, a point which indicates that the development of EVs will continue to grow. However, the EU has started facing unparalleled challenges with its dependence on energy imports and scarcity of raw materials, the two key elements discussed in this study that will support EV development in the EU. The EU has set ambitious goals in developing the energy and e-mobility sector and has provided supporting frameworks such as The European Green Deal and Fit for 55 in assisting a smooth transition to achieve such goals within the time frame.

The objective of this study is to spread awareness among its readers of the challenges and opportunities smart charging brings while also discussing bypassing the limitations of lithium-ion batteries and providing evidence supporting that advancement in both can successfully transform the EU's e-mobility sector while benefiting from each other.

The study is approached by qualitative methodology in investigating, collecting, identifying, and cross-checking the resources used throughout the study for smart charging and lithium-ion batteries while it heavily relies on the use of secondary data. A case study regarding consumer vehicle choices in the EU and a SWOT analysis is applied to strengthen the different perspectives concerning smart charging.

It is to conclude that, smart charging and innovative battery solutions hold great potential but hold weaknesses which require attention to ensure the benefits are claimed to the fullest. Together when aligned with the EU development goals and driven by a motivation for bringing a revolutionary change, both key elements play a crucial role in providing a resilient e-mobility infrastructure by reducing the charging time, enhancing energy density and range, cyclic stability and durability of batteries, improving customer experience, resource availability in the EU, and environmental impact. Ultimately, allowing the EU to become more sustainable by developing an integrated energy system while ceasing the production of ICEs by 2035 and achieving the Net Zero target by 2050.

Keywords: Electric Vehicles, Smart Charging, alternates for lithium-ion battery, Innovation, The European Green Deal.

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Glossary

AC	Alternative Current: It refers to a type of electrical current where electrons are flown back and forth at a definite interval.
AFIR	Alternative Fuel Infrastructure Regulation: Commenced in 2021, this regulation is followed by the EGD, referring to a commitment of all the public chargers to be capable of smart charging by 2031.
BEV	Battery Electric Vehicle: A type of electric vehicle that fully runs on battery and has no secondary source of propulsion.
COP28	2023 United Nations Climate Change Conference: It refers to the 28th annual conference in Dubai in 2023 where governments came together to discuss limiting and preparing for future climate change.
CO2	Carbon dioxide: It is a chemical combination that has one atom of carbon and two of oxygen. CO2 is considered one of the most crucial gases on Earth and yet in excess, it has many harms.
CV	Conventional Vehicle: Vehicles that have an internal combustion engine and rely on fossil fuels to run.
E-mobility	Electromobility: It refers to using vehicles that run on electric propulsion.
EGD	European Green Deal: A set of initiatives to transform the European Union into a green ecosystem, ultimately achieving carbon neutrality.
EV	Electric Vehicle: An EV is a type of vehicle that uses at least one electric motor for its propulsion.
gCO2eq	It is a measurement unit, where one unit is equal to one gram of carbon dioxide emission.

GHG	Green House Gases: These are the types of gases that trap heat, thus increasing the earth's temperature. Some examples of GHGs are carbon dioxide, methane, chlorofluorocarbons, and nitrous oxide.
G2V	Grid to Vehicle: It refers to a unidirectional flow of energy from an electric grid to an electric vehicle to charge it.
HEV	Hybrid Electric Vehicle: A type of electric vehicle that is a combination of at least 2 propulsion systems, one is in the form of an electric motor and the other is an internal combustion engine that uses fossil fuel.
ICE	Internal Combustion Engine: In an ICE, ignition, and combustion of fuel are required within the engine with an oxidizer to generate energy to run a vehicle.
IEA	International Energy Agency: Established in the early 70s, it refers to the autonomous intergovernmental organization that consists of 31 member countries working on the global energy sector to provide recommendations concerning ¾ of the global energy demand.
INTERCEPTS	Interdependent and Complex Electric Power and Transportation Systems: Refers to smart charging infrastructure for EVs.
KWh	Kilowatt-hours: A unit, which is used to measure the amount of energy, where 1KWh is equivalent to an appliance of 1000W using the energy for one hour. The formula for KWh is watts*time in hours/1000.
LIB	Lithium-ion battery: Refers to the most used type of rechargeable battery which consists of lithium-ions that are responsible for transferring the electric current.

MWh	Megawatt-hours: A measurement unit for energy where one MWh is equal to 1000 kWh. The formula for MWh is megawatts*hours.
PHEV	Plug-in Hybrid Electric Vehicle: A type of electric vehicle that has both an electric motor and an international combustion engine, where the battery can be charged using a grid system as well.
RFID	Radio-Frequency Identification: A technology that uses radio frequency to identify an object within the set range.
SWOT	Strengths, Weaknesses, Opportunities, and Threats: A strategic analysis tool that identifies strengths, weaknesses, opportunities, and threats.
SIB	Sodium-ion battery: Various types of rechargeable batteries use sodium ions to carry charge. It is like that of the lithium-ion battery; however, it replaces lithium with sodium as its main component to carry charge.
UK	United Kingdom: It is an island country consisting of 4 countries; England, Scotland, Wales, and the northern part of Ireland.
US	United States: The US is a country in North America with 50 states and the capital Washington, DC.
V2G	Vehicle-to-Grid: A directional technology that allows electric vehicles to send electricity back to the grid system.
V2H	Vehicle-to-Home: Another form of bidirectional technology that allows the flow of electricity from an electric vehicle to a home.
V2X	Vehicle-to-Everything: Another advanced form of bidirectional technology with which the electricity can flow from an electric vehicle to any other electrical appliance.

1 Introduction

1.1 Research Questions and Objectives

Electric vehicles (EVs) are not an invention of the 20th century. The history goes back to almost two hundred years ago (U.S. Department of Energy, 2015). Repeatedly various EVs were designed for reasons different from those in the 21st century. Recent developments in EVs and EU legislation to support sustainability during the 21st century have spurred the e-mobility demands around the world. In 2010, the number of EVs on the road worldwide was almost negligible compared to 1 million in 2016 and 30 million in 2022. In recent years, the EV market has grown enormously and according to The International Energy Agency, the total number of EVs to be on the road will rise to 240 million by 2030, with an estimated increase of 30% growth every year (EVBox, 2021). In the EU alone, an Investment Researcher Jefferies forecasted in mid-October 2023 that the sales of EVs will surpass 2 million by the end of 2023, with an increase of around 50% in 2024, 4.8 million in 2025, and doubling 2025 sales by the year 2030 (Winton, 2023).

This rapid EV growth is also putting strain on the power grid, escalating the need for power to charge EVs. Being able to reach these growing demands has been challenging and will further continue to weigh heavily on the power grids in the EU (Noyens, 2023). Reports from McKinsey predict a potential surge of 13 times by 2030 for the annual charging capacity (Dombrovskyi and Iaskova, n.d.). EV charging is positively impacting the development of renewable energy, however, there is a debate about whether the electricity consumed to charge EVs is sustainable or not. The sustainability factor is directly proportional to the sustainability and renewable goals in the EU (Conte, 2023).

In the era of sustainability, the e-mobility sector has seen one of the highest growths in recent years. Government policies related to reducing carbon emissions and consumer awareness have skyrocketed the production of EVs. With this, two major problems arise. The first one is to meet the raw materials demand to manufacture EVs and the second one is to build an integrated energy system to cope with the energy demands to charge the EVs.

To tackle this challenge, countries are taking the initiative of smart charging to manage and maintain EV charging loads and optimize energy use (www.imarcgroup.com, n.d.). However, scaling the development of revolutionizing the mobility market while aiming to meet the EU sustainability goals requires tackling EU-wide challenges concerning infrastructure, consumer awareness, and safety, as well as the source of energy consumed. In addition, some of the raw materials that are used in manufacturing are scarce and their availability is limited by factors such as market dominance and reusability (Shine, 2022). Furthermore, most of the electricity is generated by non-renewable resources in the EU, and the upcoming fleets' demand raises concerns about our current energy system's capabilities and sustainability (Conte, 2023).

The purpose of this study is to spread awareness of the challenges and opportunities in Smart Charging and delivering alternatives for lithium-ion batteries (LIBs) in the EV market within the European Union. Following are the questions that are further explored in this study to support an understanding of the development of e-mobility and sustainability of the EU:

1. What are the key challenges and opportunities of implementing smart charging infrastructure for EVs in the EU, and how do they impact sustainability and energy grid management?

2. What are the environmental and performance-based limitations of LIBs in EVs, and how do circularity and alternative battery technology promote long-term sustainability?

3. How do smart charging and alternative battery solutions combined with circularity benefit each other and foster sustainability and a green economy?

1.2 Structure of the Study

In the first chapter, the study briefly touches on the evolution of EVs, and how far we have come in developing EVs over the centuries. It also shows the recent choices made by consumers in choosing their vehicles in the EU and presents a comparison between the years 2021 and 2022. The study also intends to examine the new EU regulations affecting the transitions in the mobility market, and the goals that are set to be achieved in the given timeframe.

In the second chapter, the study explains the concept of Smart Charging and how it has many benefits but considering the scope and early-stage development in the field, the study analyses the challenges and opportunities in building an integrated energy grid system in the EU. A SWOT analysis and a case study are used to further support the aim of spreading awareness among the readers in understanding both the pros and cons to weigh contrasting opinions of Smart Charging.

The third chapter further expands its boundaries in exploring the requirement of critical raw materials that are needed to meet the demands of the upcoming EV market in supporting the success of sustainable development goals in the EU within the given target. There have been various recent developments in recycling and finding alternatives to LIBs, which are more susceptible to better performance and sustainability. The literature discusses expanding the limitation barriers on EV batteries, the harms caused due to poor recycling techniques, exploring innovative ideas as an alternative to LIBs, and techniques to recycle and reuse the old LIBs to promote circularity, improve EU independence on raw materials, balancing the demands while keeping sustainability at the core of the process.

1.3 Methodology

As the mobility sector lays the ground for a revolutionary transition from Internal Combustion Engine (ICE) to EVs, the rise of energy and infrastructure needed to support the change must be evaluated to understand the challenges and opportunities that come along the way (TelioEV, 2024). The infrastructure needed in building the charging stations and the LIBs requires rigorous material consumption where some materials have only limited supply to meet the EU sustainable goals that too along with a concentrated market for the raw materials (IEA.org, 2022), (Shine, 2022). This study explores these problems to evaluate what smart charging has to offer and the innovative approach that is required in the EU to achieve the Net Zero Goals by 2050 successfully.

The study uses qualitative methodology in investigating, collecting, identifying, and cross-checking the resources used throughout the study providing evidence that the development of smart charging and alternates for LIBs can transform the EU's e-mobility sector by 2050. The study heavily relies on using the secondary data available in presenting the findings constructively and concisely to relate to the three study questions mentioned in the introduction. The study is limited by qualitative methodology and secondary data due to limited time availability however, the use of quantitative methods can amplify the findings by interviewing corporations regarding their scope of development in smart charging, recycling methods for LIBs, and development of EVs in the EU to help in establishing causation and correlation relationship by analysing the qualitative data used in this study objectively. In addition, a case study regarding consumer vehicle choices in the EU and a SWOT analysis is applied to strengthen the different perspectives concerning smart charging.

The data is collected while ensuring a strong diversity in the resources used for various topics throughout the study. The study also invites contradictory standpoints for the challenges and opportunities in smart charging and consumer choices in the EU. The source includes database articles, EU directives and legal publications, social media, articles available online, and ChatGPT. The implication of ChatGPT is motivated by the study's inspiration to leverage technology by brainstorming with AI. ChatGPT is used at the early stages of planning the study structure and exploring different perspectives on the topic, which are further explored using other sources for the literature review, and no data is taken solely straight from ChatGPT without cross-checking it from other sources.

2 Evolution of EVs and their Demand

EVs are not an invention of the 20th century. The history goes back almost two hundred years ago (Energy.gov., n.d.). Repeatedly various EVs were designed for reasons different from those in the 21st century. The development of EVs over the 2 centuries can be broken down into 6 different stages: the early pioneers of electric mobility (1830-1880), the transition to motorized transport (1880-1914), the rise of the ICE (1914-1970), the return of EVs (1970-2003), the electric revolution (2003-2020), and the tipping point (2021 and beyond) (EVBox, 2021).

The first-ever EV was presented during a British conference by inventor Robert Anderson. It would travel at a maximum 12 km/h speed with a bare minimum range. Advancements in technology and both environmental and economic needs have shifted the trend of EVs over the decades. Fast forward to the late nineties when Toyota Pirus embarked on the journey of becoming the first ever EV to be commercially sold around the world, this was a significant turning point in addition to the growth of LIBs in the early twenties. However, the game changed when the founders of Tesla in 2006 announced the production of luxury EVs with a potential range as high as 320 km on a single charge. Their success spurred great interest in other automakers, and the EV market’s development skyrocketed (EVBox, 2021).

According to IEA, the world requires around 2 billion EVs globally on the road by 2050 to make the transport sector carbon neutral (Shine, 2022). An Investment Researcher Jefferies forecasted in mid-October 2023 that the sales of EVs in the EU will reach 2.1 million by the end of 2023, with an increase of around 50% in 2024, 4.8 million in 2025, and doubling 2025 sales by the year 2030 (Winton, 2023).

Regardless of the challenges faced with the production of semiconductors, disturbance in supply chains, and the rising inflation due to the pandemic and the war between Russia and Ukraine, consumers in the EU continue to choose EVs over ICE. Figure 1 and Figure 2 present the choices consumers made when buying a car in the EU, comparing the years 2021 and 2022 (Bello, 2023).

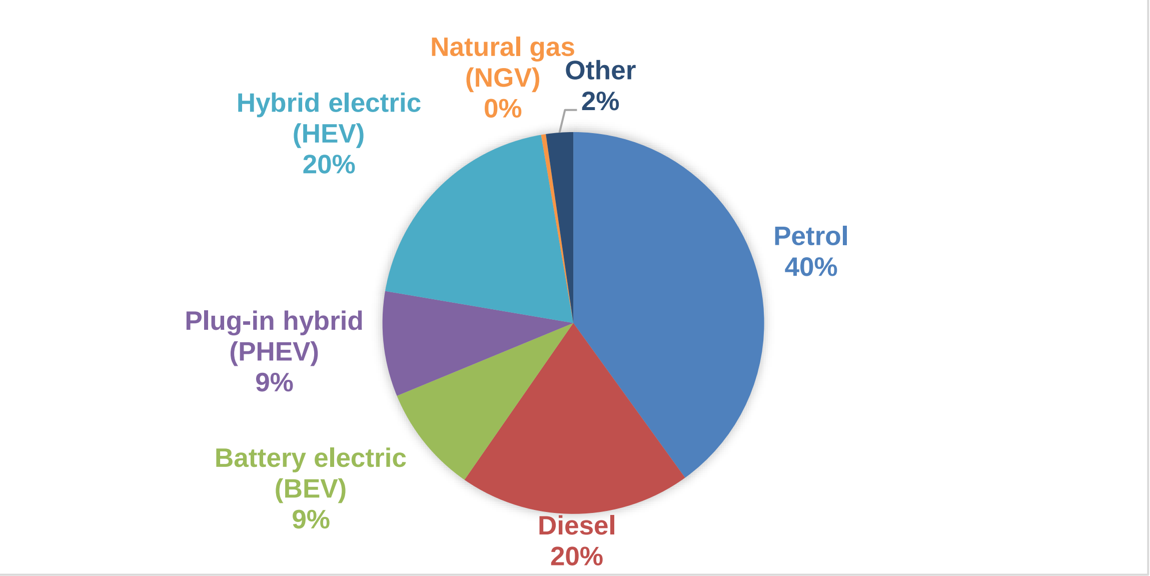


Figure 1 New passenger cars by fuel type in the EU, 2021 (Bello, 2023).

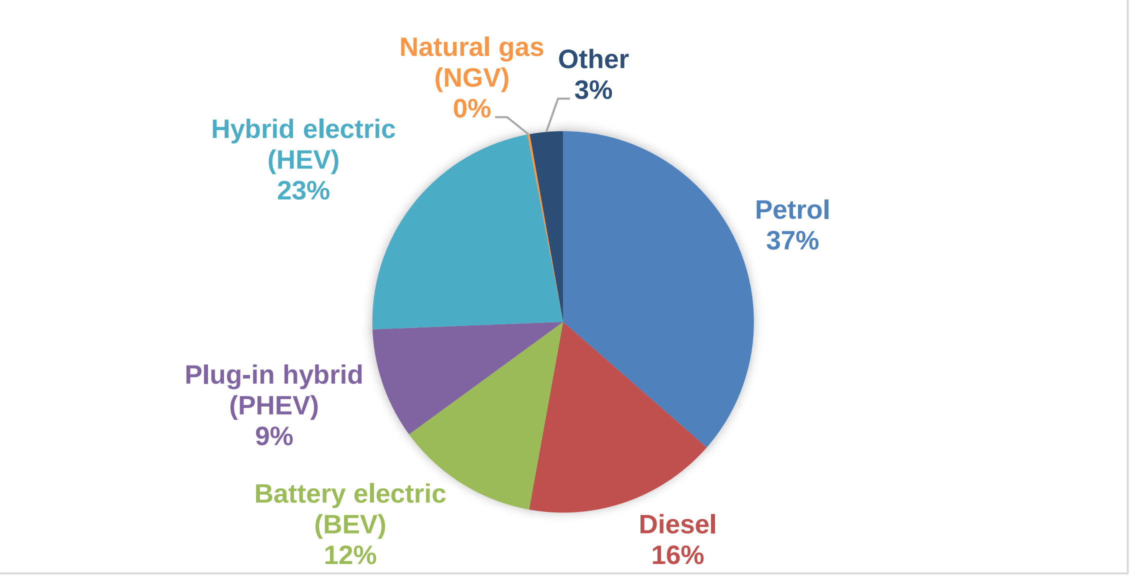


Figure 2 New passenger cars by fuel type in the EU, 2022 (Bello, 2023).

When comparing figures 1 and 2, a noticeable trend among passengers is seen in preferring ICE cars with total sales of 60% in the year 2021 which plunged to

50% after one year. Sales of both BEVs and HEVs were record-breaking in 2022, accounting for more than 12% and 22% respectively which is 3% more in both cases when compared to the previous year. HEV took over Diesel cars intending to surpass Petrol car sales which stands the strongest at 36.4% in the year 2022.

2.1 EU Plans to Reach Sustainable Goals

The European Union started facing unparalleled challenges with its dependence on energy import and scarcity of energy resources, and a strong need to lower climate change to tackle the economic crisis successfully. The motivation was to enhance innovative technology, achieve a better standpoint in the competitive industry, and open high-quality job opportunities in multiple sectors in energy efficiency (EU, 2012). In 2011, the EU Commission decided to adopt a Communication on an Energy Efficiency Plan. The goal was to limit the levels of Carbon dioxide (CO2) emissions by setting standards that affect all models of vehicles and to address all kinds of propulsion systems (EU, 2012). It was also stated in the Official Journal of the European Union 2011 that municipalities and several public bodies joined forces towards an approach of developing integrated plans for energy savings and energy supply. Member states and public bodies were urged to spread awareness among the citizens to encourage the plan of sustainable energy consumption and adopting the integrated urban approaches, resulting in energy efficiency and implementation of the energy management system. This exchange of energy experience between cities and towns must be encouraged concerning the development of innovative experiences (EU, 2012).

According to McKinsey & Company (2021), we have reached the tipping point in terms of EV infrastructure. In this place, the growth has unstoppable effects, meaning even when the future is unprecedented, the trends have a strong indication that it will only continue to grow and requires intensive innovation in charging infrastructure and sustainable alternatives to combustion engines to achieve both carbon neutrality and energy efficiency in the Union (EVBox, 2021).

Over a decade, the EU has laid out significant improvement plans for creating sustainable societies within the EU Directive 2012 and 2021, as part of the European Green Deal which is further explained in more specifics under section 3.3.3 of this study. According to an updated 2021 version of the Official Journal of the European Union, greenhouse gas emissions were lowered by ¼ while the economy saw a boost of 60% between 1990 and 2019. All the sectors covered by the greenhouse gas allowance within the EU, including transport, energy, and heat should contribute positively to meeting the target of achieving carbon neutrality in 2050 (EU, 2021). While there has been considerable expansion towards renewable energy from 2011 to 2021, the fact that many countries are still dependent on fossil fuels raises the question of whether having an EV is a sustainable option (Conte, 2023).

3 Smart Charging

EV smart chargers lead the way toward efficient and smart charging solutions, becoming increasingly important given the rising demand for EVs (Zorko, 2023).

3.1 What is smart charging?

Smart charging refers to a charging technique where four parties are constantly communicating over the cloud with each other to improve functionality, optimize energy demands, and provide accurate data. This flow of communication streamlines convenience when compared to the conventional way of charging. The four parties involved in the smart charging environment are, the EV, the smart car charger, the Charge Point Management System, and the utility network (Zorko, 2023). Smart charging includes both unidirectional and bidirectional charging. Unidirectional charging is the flow of energy from the grid to appliances or EVs, on the other hand, bidirectional charging allows the flow of energy in both directions. For instance, the energy can flow from Grid-to-vehicle (G2V) and Vehicle-to-Grid (V2G) in a bidirectional flow. Smart charging has two more concepts; Vehicle-to-home (V2H) and Vehicle-to-load (V2L). V2H is when the energy from an EV is used to power a home or business and V2L is when it is used to power appliances (Svarc, n.d.).

In addition, when connected to smart charging, it allows storing the energy during periods of low demand and sending the energy from an EV battery back to the grid system during peak times using V2G technology, contributing to grid stability and environmental sustainability. Another concept is Vehicle to Everything (V2X), with this interface users can provide electricity from the vehicles to their household, build electrical boards, or power other things (Virta, 2023b). Smart grids are designed to prioritize the use of renewable energy such as wind and solar (www.imarcgroup.com, n.d.). Below is Figure 3 which shows how the flow of energy works using V2G and G2V.

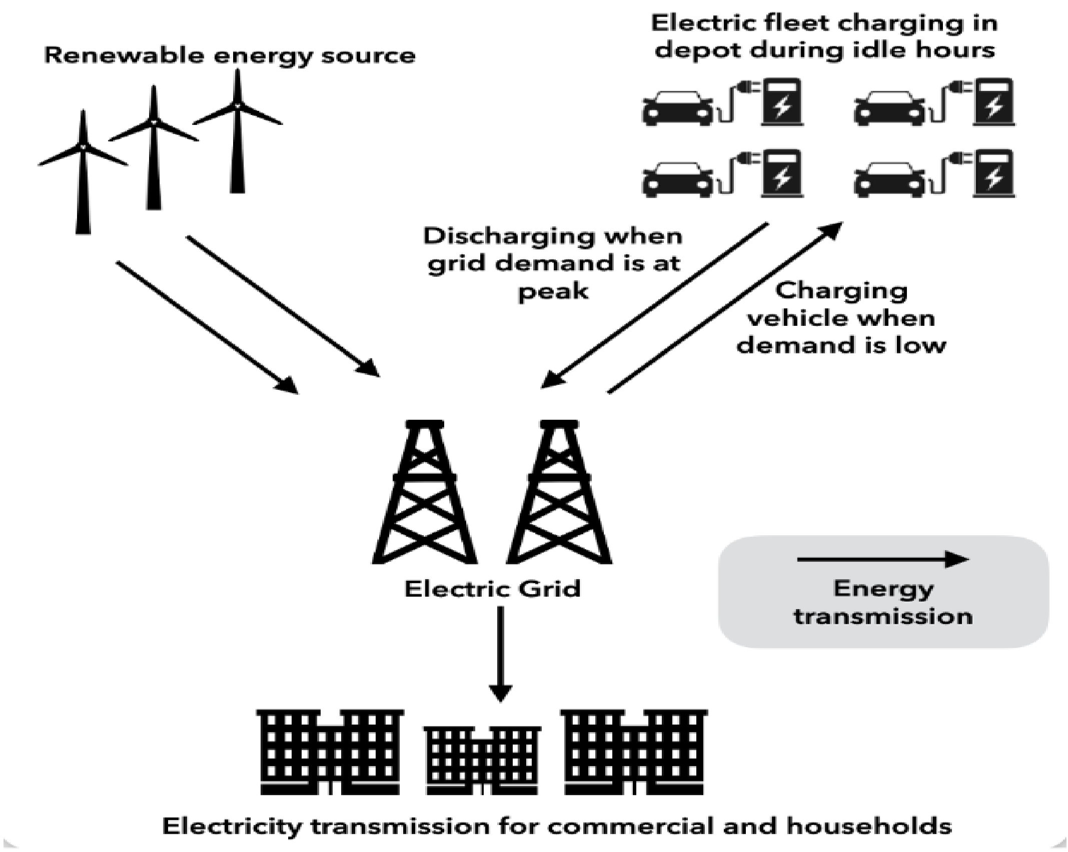


Figure 3 Flow of energy using V2G and G2V technology (PTOLEMUS Consulting Group, 2023).

The trend in bidirectional charging is influencing EV manufacturers and energy grid operators to enhance their capabilities towards smart charging and providing such technologies in their models and services (www.imarcgroup.com, n.d.).

3.2 Market Growth

The rising popularity of smart grids is positively impacting the demand for the V2G market. With the growing environmental concern and market demands for EVs, the motivation behind smart charging is its capabilities to support the development of renewable energy, reduce carbon emissions, and enhance grid stability, reliability, and efficiency, it is a win-win situation for everyone by making smarter use of renewable energy.

- EV drivers can monitor the electricity prices, charge when prices are low, and sell through V2G when prices are high.

- Power grid operators can analyze and monitor the load on the grid system and prevent overloads.

As part of the EU's sustainable goal, government, and public bodies advance in attaining an integrated system for optimizing energy efficiency and promoting sustainability in the e-mobility sector.

However, the exponential growth in EV sales has a direct impact on the power grid system. The more EVs there are, the more electricity is required to charge them. Meeting the growing electricity demand has been challenging in many parts of the world including the EU (Noyens, 2023b). According to McKinsey’s latest report on the energy demands in the EU, there can be a significant charging capacity gap as the energy demand can reach up to 132 billion kilowatt-hours annually in 2030 when compared to just 10 billion kilowatt-hours in 2020, as shown in Figure 4 below (Dombrovskyi and Iaskova, n.d.):

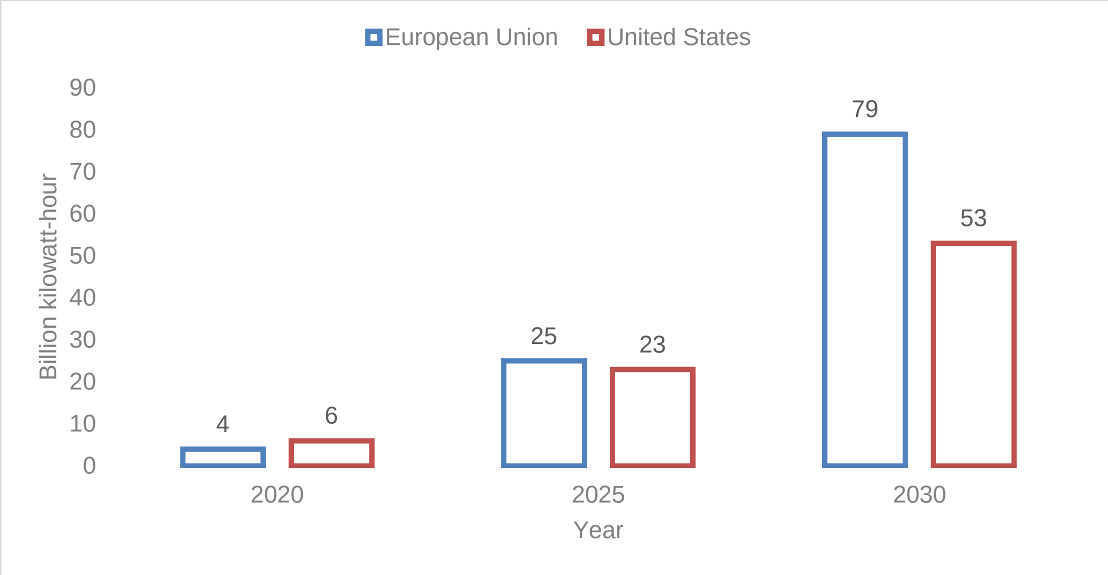


Figure 4 Total charging energy demands for EVs in the US and EU in billion kilowatt-hours (Dombrovskyi and Iaskova, n.d.).

With the rising energy demand, the demand for smart charging is also increasing. V2G is one of the most prominent technologies to efficiently respond to the upcoming demands. It is estimated that the V2G market will grow over 5 billion dollars between the years 2020 and 2024 (Virta, 2023a).

3.3 EU standards are changing the game.

The adoption of EV smart chargers in the EU is ignited by various actions taken to reduce the carbon emissions in both transport and energy sectors and combine them with a decentralized energy system. The initiatives taken in the EU are as follows:

1. Smart Charging Alignment for Europe (SCALE): It refers to a 3-year European project that focuses on developing smart charging solutions for EVs. It consists of four objectives (POLIS Network, n.d.; Dombrovskyi and Iaskova, n.d.):

a. Making available Vehicle-to-Everything (V2E) for the mass-market. V2E is a comprehensive term used for V2G, V2H, and V2L combined.

b. Developing a user-centric approach to maximize people using the plug-in technology.

c. Making the accessibility between users and feet flexible.

d. Making sure smart charging is widely available in the EU.

2. The European Green Deal (EGD): In late 2019, members of the EU state understood the urgency of climate change and emphasized the importance of transitioning towards a "resource economy" within the EU, with a commitment to improving economic growth despite not being dependent on non-renewable resources (Noyens, 2023).

3. Fit for 55: Driving from EGD, this directive stands for reducing carbon emission in the EU by 55% by 2030 (Noyens, 2023).

4. Alternative Fuels Infrastructure Regulation (AFIR): Commenced in 2021, this regulation is followed by the EGD, referring to a commitment of all public chargers to be capable of smart charging by 2031 (Noyens, 2023).

3.4 Challenges in Smart Charging

As we have briefly discussed earlier the role of smart charging in achieving the EU's sustainable goals and meeting the upcoming market demands in energy and the e-mobility sector, comes with a handful of challenges and arguments on its viability. Such challenges and arguments are discussed in section 4.4 of this study.

1. High Initial Cost of Implementation

The European Union leads the world in the adoption of EVs. With member states contributing to over a quarter of the world's EV production and EVs making up around 20 percent of new car sales in 2021 in the EU. It presents a unique opportunity to establish a leading EV ecosystem that can result in job creation, reduced air pollution, progress towards climate goals, and positioning Europe as a leader in EV technology (Conzade et al., 2022).

However, to encourage the adoption of EVs, the EU needs to expand its EV charging infrastructure. In 2021 there were 375,000 charging stations across the continent. McKinsey's analysis for the European Automobile Manufacturers Association estimates that the EU will require at least 3.4 million operational public charging points by 2030. This expansion will make it necessary to upgrade the utility grids for better electricity distribution and increased renewable energy capacity to power the future of more environmentally friendly EVs. In total, the development of the EV charging network could amount to, more than €240 billion by 2030. Below (Figure 5) is an estimate of the investment needed in the public EV-charging infrastructure, Grid upgrade investment, and Energy demand for EV charging (Conzade et al., 2022).

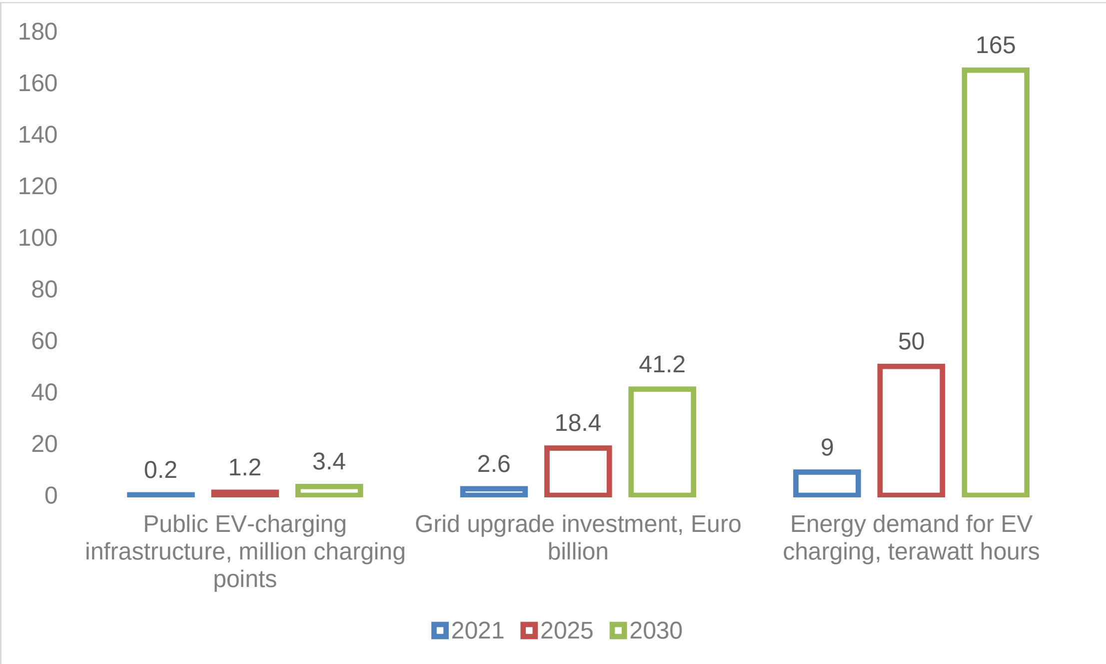


Figure 5 Infrastructure, grid, and energy requirement for growth of EVs in the EU (Conzade et al., 2022).

The cumulative investments until 2030 in € billions for Public EV-charging infrastructure, grid upgrade investment, and energy demand for EV charging are 40, 41, and 74 billion € respectively (Conzade et al., 2022).

These findings have implications for a variety of the groups involved, for instance, manufacturers of charging equipment would require a ramp-up in their production capacity. On the other hand, operators of charging points could explore partnerships with utilities to manage the anticipated surge in power demands. Moreover, automobile and truck manufacturers must be prepared to adjust to evolving consumer preferences. In addition, the potential social disparities that may arise from the implementation of this infrastructure are a cause of concern however, fortunately, by embracing design and undertaking coordination, we can strategically invest in ensuring that the infrastructure remains accessible to everyone (Conzade et al., 2022).

2. Data and Privacy

In today's data-driven world, where technology is becoming increasingly interconnected, the concerns for data safety and cyber security have been the centre of attention. This holds for also the technologies in smart charging where a variety of data is collected and processed. There is a need to understand the importance of privacy related to data in smart charging to oversee it with the highest standards (Syed, 2023).

Smart charging services are deployed on advanced programming where data is collected and analyzed to support the development of these services and enhance the customer experience to facilitate reduced costs and energy efficiency. This information is based on the user's charging habits, amount of consumption, the duration of charging, and personal details such as the user's location to name a few. This personal information when managed wrong or in an occurrence of misuse can be vulnerable to privacy breaches. For this reason, companies must take measures to protect the data and ensure consumers' data safety trust. That brings us to the question, what are the measures required to ensure data privacy in smart charging? Syed (2023) explains five measures listed below (Syed, 2023):

1. Use of anonymous data instead of personal data: As discussed, smart charging collects a large quantity of data to analyze habits, preferences,

and locations. This can be improved by replacing it with anonymous data to reduce personal data storage and avoid data leaks.

2. Data encryption: There are multiple levels of data encryption but not having any makes the data vulnerable to hackers trying to gain access. The process of encryption works as an added layer of security to protect the data.

3. Data storage: Only storing the relevant data anonymously and excluding information such as user login credentials.

4. Transparency: Customers are getting more aware of how companies can potentially use their data for marketing and third-party sharing, so it is important to be transparent about privacy practices and inform customers about how the data is being stored and managed.

5. Continuous improvement: Technology is constantly changing; hackers are developing new ways to steal data, so companies are required to stay ahead in the game and constantly improve their way of working to provide the best privacy practices and make improvements where needed.

3. Compliance and Regulations

With the installation of EV smart charging bringing many advantages, it is crucial to meet certain requirements to allow the integration of renewable energy sources in a beneficial way. Governments are actively bringing new regulations to optimize and enhance the charging infrastructure and overall experience. Two of the major regulations proposed in the EU to reduce carbon emissions from the mobility market are Fit for 55 and the EU Green Deal (EGD) (Noyens, 2023). Figure 6 below shows the tentacles of EGD's ambitions toward transforming the EU:

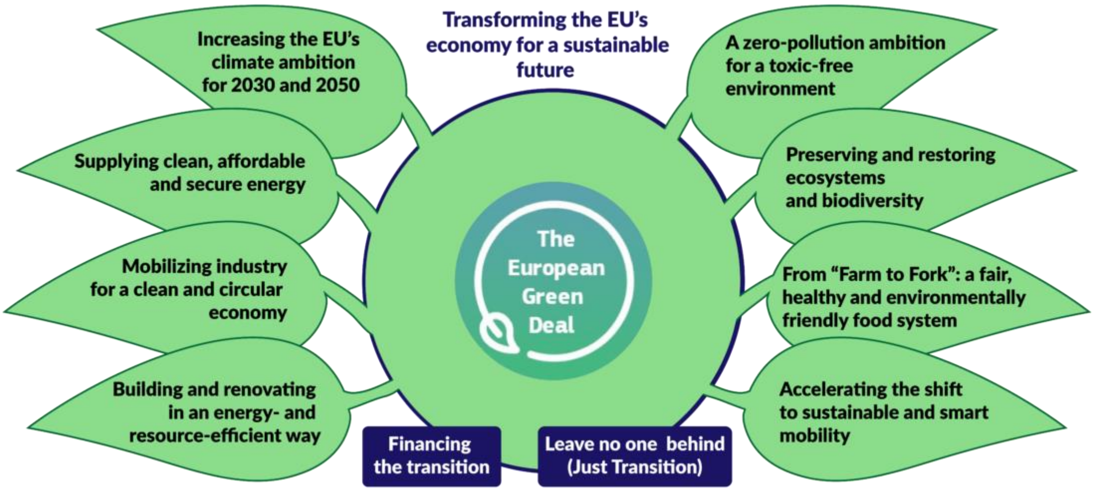


Figure 6 The European Green Deal and its ambitions in transforming the EU's economy for a sustainable future (Umbach, 2020).

EGD consists of around fifty policies which are supported by more than one trillion € in funding. Its motive is to make the EU the first continent to be carbon neutral by 2050, which will significantly lower the EU's dependence on fossil fuels and energy and reduce Green House Gases (GHG) emissions by more than 50% when compared to the levels of the 90s (Umbach, 2020).

Fit for fifty-five is derived from the EGD and refers to a set of legally binding detailed proposals for cutting down 55% of carbon emissions by 2030 and a ban on producing ICE vehicles by 2035 in the current twenty-seven member states. This poses a challenge to transition to e-mobility, in terms of which, the government formulates the regulation to have all the newly publicly accessible charging stations in the EU be digitally connected and equipped with smart charging technology, under the AFIR proposal which is part of Fit for 55 Package deal. AFIR is one of the most actively discussed policies in the EU that explains the legislative framework for public charging in the next 10 years. Additionally, AFIR discusses the need for V2G technology in chargers where it is appropriate, depending on the assessment of each Member State. Besides that, the Renewable Energy Directive III would require all private charges to be equipped with smart charging, allowing EV drivers to analyze their consumption and optimize charging behaviours (Noyens, 2023).

In addition, there have been developments in the 2023 United Nations Climate Change Conference (COP28) which took place in Dubai from 30 November 2023 to 13 December 2023, supporting the ambition of reducing carbon emissions towards net zero by 2050, with a focus on accelerating urgent actions in the upcoming decade. This includes a transition to renewable resources and reduced global emissions by 43% by 2023. The EU has dedicated a record-breaking amount of funds to the international climate transition (European Commission, 2020).

4. Adoption

(Ipsos, 2022) EVs are not an invention of the 20th century, but the EV evolution has picked up a significant pace in recent years and plans to transform the mobility and energy sector in the next decade. This process requires everyone involved to adapt to the change, and change can sometimes be particularly challenging, especially something that is practised on a global scale. Consumers have demands and preferences related to location, cost, sustainability, and reliability of the smart charging infrastructure, and these demands put pressure on the government and the EV manufacturers.

In this context, a case study was conducted by EVBOX involving four countries in the EU: Netherlands, Germany, France, and the UK demonstrating the behaviour of the general population, potential EV adopters, and EV drivers regarding the adoption of EVs.

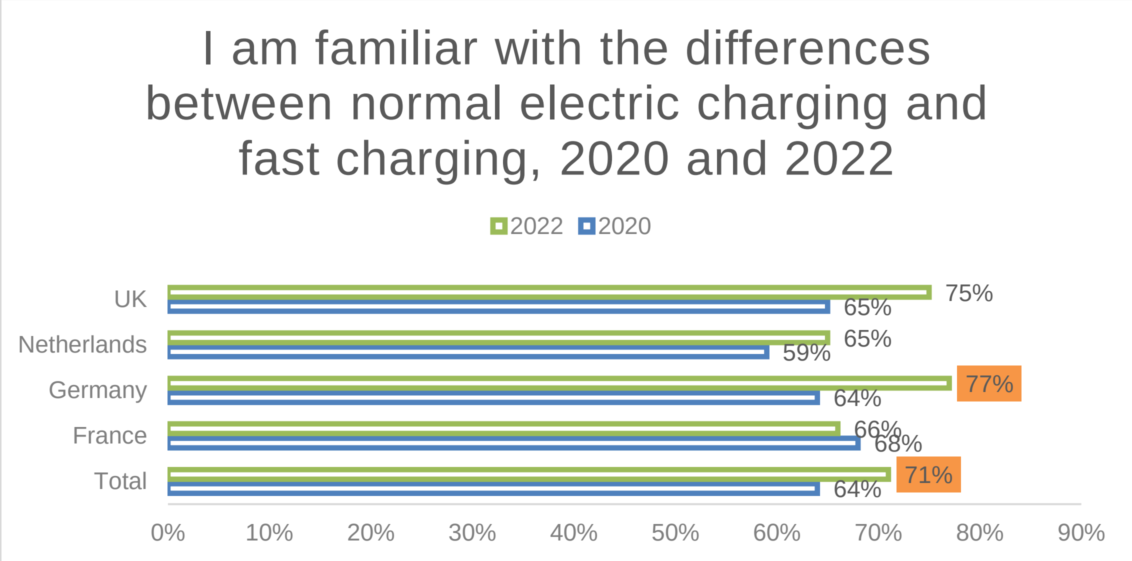


Figure 7 The figure shows the familiarity of normal and fast electric chargers among the residents of France, Germany, The Netherlands, and the UK (Ipsos, 2022).

According to Figure 7, 4/10 of EV drivers do not feel confident in their country's EV charging infrastructure. There is a surge from 2020 to 2022 in Germans finding the difference between normal electric charging and fast charging, from 64% to 77%.

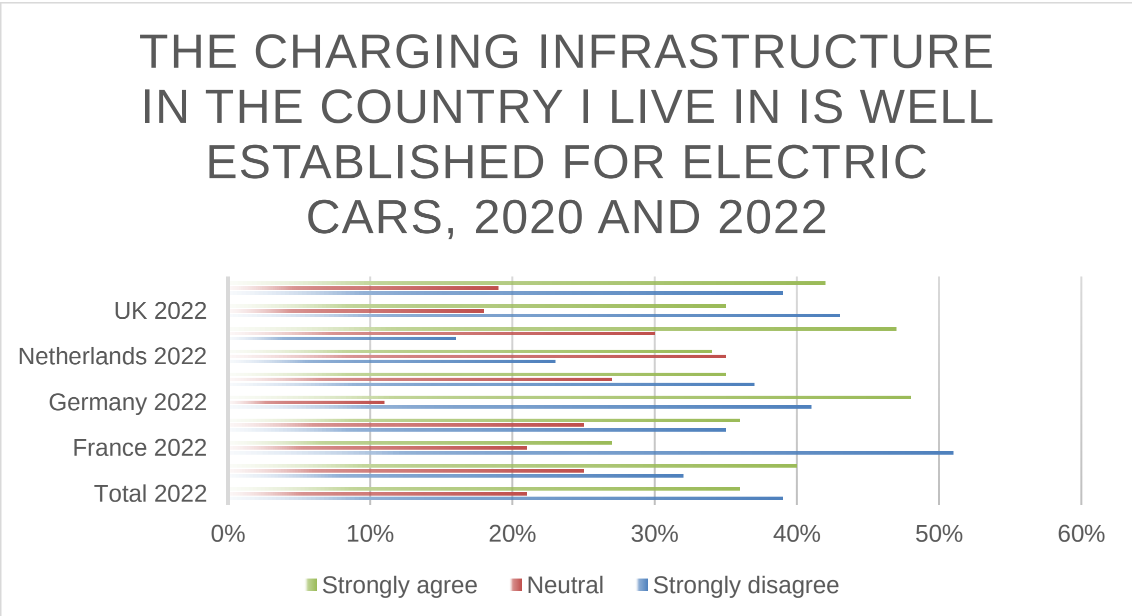


Figure 8 Shows the confidence people have in their charging infrastructure in France, Germany, The Netherlands, and the UK (Ipsos, 2022).

In Figure 8, we can see that more than half of the French population strongly disagrees that the charging infrastructure is well-established for EVs. We can also see a trend from 2020 to 2022 in all countries except Germany, the rate of people agreeing on a well-established EV charging infrastructure has plunged.

In addition, as shown in Figure 9, close to 50% of potential EV drivers are unsure where to buy a charging station.

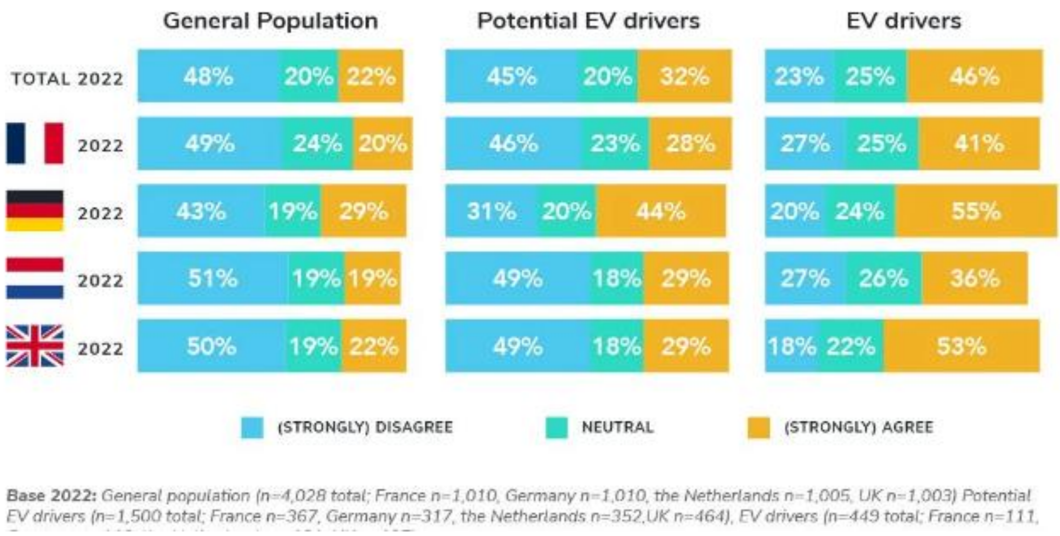


Figure 9 Illustrates the opinions of residents from France, Germany, The Netherlands, and the UK on knowing where to buy an EV charging station in the year 2022 (Ipsos, 2022).

The positive side is that around half of the EV drivers know where to buy a charging station if needed, but we can conclude that better awareness is needed among the general population and potential EV drivers on obtaining functionalities of EVs, such as a charging unit.

Another question has shown that the two most key factors determining the sale of EVs are energy efficiency and a user-friendly interface. However, there are multiple reasons shown below in Figure 10 among different countries.

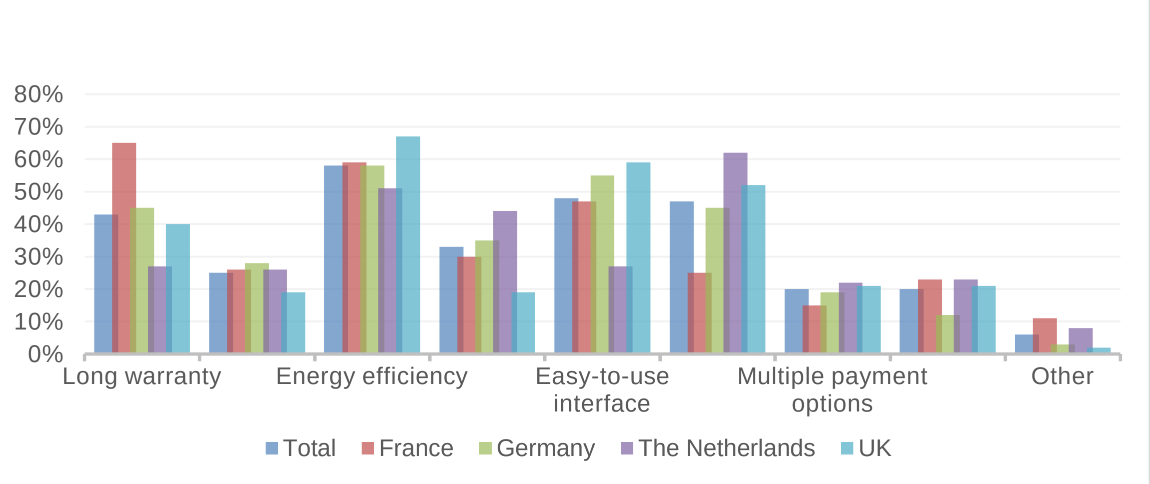


Figure 10 Shows the priorities of residents in France, Germany, The Netherlands, and the UK that influence their decision to buy an EV in the year 2022 (Ipsos, 2022).

The top four most influential elements of prioritizing residents of all four nations to buy an EV were long warranty, Energy efficiency, user-friendly interface, and clarity about charging session fees. On the contrary, the least elements that influenced the general population's decision were multiple payment options, accessible by any kind of user, maintenance service, and others.

5. Interoperability

(ElaadNL, n.d.) The types of different EVs are rising, including cars, trucks, vans, and even electric planes. At the same time, the types of EV chargers are also expanding. This becomes a problematic situation when EVs are not able to communicate with the charging infrastructure in the same language, or vice-versa. This is where the concept of Interoperability is applied, it refers to a way where different systems can connect and communicate in a coordinated manner without the need for an end user. It is also referred to as open communication and is considered one of the key elements to accelerate the adoption of EVs, promote innovation, and minimize cost while shaping the e-mobility sector towards improved sustainability.

Open standards are part of open communication that provides a set of rules and guidelines for communication. The connections of open standards are explained below:

1. Open Charge Point Protocol (OCPP): This refers to a globally and openly communicated protocol between the charging station and the central system of the charging station. It is used for charging transactions and can transfer data between vehicles and the electricity grid.

2. Open Smart Charging Protocol (OSCP): A protocol where data is communicated between the charging system and energy system regarding a 24-hour forecast of the grid's available capacity. It helps the service provider in adjusting the EV charging profiles while considering the limits of the capacity available.

3. Open Charge Point Interface (OCPI): An open protocol between operators and service providers. This provides a variety of accurate information regarding the location, availability, and pricing, manages real-time billing, manages bilateral roaming, and works as a platform for mobile access to charging stations.

4. Open Automated Demand Response (Open ADR): To maintain the demand and supply for energy, a standardized way of communication over the Internet is required. Using the Open ADR technology, DR signals can be communicated among electricity suppliers, system operators, and customers.

5. ICE 61851 and ISO 15118: Both standards were developed to ensure a basic level of communication. Parties involved in ICE 61850 are the charging point and the energy supplier, meanwhile, ISO/ICE 15118 communicates between the EV and the charging point.

6. Roaming: It is common for the EU to drive through the continent using their vehicles, to facilitate charging available to everyone within the EU,

roaming standards are required at any given charging point. This intergenerational step supports the innovation and adoption of EVs in the EU.

To solve the above-mentioned problem discussed in connections with open communication, both the EV and the charging infrastructure need to comply with each other. A software update in the charging infrastructure is our one-step solution in most cases.

6. Battery degradation

V2G is a powerful technology that can stabilize energy demands during peak hours by selling the electricity back to the grid. According to an estimate, EV owners can save around €850 – €1450 in a year. Companies such as Nissan, Hyundai, and Volkswagen are introducing more models that support V2G technology, along with new charging stations installed with smart charging capabilities. (PTOLEMUS Consulting Group, 2023).

However, as paramount as V2G is, it comes with a challenge. During the process of charging and discharging, electors are damaged, and this causes the LIB to lose its full capacity over time (Minos, 2023).

According to researchers, the use of V2G technology two times a day can lead to a 75% capacity reduction in approximately 5 years, meanwhile, using it once a day can reduce the battery capacity by 33%. If this is the case, companies would need to reconsider the battery warranty that is currently around 10 years in the EVs and it would also significantly affect EV sales, as the cost of a LIB weighs heavily on its price (PTOLEMUS Consulting Group, 2023).

On the contrary, studies conducted at the University of Warwick suggest that managed use of V2G can enhance the use of batteries and reduce battery degradation (PTOLEMUS Consulting Group, 2023).

To conclude, the use of unregulated and unmanaged V2G can be harmful to batteries by reducing their range and residual value. This brings a necessity to find smart and innovative ways to adopt V2G which supports a sustainable future for the e-mobility sector (PTOLEMUS Consulting Group, 2023).

7. Sustainability as a Challenge

The energy used in charging the growing demand for EV fleets raises whether the source of electricity in the EU aligns with those sustainable goals derived to establish an environmentally friendly eco-system. To achieve NetZero targets of carbon neutrality, the source of energy generated demands clean energy (EU, 2021). Many countries are shifting towards renewable resources, however, as shown in Figure 11, around half of the European Countries are still dependent on electricity generated from fossil fuels. This poses a challenge to the reliability of sustainable use of energy in smart charging.

According to the data derived from the research done by Electricity Maps and the IEA, 25% of EU’s electricity comes from nuclear energy, 20% from Natural gas, 14% from coal, 26% from Hydro and Wind, 6% from Solar, 5% from Biofuels, Petroleum contributes to 2% and another 2% from other sources. Germany accounted for generating 34% of its electricity using coal, where wind energy is a close second at 25%. Moreover, out of all the European countries, Sweden has the lowest carbon intensity of 37 gCO2eq/KWH, whereas Poland has the highest at 866 gCO2eq/KWH (Conte, 2023).

Among others, the UK, Netherlands, and Italy are primarily dependent on natural gas-powered electricity in the year 2021, where Italy is the most reliant of the three at 42% followed by the Netherlands at 40% and the UK at 38%. All three nations are not too far from each other (Conte, 2023).

Europe has taken steady steps in transitioning towards renewable resources of energy, The data below shows the difference in sources of energy generated in the EU over a decade (Conte, 2023). Figure 11 shows the source of electricity in Europe by Country (Conte, 2023):

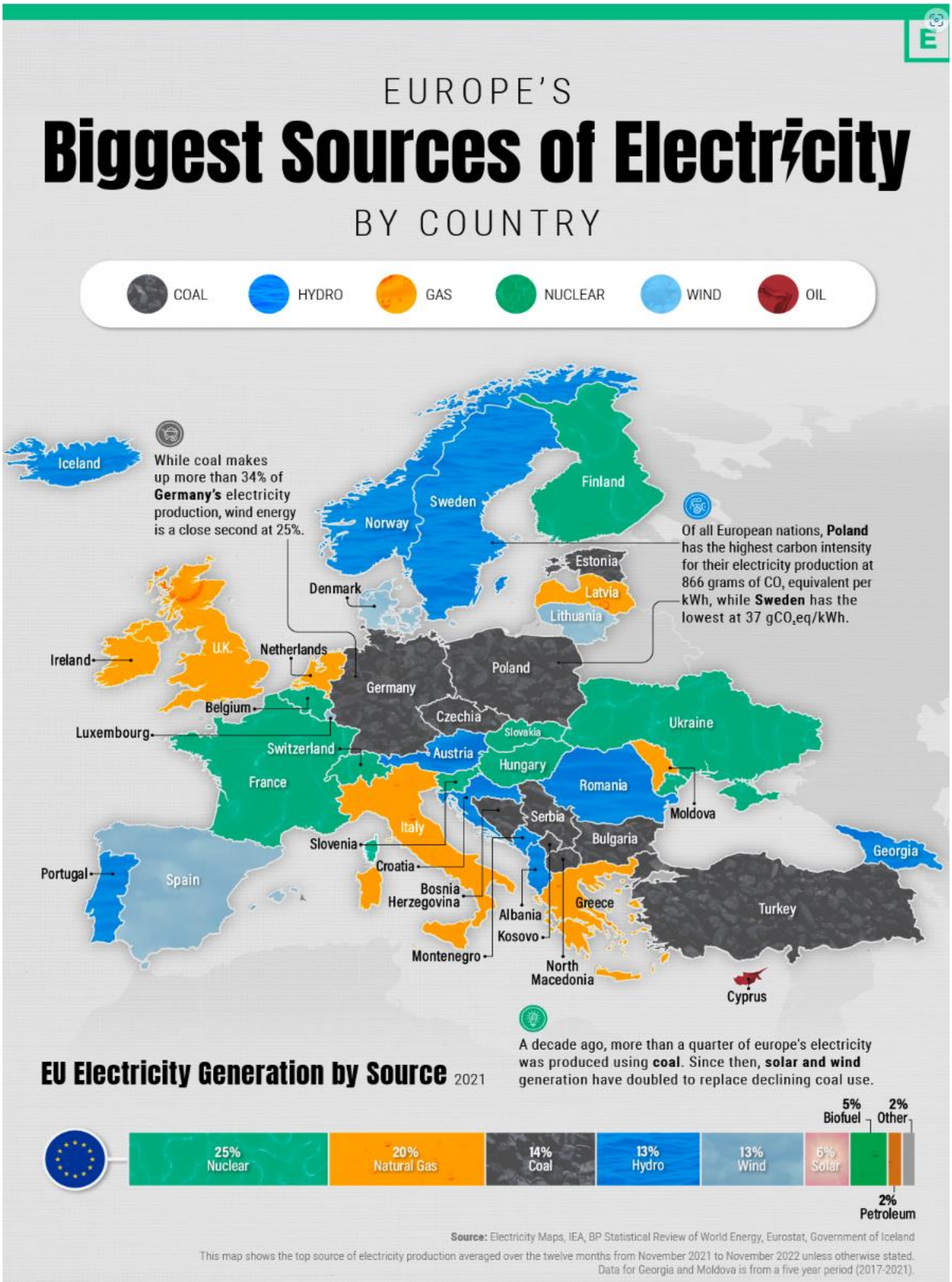


Figure 11 Europe's biggest source of electricity by country, from November 2021 - November 2022 (Conte, 2023).

Please note that in Figure 12, fossil fuels emit carbon emissions and are non-renewable and non-sustainable, so they are marked in colour red, and renewable and natural energy sources are in green, nuclear energy is marked in yellow because even though it does not emit enough carbon emission to categorize as non-sustainable, however, it is a non-renewable source of energy, and other sources are marked in blue.

Source	EU Electricity Generation Share (2011)	EU Electricity Generation Share (2021)
Nuclear	29%	25%
Coal	25%	14%
Natural Gas	19%	20%
Hydropower	10%	13%
Wind	6%	13%
Oil	5%	2%
Solar	2%	6%
Biofuel	4%	5%
Other	n/a	2%

Figure 12 Illustrates a comparison between the years 2011 and 2021 for the source of electricity generated in the EU (Conte, 2023).

In both years, nuclear energy has dominated the electricity source, however, in 2021, the dependency on fossil fuels which includes oil, natural gas, and coal plunged from 49% to 36% when compared to the year 2011. In addition, during a shift of 10 years, renewable energy made up 32% when compared to only 18% back in 2011. Another prominent development can be seen with the expansion of wind and solar-based electricity, rising more than twice in 10 years, and reaching 19% in the year 2021 (Conte, 2023).

In Figure 13, we can see the highlight of the highest share of each energy source in the EU, in 2021 (Conte, 2023). Please note that colour shades are allocated below from red, yellow, and green according to their share where red is marked with the highest value and green with the lowest.

Country	Energy source	Energy value
Malta	Solar	11.60%
Denmark	Wind	48.60%
Austria	Hydro	60.10%
France	Nuclear	68.40%
Poland	Solid fossil fuels	71.10%
Malta	Natural gas	86.10%
Cyprus	Oil and petroleum products	84.90%

Figure 13 Highest shares of each energy source in the EU, 2021 (ec.europa.eu, 2023).

While the development of renewable energy sources sounds promising in the EU, the energy sector is still being dominated by non-sustainable and non-renewable sources to produce electricity. There is room for improvement to reduce greenhouse gas emissions and mitigate climate change (EU, 2012).

3.5 Opportunities in Smart Charging

Smart charging is a state-of-the-art technology that has the potential to create a thriving ecosystem that uses renewable energy, is sustainable, unlocks opportunities to build integrated charging infrastructure, enables balancing energy demands during peak periods, and ultimately increases the adoption of EV fleets and maximizing sales. Some of the many opportunities that come with smart charging are discussed in more detail below:

a. Sustainability as an Opportunity

Studies show that around 50% of Finnish consumers have opted for EVs to minimize carbon emissions while 70% of consumers would prefer to opt for an EV for environmental reasons in the US. However, the question that needs to be discussed is how clean the EV charging depends on the source of energy used (Hämmäinen, 2023).

As discussed in section 4.4.7 of this study, Nuclear energy is the most dominant source of energy in the EU, and even though it has been on a decline, nuclear energy is considered sustainable energy, because it commits untraceable levels of CO2. This has a positive impact, as nuclear energy helps in achieving carbon neutrality, as part of the NetZero 2050 directive.

Since the commencement of the Russian-Ukrainian war, countries in the EU have given utmost importance to energy independence, and many countries are taking the opportunity to accelerate their transition towards renewable energy sources (Conte, 2023).

According to a report from Ember, there has been notable development with solar and wind energy in 2022, making up 22% of the total source of energy generated in the EU, exceeding natural gas at 20%. On the contrary, the EU has also seen a slight increase in fossil fuel electricity generation in 2022, but it is predicted to decline by as much as 20% in 2023. This allows the EU to boost the shift towards renewable energy that promises low carbon emissions (Conte, 2023).

One of the multitudes of benefits that smart charging brings is the freedom for consumers to charge their fleet when electricity is available from renewable sources (Hämmäinen, 2023). According to the report “How to maximize emissions reduction by Smart Charging EVs” (Daneils et al., 2022), consumers can save around 400 KG of CO2 per vehicle annually when optimized charging is used. It further depends on other factors such as location and the source of energy. For instance, Figure 12 shows Finnish CO2 intensity in January 2023. If an EV with a 50-kWh battery is charged at the lowest CO2 range, it can save 3.5kg of C02 in one charge session using smart charging (Hämmäinen, 2023). Below, in Figure 14, a detailed analysis of CO2 intensity in Finland is shown for us to better understand the fluctuation on different days:

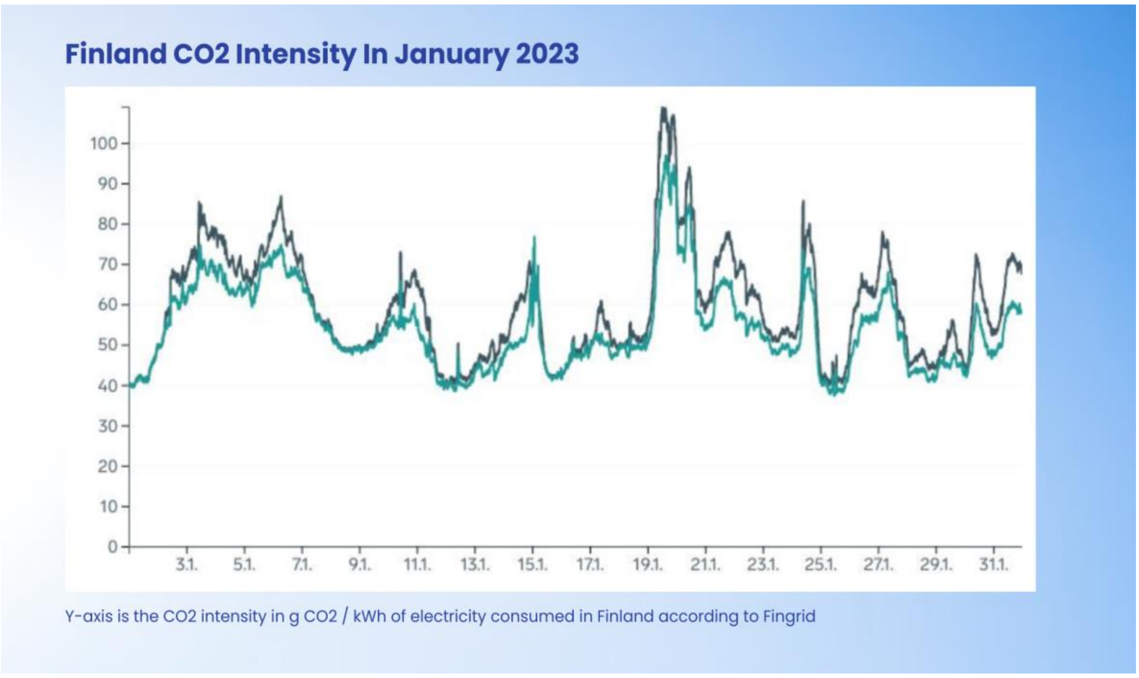


Figure 14 Finland's CO2 intensity in January 2023 (Hämmäinen, 2023).

Another study from Fortum, a Finnish energy company shows that smart charging offers sustainable ways to save 20% of charging costs on EVs, by using the automated charging feature through their application (www.fortum.com, 2022).

b. Smart Grid Integration

The demand for rising EVs is directly proportional to the demand for energy. The current infrastructure, however, can experience a massive constraint on meeting the future energy demands and hence, a balance on the grid system is required (European Environment Agency, 2016). An example of extensive grid loads due to the extended cold spell in the Nordic countries that resulted in the electricity prices skyrocketing more than 20 times higher than normal is shown below:

According to Nord Pool, 2nd of January 2024 noted a relatively high spot price in Finland when it reached up to 60 cents/kWh during the peak hours while the average stood at 22 cents/kWh (News, 2024), meanwhile, the average price was returned to 12.4 cents KWh the next day. On the same day, 3 January 2024, Finland experienced the second highest demand of 15000 MWh following 15370 MWh on 8 January 2021 (Teivainen, 2024). This significant rise in the electricity demand skyrocketed the spot price on 5 Jan 2024 when it reached more than €2 KWh or 235 cents KWh during the peak hours, mainly between 3-9 pm (Työ- ja elinkeinoministeriö, 2024; Huttunen, 2024).

Fingrid, the Finnish transmission system operator, has suggested energy-saving measures, especially when the demand is high. One such piece of advice is shifting the timing of electricity consumption towards low-demand hours (Työ- ja elinkeinoministeriö, 2024). With the help of V2G technologies, EVs can send energy back to the grid system to maintain the energy demands. Smart charging technological advancement in the grid system has the potential to also revolutionize EV charging while making the energy market more environmentally friendly (Energy5, 2024a).

Smart grid integration refers to connecting the grid system to the EV chargers where data is shared based on real-time enabling advanced and smarter management of the electricity generation, and consumption, and ensuring efficient flow of electricity. Some of the ways to unlock smart grid integration’s full potential are as follows (Energy5, 2024a):

1. Optimized charging: Using the interoperability communication protocols discussed in section 4.4.5 of this study, different parties involved in smart charging can leverage the opportunity of real-time data sharing related to electricity forecast, rates, grid congestion, and the type of electricity used to power the EVs. This allows consumers to charge EVs during the most cost-effective and sustainable times.

2. Grid stability: Consumers can benefit from selling the electricity during peak hours using V2G technology from their homes and electricity operators can benefit in delivering the electricity to the consumers while maintaining the grid stability and avoiding expensive grid infrastructure upgrades.

3. Renewable energy: It allows consumers to take advantage of renewable energy by enabling them to choose the type of electricity used for charging EVs.

We can safely conclude that smart grid charging is paving the way towards balancing grid demands and emission-free mobility at the same time.

c. Improved Consumer Experience

In a world that is driven by technologies to provide consumers with convenience, flexibility, freedom, awareness, and safety have become a key element of success stories. Understanding the importance of the e-mobility sector with the rising demands of energy to achieve EU sustainable goals, improving consumer experience has become a necessity. Some of the ways to revolutionize the overall experience of smart charging are discussed below (Energy5, 2024b):

1. Enhanced connectivity and integration: According to the study case discussed in figure 8 and figure 9 of section 4.4.4, some of the most influential reasons among consumers to buy an EV include their concern related to connectivity (easy to use interface) and well-defined charging costs. This integration of EV charging services holds the potential to enhance consumer experience.

2. Plug-and-play compatibility: Interoperability allows modern charging stations to support various models of EVs and eliminates the need for multiple charging cables, making it a hassle-free experience.

3. Plug-and-charge: There is no end to innovation and technology advancement that can enhance the customer experience. With the evolvement of plug-in services, plug-and-charge is an advanced method that allows EV drivers to identify themselves by simply plugging in. It follows ISO015118 standard protocol for V2G communication and real-time data transmission (Virta, 2023a).

4. Fast charging: Consumers have been resistant to buying an EV considering the long charging duration when compared to fuelling an ICE vehicle. Evs have slow chargers with AC technology, while also fast chargers with a typical power rating ranging from 7-22 kW (U.S. Department of Transportation, 2022). There are rapid and ultra-rapid chargers available to minimize the charging time, where the charger has a rating of around 60 KW, and ultra-rapid chargers can range from 100 to 600 KW (Ltd, n.d.). A slow charger can take 5-6 hours to charge a PHEV from empty and 40-50 hours for a BEV, while a fast charger a PHEV 1-2 hours, and less than 30 minutes with an ultra-rapid charger, making them the fastest way to charge an EV. However, most of the PHEVs in the market are not equipped to support fast chargers. Figure 15 below provides an overview of EV chargers:

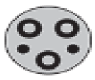
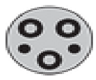
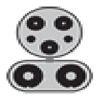
	Level 1	**Level 2**	**DC Fast Charging**
Connector Type[2]	J1772 connector 	J1772 connector 	CCS connector  CHAdeMO connector  Tesla connector 
Voltage[3]	120 V AC	208 - 240 V AC	400 V - 1000 V DC
Typical Power Output	1 kW	7 kW - 19 kW	50 - 350 kW
Estimated PHEV Charge Time from Empty[4]	5 - 6 hours	1 - 2 hours	N/A
Estimated BEV Charge Time from Empty[5]	40 - 50 hours	4 - 10 hours	20 minutes - 1 hour[6]
Estimated Electric Range per Hour of Charging	2 - 5 miles	10 - 20 miles	180 - 240 miles
Typical Locations	Home	Home, Workplace, and Public	Public

Figure 15 Illustrates a comparison between 3 different EV chargers on their performance based on power input, charging time, and location. A 60 KWh battery is considered when estimating the above numbers (U.S. Department of Transportation, 2022).

5. Advance payment option: Advance methods are eliminating the need for physical cash. EV charging stations are offering payments through mobile applications, Radio Frequency Identification (RFID) cards, debit, and credit cards reducing the requirement to enter Personal Identification codes or card details and collecting receipts.

6. Charging station locator: With the rise in charging infrastructure, charging stations are becoming increasingly prevalent in different geographical areas. The charging station locator lets EV owners scan the availability of charging stations on real real-time basis.

With enhanced charging networks and advancements in smart charging integration, customers are finding themselves at ease with increased accessibility, shorter waiting times with faster charging, convenient ways of identification and making payments, user-friendly charging infrastructure, and rapidly growing geographical coverage, ultimately resulting in boosting consumer satisfaction.

d. Reduced Energy Cost

A case study done by True Energy, a Telematica customer based in the EU, has concluded that the use of smart charging can lead to a saving of anywhere from 200 to 100 dollars annually. The result was achieved when EV drivers charged the vehicles during the off-peak electricity period. The application is backed with AI, where it can be set to automatically charge an EV during off-peak hours without the supervision of its owner and by the source of electricity (Jain, 2023).

3.6 Smart Charging SWOT Analysis

The Strengths, Weakness, Opportunities, and Threats (SWOT) analysis is based on Interdependent and Complex Electric Power and Transportation Systems (INTERCEPTS). While EVs are paving the way for an environmentally friendly transmission with its abilities of bidirectional energy flow to achieve improved grid stability, peak load management, and cost-effectiveness, the integration of EVs on a global scale also invites threats along with it. The SWOT analysis delivers insights on smart charging integration to support better planning and preparedness ahead to harness its full potential. Raouf, Mousavian, and Ghazinour (2021) explain the SWOT analysis below (Raouf, Mousavian, and Ghazinour, 2021):

I. Strengths

a. Energy storage: With the increasing demands for energy in the EU, EVs provide a robust advantage of energy storage in supporting the ancillary services for the power grid and improving the penetration of renewable energy sources by using the bidirectional flow of electricity. This concept is considered one of the key strengths of the INTERCEPTS.

b. Availability and affordability of EVs: In 2019, it is estimated that 33% of the total cost of an EV is derived from the LIB. However, according to a recent prediction, the battery cost will plunge by 13% or more by the year 2025 making them more affordable. Mobility manufacturers are also competing in developing economical options for consumers and shifting their focus on the production of EVs from Convention vehicles (CVs).

c. Public awareness of climate change: CVs are responsible for the highest contribution of smog-forming pollutants, and it is no mystery to the people that sustainable and ecological resources must be prioritized to tackle climate change. Regulations such as COP28, Fit for 55, and the EU Green Deal are great initiatives to spread awareness and encourage everyone towards a greener future.

II. Weaknesses

a. Implementation barriers: The main objectives for V2G implementation are to substantially increase the rate of renewable energy sources and the profit for EV aggregators and the electricity market while ensuring that power losses and operational costs are at the minimum. However, there are numerous challenges with the bidirectional flow which make this goal incredibly difficult to rely on.

b. Investment cost: INTERCEPTS' success heavily relies on the development of smart charging, which requires a significant change in the energy infrastructure resulting from the humongous upfront investment. The cost includes the whole distribution network and its maintenance such as the charging stations, grid operations, enabling V2G technologies in devices, transformers, meters, and the EV battery itself is one of the biggest concerns of EV owners.

c. Time of use (ToU) electricity price: Understanding the power quality issue is an important factor in managing the ToU, as electricity demand can negatively affect the voltage quality and result in increased power cuts. To solve this, demand response and pricing strategies need to lead the way in evaluating different prices during each hour of the day so the charging demand can be shifted to off-peak and mid-peak hours.

d. Battery degradation of EVs: Since EV battery is the most valuable component of an EV, costing around 33% of the total cost. All LIBs get degraded with charging and this is a major concern among consumers when adopting V2G technology. The phenomena of battery degradation are carefully explained in 4.4.6 of this study.

III. Opportunities

a. Modern business model and revenue streams: Smart charging is a complex technology that delivers equal opportunities to everyone involved in it. There are many constraints to fully establish the smart charging infrastructure such as discussed previously in this study in section 4.4 under “challenges in smart charging”, but it also invites appropriate business models with opportunities to satisfy the needs of technical and physical objectives.

Other opportunities such as sustainability factors, improved grid integration, enhancing overall customer experience, and reduced energy costs are explained briefly in section 4.5 of this study.

IV. Threats

a. System security: Transportation is considered more vulnerable and exposed to cyberattacks, physical attacks, or a combination of both. Due to such, a holistic resilience cycle (HRC) is introduced where the aim is to prevent, detain, mitigate, and recover.

b. Battery degradation cost: The significant impact of battery performance after using LIBs due to losing its electrons with use is a threat and is further explained in specific detail in section 4.4.6 of this study.

c. Power grid overloading cost: While INTERCEPTS open the gate for many opportunities for new business models, it can also cause problems if not managed properly. For instance, charging too many EVs at the same time can cause overload on the grid and damage the lifespan of utility equipment. A demand response strategy is introduced to tackle such a challenge however, some upgrades may still be required in EV owners' homes and the power grid.

4 Lithium-ion Batteries in EVs

What differentiates an EV from an ICE vehicle is the replacement of a battery that generates electricity to run the vehicle's motor, allowing the advantage of removing the ICE from it. The most common element used in the production of EV batteries is lithium, which is also known as white gold in the EV sector. On average, the United States Department of Energy Science estimated that 8 kg of lithium is required in a single EV battery. As quoted by Elon Musk previously in the article, lithium is like the salt in the salad. Meanwhile, it is a vital component in the production of batteries, lithium has already started to face shortages to meet global demands. To achieve the NetZero goal by 2050, we need around two billion EVs on the road but considering the limited amount of raw material, it raises the concern of whether we have enough lithium to fulfil that need or not. According to the US Geological Survey, there are around 22 million thousand kg of lithium kept as a worldwide reserve. It should be enough to produce a little less than 2.5 billion EVs by 2050 to meet the NetZero goal, however, all the reserved lithium cannot be used in the production of EVs and requires batteries to host other electronic items (Shine, 2022).

Apart from the scarcity of lithium and other critical raw materials, another critical element to reflect on is the process of mining the minerals from Earth. Lithium extraction is a heavily weighed process that requires using thousands of tons of water in one day at one location. To understand the scope of water usage, Bolivia’s San Cristobal mine has been reported to use around 50,000 litres of water per day. What makes the situation even more challenging is the availability of lithium in drought-prone locations worldwide, including the Lithium Triangle and Australia. IEA has also reported these places are subjected to environmental calamities which makes the process of ensuring reliable and sustainable supplies more rigid. In addition, due to the increasing awareness towards the criticality of such raw materials, there have been widespread protests around the world, making Serbia close a lithium mine, as locals were concerned it would cause irreversible harm and lead to water shortage soon (Shine, 2022).

With the increasing demands, concentrated market, harms caused due to poor handling of used batteries (Anderson, 2023b), and the scarcity of raw materials, circularity is an opportunity of this decade. It has been studied that 80% of the battery can be recycled with around 95% of its valuable metals recovered in the process. According to a forecast by the World Economic Forum, around 54% of EV batteries need to be recycled by the year 2030, and recycled materials can make up to 7% of the total raw materials requirement for that year. China is actively seeking recycling opportunities and heavily investing in them, if the EU and other nations want to succeed in becoming more independent in the e-mobility sector, then innovation must be used to its fullest. Government, enterprises, and consumers all can work in creating a circular ecosystem while playing distinct roles. In Finland, Fortum has invented a state-of-the-art solution using a combination of mechanical and hydrometallurgical technologies for recycling batteries. This allows safe and sustainable extraction of minerals such as lithium, cobalt, manganese, and nickel from the used batteries and can be used to produce new ones (Fortum, n.d.).

4.1 What is a Lithium-ion battery?

A LIB is a combination of an anode, cathode, separator, electrons, and two current collectors, i.e. the positive and the negative sides. The role of the anode and cathode is to store lithium and when the battery is either used or charged, the electors carry the lithium ions from one direction to another through the separator (Carreon, 2023).

LIBs can store large amounts of electricity while using smaller packages when compared to most of the other battery technologies and are resilient in high and low temperatures (Carreon, 2023). According to Thunder Said Energy, it is estimated that the density of LIBs will double in the 2030s and continue to reach an ultimate quadruple level in the future (Thunder Said Energy, n.d.).

Lithium is also known as white gold in the EV sector and is the most common material due to its high energy density. Meanwhile, it is an important component in the production of batteries, lithium has already started to face shortages to meet global demands (Shine, 2022).

4.2 Scarcity of Raw Materials

One of the core challenges of lithium is its resources which are concentrated in only a few places. South America is known as the Lithium Triangle, for its reason to hold around 60% of all Earth’s lithium resources. Chile, Argentina, and Bolivia are the three countries part of the Lithium Triangle, where Chile has the highest ranking among the three in the world. However, according to the IEA, China holds around 70-80% of all lithium shares and accounts for the largest production of LIBs for EVs in the world. The top 5 companies are accountable for 75% of global production capacity (Shine, 2022). In Dec 2023, China placed a ban on the extraction of rare earths which has a significant effect on the availability of materials needed to produce Li-ion batteries. Western countries are at a technical disadvantage when it comes to solvent extraction processes. It also takes years to build a facility with a capacity to have several functions including separations, processing, and manufacturing of these raw materials. Almost all EV producers are dependent on China for the raw material. With its dominant resources, China also plays a crucial role in determining the prices of these minerals and affecting the supply chain. (Baskaran, 2024).

EU has relied on China for around 9/10 of all the rare earths including 60 percent for lithium. COVID-19 had a major impact on the world's supply chain and the EU had a lesson to be learned, especially when the supplies were shut for natural gas from Moscow during the Russian-Ukrainian war. European Union implemented The Critical Raw Material Act to ensure Europe can meet the demands for growing its energy market and supporting the production of e-mobility. According to the report published on 18 Dec 2023, the EU is planning on ending its dependency on China for the supply of crucial minerals (Reuters, 2023).

It is estimated that around 80% of the battery cost in 2022 as compared to only 40% back in 2015 is related to its mineral requirement in manufacturing. These prices reached a historic high due to the increased demand and lower supplies. The inflation in the EU and the Russian-Ukrainian war have made matters worse (Barrera, 2022). Rare earth consists of 17 metals used in making magnets in EVs, wind turbines, and other electronics (nationthailand, 2023).

Tesla 2021 made changes in the chemistry of their LIBs which have made possible the production of those batteries without the need for both cobalt and nickel (Barrera, 2022). However, an enormous amount of various minerals is required to meet the market demands to produce batteries. Figure 16 provides a contradiction between the availability of minerals in the world when compared to the amount that is needed to meet the sustainable development goals. Figure 10 shows that the demand for raw materials is rising at a tremendous rate, requiring around 5000 m3 in 2020 to around 30000 m3 in 2030 and 35000 m3 in 2040. However, Figure 16 also illustrates the actual need to meet the SDGs in 2030 and 2040 would require more than 60000 m3 and 120000 m3 of minerals respectively (IEA.org, 2022):

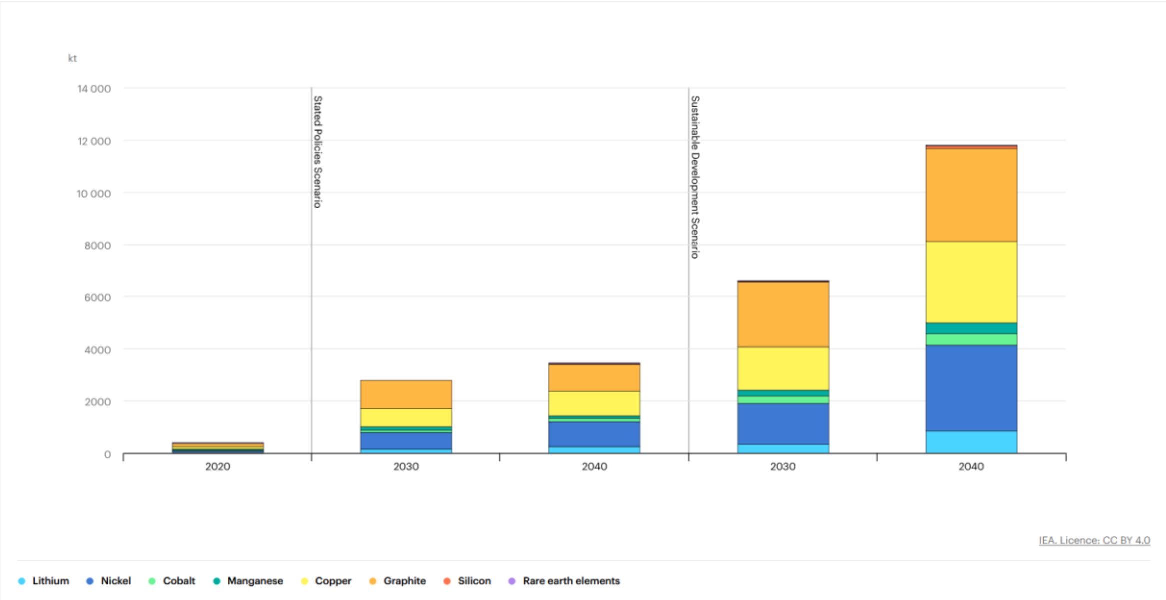


Figure 16 Available minerals to meet the sustainable development goal (SDG) in the EV market vs. the required minerals to meet the SDG (IEA.org, 2022).

4.3 The mineral content of battery chemistries, by weight

According to research done by BloombergNEF, the amount of lithium in a battery is not as significant as some of the other minerals, but the availability of the lithium mineral and the correct kind can cause problems. Elon Musk, in 2016, emphasized the importance of lithium in a battery, calling it ‘’the salt in your salad’’ and it weighs around 10% of the battery mass. Figure 17 shows the mineral content of battery chemistries, by weight (Barrera, 2022b):

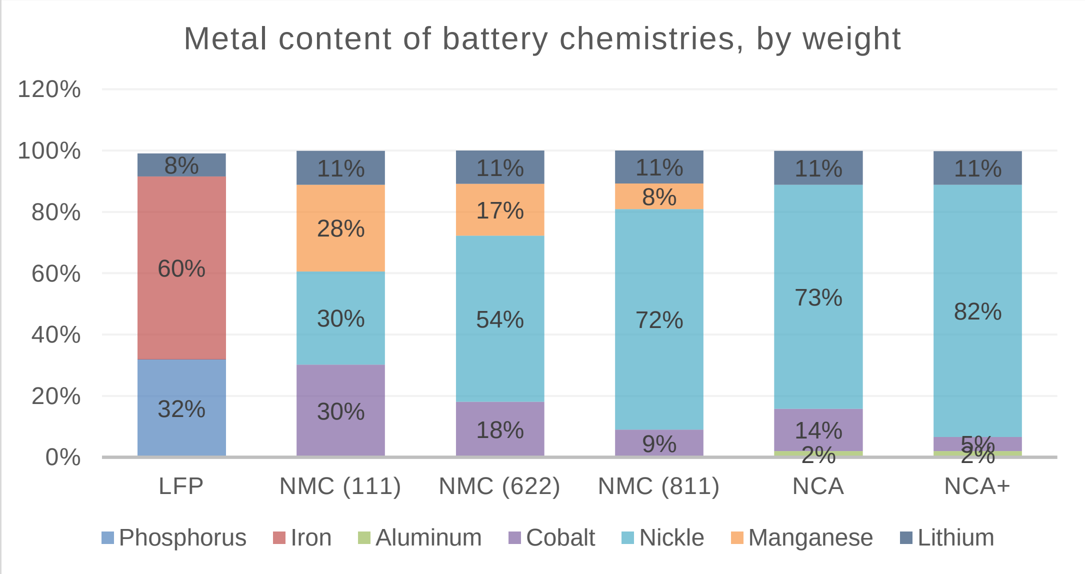


Figure 17 Metal content of battery chemistries, by weight (Barrera, 2022b).

4.4 New Chemistries

Major concerns with the availability of raw materials in a LIB used in an EV are related to cobalt, lithium, and nickel. These materials can develop supply shortages when the demand for new EVs increases in the future (Anderson, 2023b).

Intensive studies are underway to find replacements for the cathode and anode materials in the battery to deal with the scarcity of raw materials. The idea is to replace the monovalent Lithium-ion with other monovalent such as Sodium and Potassium, or with multivalent ions such as Magnesium, Calcium, Zinc, or Aluminium-ions (Fichtner, 2021a).

4.5 Harms Caused by Lithium

In Europe, in 2023, less than 40% of e-waste was recycled (European Parliament, 2020). Studies are showing that if the recycling of e-waste is not handled in a standardized way it can cause harm to the environment and human health, for instance, when the disposed material ends up in the lakes, it can make its way to the food chain. Some are the harmful ways are discussed below (Łukasz et al., 2023):

a) Cobalt is characterized as carcinogenic to humans and can cause both neurological and cardiovascular diseases in human beings. Cobal leads to increased levels of C02+ ions which damage the DNA and due to its tendency to active hypoxia-inducible factor, it can cause tumours.

b) Nickel is ranked as the 7^{th} toxic substance to damage human health and 9^{th} in terms of causing global warming. Environmental contamination was discovered in many countries including Finland and emissions of sulphur dioxide can cause acid rain. Exposure to Nickel can result in immunotoxicity, and cardiovascular, and respiratory diseases at various doses.

c) Lithium mining has seen controversial discussion in terms of sustainability, damage to the ecosystem, and overproduction. A few mines in Australia, two brine operations in Argentina and Chile, and two producers in China deliver over 95% of the lithium. Protected market growth and supervision are required to facilitate sustainable production and lithium mining. Apart from that, lithium exposure can cause bipolar disorder and several other side effects, in connection to human hormones and glands.

4.6 Measures

As discussed previously in the section 4.2 of this study “Scarcity of Raw Material”, the available raw materials will not be sufficient to meet the demand to produce EVs in the future. Some of the innovative approaches toward boosting a circular economy in the EV sector to tackle this problem will be mentioned below:

4.6.1 Reusing Methods

1. Cascade utilization: It refers to a method where when batteries reach their originally estimated machine life, but the battery life is still above 80% then it can be used for other purposes to generate electricity where low power is required. For instance, storage devices, portable generators, fast charging stations for EVs, etc (admin, 2018).

2. Recycling: Even though EV batteries are made durable as compared to other LIBs, their expected lifespan is around 15-20 years. But eventually, it takes the fall when the battery reaches health levels of 80% or below and ideally, its function to serve its original motives has degraded and has limited its ability as an EV battery (EVBox, 2023).

   LIBs are made with various precious minerals including cobalt, lithium, aluminium, graphite, nickel, etc that can be separated. Studies have shown that 95% of materials used in an EV battery can be recycled (EVBox, 2023).

   Recycling methods are further divided into different methods depending on the material recovery (US Department of Energy, 2019)

   a) Smelting: This process is operational and can be applied to various battery types for recovering basic elements or salts. It takes place at high temperatures and the recovered material then can be used for its suitability while lithium is used for construction material.

   b) Direct recovery: All the active components can be recovered using a range of chemical and physical processes at a low temperature with less energy consumption when compared to smelting.

4.7 Innovative Solutions

With the world facing the scarcity of raw materials and the uneven market distribution of those materials, there is room for advancement in the development of innovative solutions. This will lessen the dependency of many countries on raw materials, will strive to achieve more sustainable options, and is a pathway to better EVs eventually. Some of the innovative solutions for enhancing sustainability, boosting circularity, and improving performance that takes us closer to the NetZero (Regulation (EU) 2021/1119 of the European Parliament and of the Council, 2021) mission are as follows:

a) Smart engineering: Most of the carmakers in the world rely either on Lithium Nickel Manganese Cobalt Oxide Batteries (NMC) or Lithium Nickel Cobalt Aluminium Oxide batteries (NCA). However, recent studies have taken a crucial step in redesigning the battery pack and its internal components (Fichtner, 2021b).

   There are two approaches when designing a LIB, the first is the conventional design and the other is the Cell-To-Pack design. In the conventional version, each cell is individually packaged and is around the size of a chocolate bar, which is then arranged together with a total of 10 other cells to form a module, which then forms a battery pack. Each module relates to the battery pack and is protected from external damage. With this approach, there is around 25% - 30% storage material while the rest is the packing material. On the other hand, with the Cell-To-Pack approach, a few but larger cells are installed in making a battery pack. It increases the storage material to 40% - 45% with 40% fewer parts required for production. Figure 18 below represents the two different designs discussed above (Fichtner, 2021b):

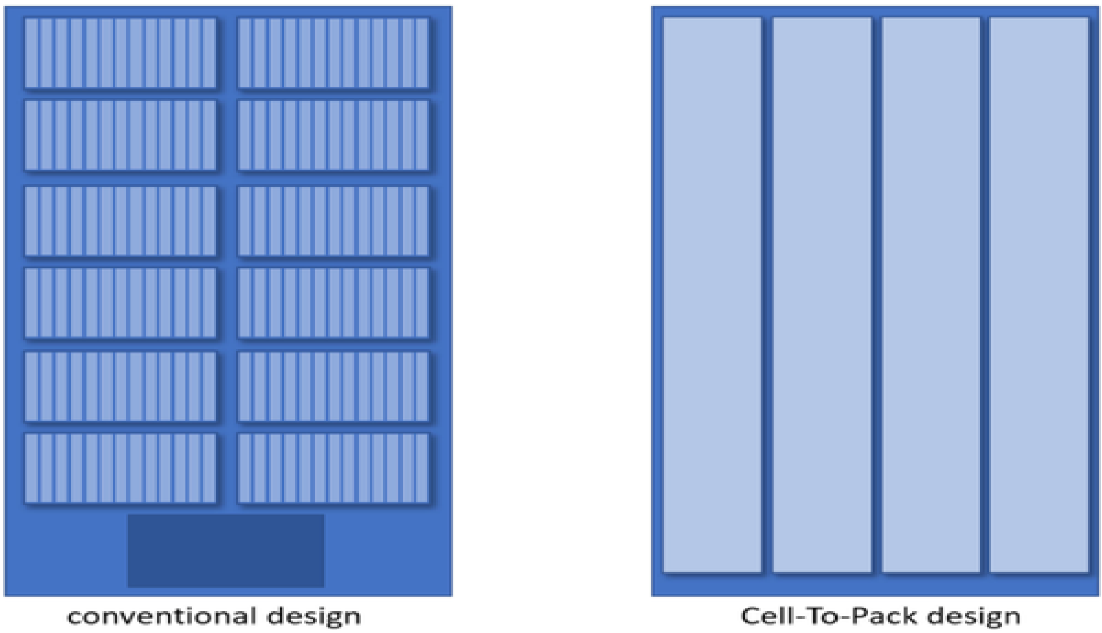


Figure 18 Schematic image of the Conventional and Cell-To-Pack battery design for NCA and NMC battery design. (Fichtner, 2021b).

b) Use of Gemini: A car battery made with Gemini was able to travel 1200km on a single charge. This is three times more than Tesla's current most advanced model range. Gemini battery was tested in the state of Michigan using a Tesla Model S which was driven at an average of 90 km speed. Gemini cuts lithium use by 20% and graphite use by 60%. The battery will be fitted into BMW's iX electric SUV by the end of 2022, and it will cover 965km on a full charge (Stelle, 2023). Figure 19 is a comparison between Gemini vs. EV battery industries:

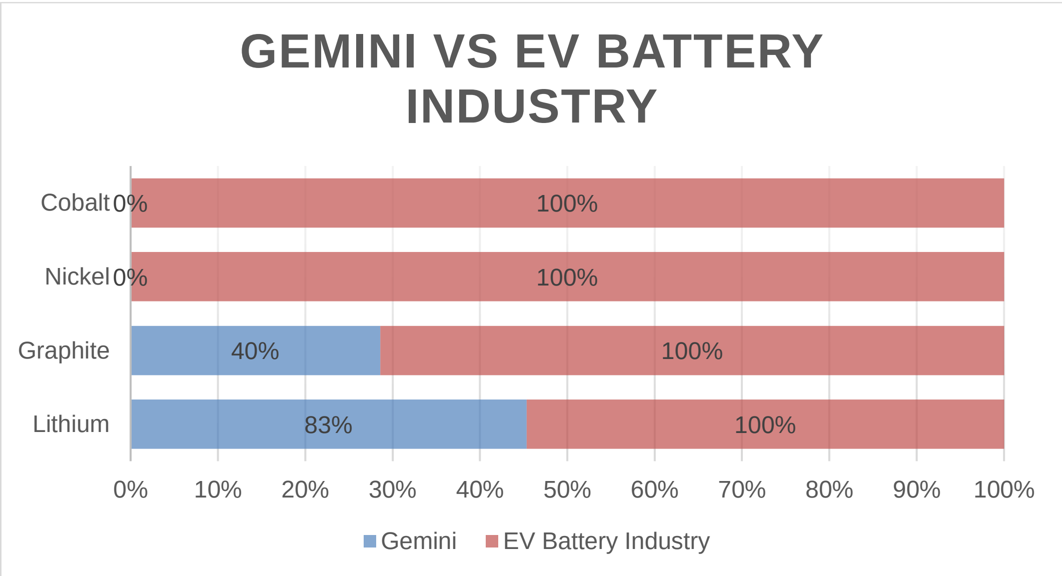


Figure 19 Gemini vs. EV Battery Industry (Stelle, 2023).

c) Carbon-negative car: The world's first carbon-negative car that removes CO_2 from the atmosphere as it drives. Each car can remove 2kg of CO_2 every 32000km. That is 10% of the carbon absorbed by a typical tree. It might not seem like much, but if adopted at scale it could make a big difference (Lockett, 2022).

Its body panels are made from 3D-printed plastic, which cuts down on waste. The panels are also 100% recyclable. On top of that, the creators claim that the captured carbon could be used to make fuel. This car is called Zem and was designed by students at the Eindhoven University of Technology in the Netherlands. However, critics say, that a person who drives it exhales 1kg

CO2/day, so this concept is good for marketing purposes (Lockett, 2022). Figure 20 below shows an image of a carbon-negative car on the road.

Figure 20 Sustainable electric car that turns clean the air when driven (Lockett, 2022).

d) Green technology: Scientists at Maryland University have just invented a renewable battery made from crustacean shells. It uses chitin, the chemical that makes shells hard. It is also found in fungi and insect exoskeletons. Usually, Chitin goes to waste when crustacean shells are tossed in food trash (Quaglia, 2022).

When the battery's life is over, most of it can be broken down by microbes in just 5 months except lithium-ion which can take hundreds of years to break down. Either way, zinc is left behind. Now, Chitin can be combined with zinc to create an innovative battery that would retain up to 99% of its capacity after 1000 charges (Quaglia, 2022). Figure 21 is the process of how the biomaterial is combined with the leftover battery component to make a new and green battery.

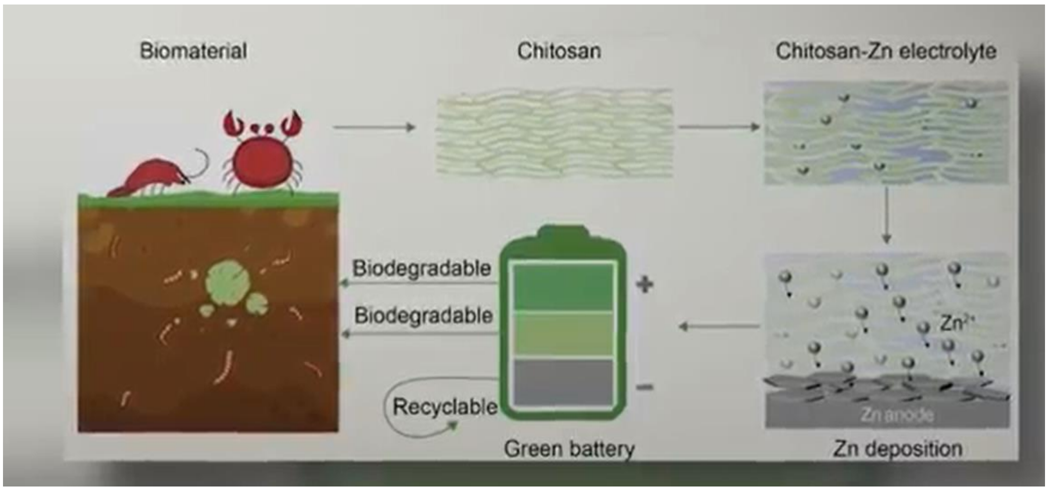


Figure 21 Shows the breakdown of leftover components in a green battery (Quaglia, 2022).

e) Sodium-ion batteries (SIBs): The abundant availability and chemical properties of sodium make it the most promising substitute for LIBs. Sodium is considered more environmentally friendly due to its less toxicity found in salt when compared to lithium salt and does not require scarce materials such as cobalt and nickel for production. In recent years, extensive research has been done on sodium’s low cost, sustainability factors, and availability (Decai et al., 2021).

Lithium is the third-lightest period element, sodium, however, has a bigger radius and weighs around 4 times heavier than lithium in providing the same energy density. The lightweight nature of LIBs has been the major reason for their widespread adoption with smaller electronics around the world. In contrast, weight is not necessarily a big problem when it comes to grid-scale energy storage systems or in heavy transportation like trucks and ships, implementing it in the EVs can be more challenging though. In addition, sodium has low energy density and sluggish electron reactions which can further hinder the development of sodium ion storage devices (Anderson, 2023a).

On the bright side, SIBs are becoming progressively attractive to developers due to their cost advantage. Even though it might not completely replace LIBs, new research and development in SIBs are showing promising results by offering a compelling alternative where size and weight are not much of a constraint. In addition, changes in cathode material in SIBs are under development and can potentially improve its energy density for EVs (Anderson, 2023a).

5 Conclusion

To conclude, the substantial growth in the EV market has reached a tipping point, and the development from here onwards will continue to grow requiring intensive planning and innovative solutions to tackle challenges concerning rising energy demands, raw materials, and infrastructure in the EU.

The EU has laid out frameworks and subsidies to support the development of an integrated energy system and lower their dependence on raw materials from other nations. Some of the frameworks are strongly supported by EGD and Fit for 55 which are ensuring an achievable plan for becoming more sustainable in terms of energy efficiency and carbon neutrality.

Smart Charging is a state-of-the-art technology that is proving to be a win-win situation for all the parties involved including EV buyers and charging operators by allowing the flexibility to charge and sell the electricity according to the market price and maintain the grid load. Smart charging also helps in reducing charging time as more powerful chargers are being developed along with new battery chemistries allowing enhanced capabilities compared to the traditional LIBs. Numerous other opportunities support the development of Smart Charging by enhancing privacy, and flexibility, and promoting renewable energy in the EU. However, multiple challenges need to be faced to benefit from its full capabilities.

In addition, as previously discussed, lithium is considered white gold to manufacture LIBs, which are the most used rechargeable batteries around the world. However, LIBs have limited performance and scarce raw materials. 9/10 rare earth metals and 60% lithium are imported from China. LIBs are also outperformed by more advanced batteries such as the Gemini battery. Innovative approaches are mandatory in ensuring that new approaches are used in enhancing battery performances and making them more sustainable and environmentally friendly. Along with other innovative approaches, recycling and reuse ensure that there is enough raw material to manufacture new batteries and to avoid the harm caused due to lenient handling practices.

Together Smart Charging and innovative charging solutions when aligned with the EU development goals and driven by a motivation for bringing a revolutionary change play a crucial role in providing a resilient e-mobility infrastructure by reducing the charging time, enhancing energy density and range, cyclic stability and durability of batteries, improved customer experience, resource availability, and environmental impact.

Hence, both research areas hold immense potential together in shaping the EU’s economy, its independence on raw material and supply chains, transforming the e-mobility market, and making the EU more sustainable by developing an integrated energy system while ceasing the production of ICEs by 2035 and achieving the Net Zero target by 2050.

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