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Review and monitoring of emerging issues and sustainable development goals:
Transport Trends and Challenges in the road, rail, and inland waterways sectors

General trends and developments surrounding electric vehicles and their charging infrastructure – interdependencies between electric mobility and the energy system*

Note by the secretariat

I. Introduction

1. Further to the request of the Working Party on Transport Trends and Economics (WP.5) at its previous session to designate its Transport Trends and Economics 2022–2023 publication on general trends and developments surrounding electric vehicles and their charging infrastructure, a draft publication as contained in ECE/TRANS/2023/4, ECE/TRANS/2023/5, ECE/TRANS/WP.5/2023/6, ECE/TRANS/WP.5/2023/7, and ECE/TRANS/WP.5/2023/8 has been elaborated by the secretariat and an external consultant and will be presented for feedback.[1]

2. The present document explores the interdependencies between electric mobility and the wider energy system. It investigates opportunities for a more seamless integration of EV charging infrastructure with the energy system, particularly through the utilization of V2G technologies which allow to reduce dependence on traditional power plants, propels the widespread adoption of renewable energy, and paves the way for a more sustainable future for transportation and energy systems. From Section IV onwards (paras. 51–60) it draws some preliminary general conclusions for the publication including also on the aspects

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* This document was scheduled for publication after the standard publication date owing to circumstances beyond the submitter's control.

[1] Staff of both the ECE Sustainable Transport and Sustainable Energy Divisions have been consulted in the process of developing documents no. 4 to 8. At the ECE Sustainable Transport Division staff in the Transport Facilitation and Economics; Vehicle Regulations; Road Traffic Safety and Transport Innovations; and Intermodal Transport and Logistics sections have contributed and will together with the ECE Sustainable Energy Division remain closely involved in the further elaboration of the publication.

covered in working documents 4, 5, 6 and 7 as referred to above. For ease of reference, this preliminary concluding part has been reproduced in the three ECE working languages as informal document no. 4.

3. WP.5 delegates are invited to provide feedback and suggestions for improvement of the text and to deliver presentations on national case studies and best practice examples for inclusion in the final version of the publication.

II. Electric mobility and the energy system

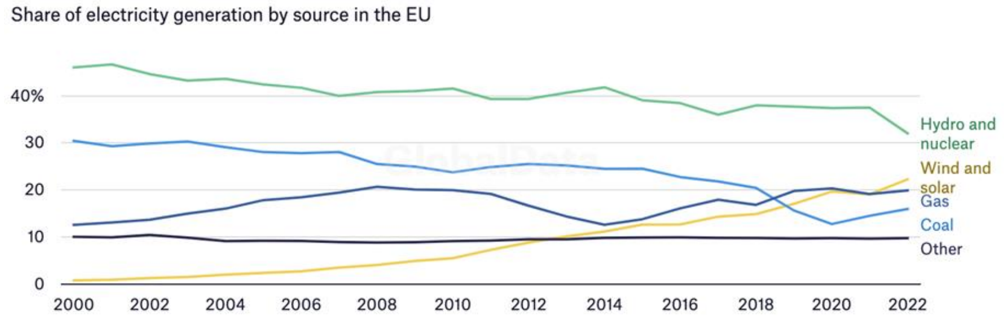
A. Electric vehicle zero emission

4. EVs show a significant greenhouse gas (GHG) emissions advantage even when powered by average grid electricity. However, they require a significant supply of renewable energy or reliance on carbon capture and storage (CCS) to be considered low-carbon options. Increasing the GHG emissions advantage of EVs is thus not only done by the implementation of growing EV ecosystems and markets but through a holistic transformation of the energy system with a strong focus on growing the shares of renewable electricity in the energy mix.

5. In recent years, there has been a notable trend of growing renewables in the European Union and beyond, primarily driven by policies and strategies aimed at transitioning to a low-carbon and sustainable energy system. The European Union has set ambitious renewable energy targets, such as the target of achieving at least 32 per cent of its final energy consumption from renewable sources by 2030. This has led to increased investments in renewable technologies like wind, solar, and biomass, as well as supportive policies, such as feed-in tariffs, auctions, and renewable energy certificates, which have incentivized renewable energy deployment. Additionally, other countries and regions around the world have also adopted similar renewable energy policies and strategies, contributing to the global growth of renewable energy capacity and the transition to a cleaner and more sustainable energy future.[2]

Figure I

Share of electricity generation by source in the EU



Source: Energy Monitor.[3] Accessed on 8 June 2023.

6. Integrating renewables into the grid presents challenges for grid reliability due to their intermittent nature. Matching variable renewable generation with consumer demand in real-time requires advanced forecasting, grid flexibility measures like energy storage, and smart grid technologies. Robust transmission infrastructure and backup mechanisms are also necessary. Overcoming these challenges ensures reliable integration and a sustainable energy system. As every region has its own geographical characteristics, every region has its own strategy for integrating various renewable energy generation technologies. Where densely populated regions, such as the Netherlands, integrate residential solar due to a lack of space

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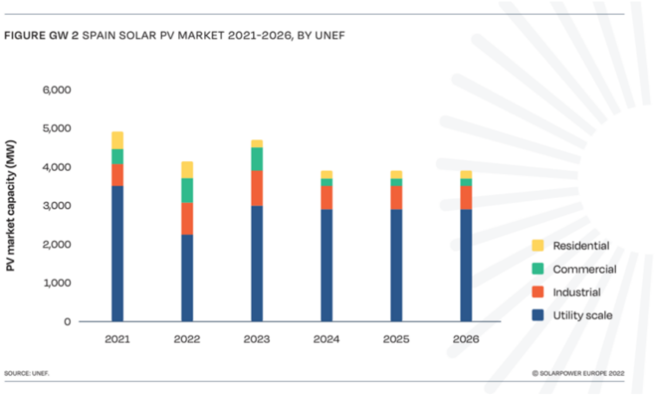
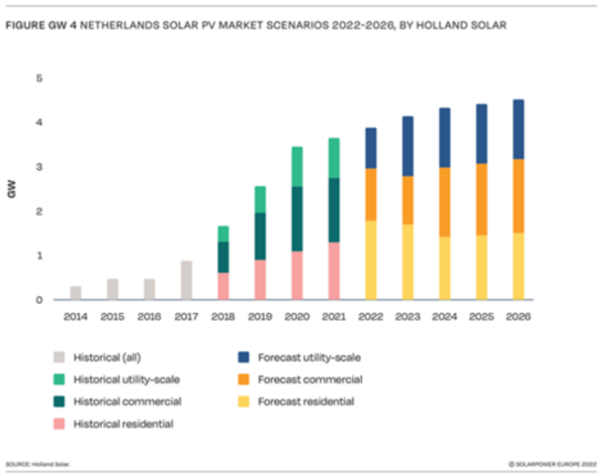
[2] https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-targets_en

[3] www.energymonitor.ai/tech/renewables/europe-renewables-in-2022-in-five-charts-and-what-to-expect-in-2023/

for larger solar parks, other regions, such as Spain, integrate utility-scale solar parks. Both trends in electricity generation impose specific risks for maintaining the grid's reliability and thus require impact-specific solutions and technologies.

Figure II
Solar photovoltaic markets of Spain and the Netherlands





Source: Solar Power Europe (2022)

B. Addressing renewable energy sources integration

7. The performance of Renewable Energy Sources (RES) is unpredictable, varying daily and hourly based on factors such as weather conditions and fluctuating wind speeds. These variations pose challenges for grid stability, requiring innovative solutions to effectively manage the daily and hourly fluctuations in RES electricity generation. One key approach to addressing these challenges is advanced forecasting. By leveraging weather data, historical patterns, and sophisticated modelling techniques, accurate forecasting enables grid operators and energy market participants to anticipate changes in renewable energy output. This information allows for better planning and management of the grid, optimizing the dispatch of electricity and balancing supply and demand. Real-time forecasting systems provide valuable insights into short-term variations, enabling operators to make rapid adjustments and maintain grid stability.

8. Energy storage technologies also play a crucial role in managing the daily and hourly fluctuations in RES electricity generation. Energy storage systems, such as batteries and pumped hydro storage, offer the capability to capture and store excess electricity during periods of high renewable energy output. This stored energy can then be discharged during periods of low-RES generation, helping to bridge the gap between supply and demand and ensure a more stable power supply. Energy storage provides grid operators with the flexibility to balance the intermittent nature of RESs and maintain a reliable energy system. Additionally, demand response programs play a significant role in managing the fluctuations

in RES electricity generation. These programs incentivize consumers to adjust their electricity usage based on the availability of renewable energy. By encouraging consumers to shift their consumption to periods of high-RES generation or reduce consumption during periods of low generation, demand response programs contribute to a more balanced and efficient energy system.

9. Traditionally, power plants with large spinning masses have served as a backbone for maintaining the stability of the energy grid. A so-called spinning reserve refers to the capacity of power plants that are kept ready and synchronized with the grid to provide immediate electricity supply in case of unexpected changes in demand or generation fluctuations. They act as a buffer to maintain grid stability and ensure reliable power supply by quickly adjusting their output to match the required demand. Spinning reserves help address the variability of renewable energy sources and contribute to the stability and resilience of the electricity system. These spinning reserves comprise turbines always operating, provide immediate response capabilities to balance the supply-demand dynamics, and uphold the standardized frequency range. However, the shift towards RESs, which often lack large spinning masses, poses a challenge to the grid's frequency regulation. Without the spinning reserves, deviations from the standard frequency range can occur due to imbalances between power supply and demand. These frequency problems, whether a rise or fall in frequencies, can disrupt the efficient operation of electrical devices and equipment connected to the grid. Spinning reserves provide a rapid response to sudden fluctuations, while load balancing manages power generation to maintain grid stability and reliability.

10. The integration of EVs into the energy system itself also poses similar challenges due to their unpredictable charging behavior and the relatively high demand for charging compared to typical home electricity consumption. The charging patterns of EV owners can vary significantly, influenced by individual preferences, daily routines, and availability of charging infrastructure. This unpredictability introduces a level of uncertainty in the energy system, as the grid must be prepared to handle sudden surges in demand when many EVs simultaneously plug in for charging.

11. The charging requirements of EVs can surpass the typical electricity consumption of households. While residential power consumption primarily involves lighting, appliances, and electronics, the charging process for EVs requires a considerably higher amount of electricity. This increased demand can strain the energy system, especially during peak hours when electricity usage is already at its highest. Without appropriate management strategies and infrastructure upgrades, the simultaneous charging of multiple EVs can lead to grid congestion, voltage fluctuations, and compromised system stability.

12. To address these challenges, the implementation of smart charging and vehicle-to-grid (V2G) technology becomes crucial. Smart charging refers to an intelligent approach to EV charging that optimizes the process based on grid conditions, electricity prices, and user preferences. It helps avoid peak demand periods, balances the charging load, and maximizes the use of renewable energy. Smart charging involves technologies that enable real-time monitoring, control, and coordination between EVs, charging stations, and the grid operator. By enabling energy flow between EVs and the grid, V2G systems offer the opportunity to utilize EV batteries not only as energy consumers but also as energy sources. During periods of high demand, EVs can discharge stored electricity back into the grid, reducing the need for additional conventional power generation. The V2G technology allows EVs to actively participate in the energy system by charging during off-peak periods and discharging power back into the grid during peak demand. This mechanism helps to regulate frequencies, balance supply and demand, and thus maintain a stable energy grid.

13. While V2G focuses specifically on EV-to-grid interaction, V2X refers to the communication and energy exchange between electric vehicles (EVs) and various entities, including the grid, infrastructure, vehicles, and smart homes. V2G specifically refers to the interaction between EVs and the electrical grid, enabling EVs to supply energy back to the grid.[4]

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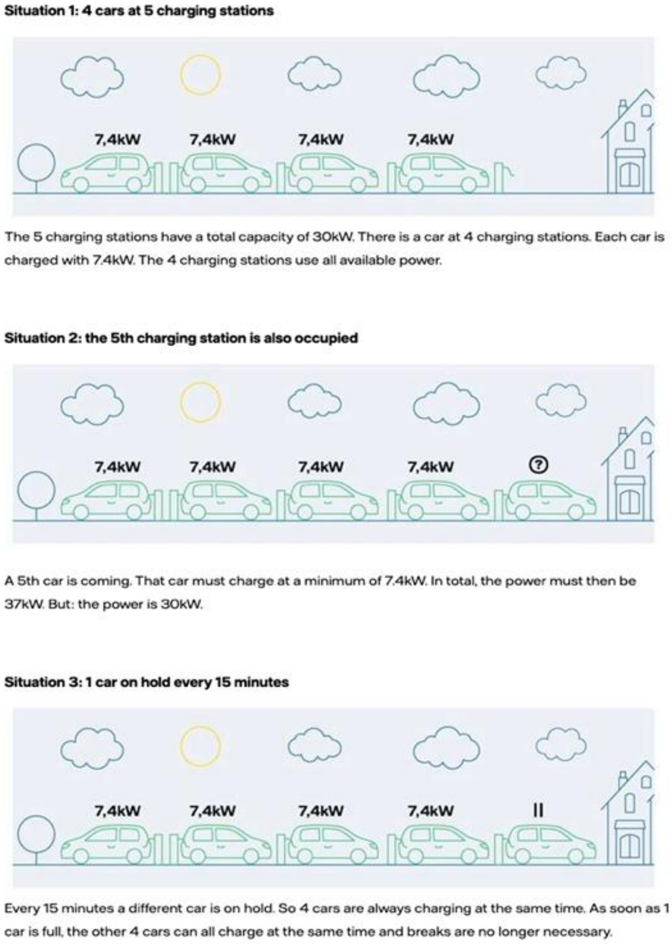
[4] This report states that batteries in EVs have the potential for meeting grid storage demand by 2030 in most regions of the world: https://www.nature.com/articles/s41467-022-35393-0.

Figure III
Dynamic Load Balancing with multiple charging stations



Situation 1: 4 cars at 5 charging stations

The 5 charging stations have a total capacity of 30kW. There is a car at 4 charging stations. Each car is charged with 7.4kW. The 4 charging stations use all available power.

Situation 2: the 5th charging station is also occupied

A 5th car is coming. That car must charge at a minimum of 7.4kW. In total, the power must then be 37kW. But: the power is 30kW.

Situation 3: 1 car on hold every 15 minutes

Every 15 minutes a different car is on hold. So 4 cars are always charging at the same time. As soon as 1 car is full, the other 4 cars can all charge at the same time and breaks are no longer necessary.

Source: Vattenfall.[5] Accessed on 8 June 2023.

C. Technology definitions

14. Smart charging and V2G technology encompass the seamless flow of energy, information, and financial transactions between EV owners, aggregators, and the power grid, with the ultimate objective of achieving a stable balance between energy supply and demand. The underlying structure of V2G systems revolves around three pivotal components: plug-in connection equipment, communication, and control devices that facilitate a synergistic relationship between the grid operator and EV battery conditions, and metering devices that accurately measure the flow of power in both directions.

15. V2G systems incorporate an incentive-driven pricing strategy designed to motivate EV owners to actively participate in the charging and discharging processes. During periods of off-peak demand, characterized by an abundance of surplus power within the grid, EV owners can charge their vehicles at reduced rates. Conversely, during peak demand periods when the grid faces a shortage, EVs can discharge stored power back into the grid at higher rates. This unique pricing plan empowers EV owners to reap financial benefits through their active engagement in the system.

16. In the realm of EV charging integration, effective communication among the grid operator, electricity market, and EV users is of paramount importance. With the advent of advanced technologies, such as applications on smartphones, a new dimension of communication has emerged, enabling real-time interaction and coordination. Through

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[5] https://incharge.vattenfall.nl/kennis/smart-charging

dedicated smartphone applications, EV users can receive information about grid conditions, pricing signals, and demand forecasts. This empowers them to make informed decisions regarding their charging preferences and schedules. For instance, users can access data on electricity prices during different time periods, allowing them to optimize their charging patterns to take advantage of lower rates during off-peak hours. They can also receive notifications or alerts from the grid operator regarding grid constraints or events that may require adjustments in their charging behavior. Moreover, electricity markets can leverage smartphone applications to facilitate demand response programs. These programs incentivize EV users to adjust their charging behavior based on market signals. For example, during periods of high electricity demand, the market can send price signals to EV users, encouraging them to delay or reduce their charging activities. In response, EV users can adjust their charging schedules to align with grid needs and potentially benefit from lower electricity prices. This dynamic interaction between the electricity market and EV users fosters a more efficient utilization of available energy resources and enhances grid resilience.

17. The economic advantages associated with these technologies are undeniable. Within the traditional regulatory framework, large-scale generators are activated during emergencies and power shortages to meet the escalating demand, resulting in exorbitant operational and maintenance costs. V2G systems empower EVs to store surplus energy during off-peak periods and discharge it back into the grid during peak demand. Consequently, this innovative system substantially reduces dependence on central power plants during periods of heightened energy consumption. Furthermore, the integration of RES and EV charging requires investment in transmission and distribution grids. The implementation of smart charging and V2G systems decrease the need for investment in grid reinforcements and regular battery storage systems. The pricing models serve as powerful incentives for EV owners, enabling them to procure electricity for their driving needs at more affordable rates during off-peak hours and subsequently sell any excess stored power during peak demand at higher rates, thus generating profits. Such pricing models, engage the EV owner in the transformation as a pro-active consumer (prosumer) within the energy system in contrast to tax schemes that burden citizens with the growing burden of electricity infrastructure investments.

Box 1

Flexpower Amsterdam

The Flexpower Amsterdam project aimed to determine the feasibility of adjusting the charging speed of electric vehicles based on the availability of energy in the power grid. To achieve this, 100 charging stations were equipped with special software that allowed for flexible charging speeds throughout the day. Charging would be faster during non-peak hours and slightly slower during peak hours.

The results showed that flexible or smart charging allowed electric vehicles to charge faster without inconveniencing users. The use of flexible charging also distributed charging costs over more kilowatt-hours, improved the occupancy rate of charging stations, optimized electricity network usage without capacity expansion, and increased the utilization of solar-generated electricity due to faster charging during the day.

Source: Elaadnl.[6] Accessed on 16 June 2023.

Box 2

Increased renewable energy consumption with electric vehicles

A pilot at the Leicester City Hall aimed to integrate on-site renewable energy generation with electric vehicle (EV) charging to reduce carbon footprint and promote sustainable transportation. The analysis of four EVs and their charging profiles demonstrated successful CO2 reduction. The set zero-emission kilometer target was not met due to PV generation being consumed by the building's energy needs. The virtual carport model showed a feasible

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[6] https://elaad.nl/en/projects/flexpower-amsterdam/

achievement of 41 per cent energy autonomy for the site. Overall, the study highlighted the benefits of smart charging and its potential for integrating renewable energy and EVs, contributing to a sustainable and environmentally friendly transportation system.

Source: Amsterdam University of Applied Science (2020)

Box 3

Geneva's breakthrough flash-charging technology for urban public transport

In May 2013, the city of Geneva started the pilot of the innovative TOSA (Trolleybus Optimisation Système Alimentation) project, enabled by groundbreaking flash-charging technology. Designed to navigate the full bus route of the city, the TOSA bus is equipped with lightweight onboard batteries which receive 600kW charges from a laser-guided arm in 15-20 seconds during regular passenger exchange at bus stops. This revolutionary technology, developed by global technology leader ABB, ensures seamless bus operation from one charging station to the next. The success of the pilot project had led to full-scale operation of the Geneva's bus line 23 started in 2018, with the following route specifications: (a) Fleet: 12 articulated buses (18 meter); (b) Flash charging stations at 13 of the 50 bus stops, which provide charges of 600 kW in 15-20 seconds; (c) Terminal feeding stations, which deliver prolonged charges of 400 kW in 4-5 minutes to fully top-up the on-board batteries.

Photos by UNtoday[7] (left) and the Canton of Geneva[8] (right)

The TOSA bus system is designed to cater to a maximum of 133 passengers by utilizing 100 per cent electric propulsion, eliminating the need for overhead lines. The buses are equipped with small and lightweight batteries (38 kWh) that can be mounted on the roof, ensuring the full utilization of the vehicles' passenger-carrying capacity. At designated stops, a robotic arm automatically extends from the bus roof to connect to an overhead charging station, utilizing "flash" charging to replenish battery power within the 15-second passenger embarkation and disembarkation window.

ABB's technology, developed in partnership with other key stakeholders, not only ensures a swift flash charge within 15-20 seconds, but it also maximizes transportation capacity and energy efficiency. The high-power overhead flash charging system is inherently safe, with connectors energized only when engaged. The TOSA project, therefore, elegantly sidesteps the electromagnetic fields usually associated with inductive charging concepts.

Key success factors

- The TOSA bus system, being quiet and emission-free, presents an attractive alternative to diesel buses and traditional trolleybus routes with overhead lines. The

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[7] https://untoday.org/genevas-public-transportation-in-a-pandemic-world/

[8] https://www.ge.ch/dossier/bus-tosa-innovation-mobilite-au-service-genevois/ligne-23-premiere-mondiale/ligne-23

visual clutter of overhead electric lines, often a barrier to trolleybus acceptance, can be relegated to the past with the adoption of flash-charging technology.

- Implementing the pilot project is of great significance for improving the policy package, standards and specifications, and verifying the technical feasibility and operation models.

Source: CEPS (2016), Augé (2022)

18. Uncoordinated charging, characterized by vehicles charging indiscriminately upon connection to the grid without considering peak times, can cause turbulence within the grid. Coordinated EV charging can be achieved through three distinct methodologies: individual signalling to each vehicle, signalling to a centralized controller overseeing EVs within a designated facility (e.g., parking lot/charging hub and commercial fleets at company parking), or management by a third-party aggregator responsible for coordinating dispersedly located vehicles. Aggregators can serve as central units that consolidate the collective energy of numerous EVs. Their primary responsibilities entail monitoring, controlling, and supporting the grid by providing essential ancillary services. Aggregators must devise effective dispatching strategies to cater to driving demand, regulate frequency, and optimize profitability. The design of charging infrastructure plays a crucial role in enabling and maximizing the potential of coordinated charging. An efficient and well-designed charging infrastructure should consider factors such as location, capacity, and connectivity. Strategic placement of charging stations in key locations, such as parking lots or commercial hubs, can facilitate centralized control and coordination of EV charging.

19. For heavy-duty vehicles such as electric trucks, similar mechanisms, and technologies could be helpful to maintain the reliability of the grid and increase the possibilities to integrate charging facilities for the charging of electric vehicles. Electric trucks generally follow a return-to-base strategy, where chargers are located at the starting and ending points of truck routes, commonly used by cargo, freight, and delivery services. Although this strategy is increasingly feasible and appealing, it presents challenges related to facility peak demand, leading to higher demand charges and the need for electrical infrastructure upgrades in specific cases. Especially in geographical regions with a high share of facilities such as distribution centers. Unlike the charging of light-duty passenger vehicles, which involves low-distributed charging loads and longer charging periods, the charging problem for ET fleets at commercial premises is significantly more complex. ETs have larger battery sizes and require high-power charging infrastructure, resulting in a substantial increase in peak demand compared to electric vehicle (EV) fleets. Additionally, the strict operational schedules that are strongly related to the quality of service of, for example, a logistics company, affect their availability for charging, further impacting the peak demand for ET fleet charging. Besides, the buildings of the companies that make use of ETs, in general, have large flat roofs that are very appealing for larger-scale solar roofs. Aligning the electricity generation with the charging demand on the premise of the company or together with the electricity demand and generation of companies within the same commercial area provides great opportunities for smart charging and V2G applications. (Al-Hanahi et al., 2022) (WDP, 2022)

20. The implementation of V2G systems encounters several limitations and considerations that warrant careful attention for successful integration. These encompass battery wear and degradation over time, limited availability of charging stations and associated equipment, substantial initial investments, and the need for standardized protocols and interoperability.

21. EV batteries, while designed for robust performance, are subject to gradual capacity loss over time. The frequent charging and discharging cycles associated with smart charging and V2G operations can accelerate this degradation process, reducing battery lifespan and overall efficiency. Mitigating this limitation requires thorough monitoring and management of battery health, implementing advanced battery management systems, and adopting charging strategies that optimize battery longevity. Research and development efforts are ongoing to enhance battery technology and prolong the lifespan of EV batteries.

22. To support the widespread adoption of V2G systems, an extensive network of smart charging infrastructure must be established. Current charging infrastructure is in many places in the early stages of development and developed charging infrastructure does currently not have standard functionalities to support smart charging and V2G applications.

23. The successful integration of Smart Charging and V2G systems relies on standardized protocols and interoperability between different EV models, charging infrastructure providers, grid operators, and energy market participants. Ensuring seamless communication and compatibility across diverse systems and stakeholders is crucial for efficient V2G operations. Establishing common technical standards, such as communication protocols and power exchange interfaces, helps facilitate interoperability and promotes a harmonized V2G ecosystem. Collaborative efforts among industry stakeholders, regulatory bodies, and standardization organizations are necessary to address this challenge and enable widespread adoption. The ISO15118-20 is an example of a protocol that supports the standardization of data protocols to enhance interoperability.

24. The implementation of Smart Charging and V2G systems requires a supportive regulatory and policy framework to address legal and market barriers. Clear regulations concerning grid connection, power pricing, and energy market participation for EVs are essential for encouraging widespread adoption. Additionally, establishing guidelines for data privacy, cybersecurity, and liability issues associated with the operations should ensure the protection of consumer rights and maintains system integrity.

D. Conclusion

25. The seamless integration of EV charging infrastructure with the energy system, particularly through the utilization of V2G technology, presents a promising solution to enhance the reliability, stability, and economic efficiency of renewable energy sources. By effectively managing the flow of energy, incentivizing EV owners, and harnessing the potential of aggregators, V2G systems can significantly contribute to the creation of a sustainable and resilient energy grid. This integration reduces dependence on traditional power plants, propels the widespread adoption of renewable energy, and paves the way for a more sustainable future for transportation and energy systems.

E. Recommendations

26. It is important to recognize and communicate that investing in the development of the EV ecosystem represents a strategic investment in the construction of a green energy system. The transition to electric mobility brings about opportunities for effectively integrating renewable energy sources. By highlighting the environmental and energy system benefits, policymakers and stakeholders can prioritize and allocate resources to support the growth of the electric mobility ecosystem.

27. When designing charging infrastructure, it is crucial to move beyond solely focusing on convenience for EV drivers. Instead, the design should align with the broader goals and requirements of transforming the energy system. By integrating charging infrastructure into the overall energy system design, the utilization of renewable energy can be optimized, and grid congestion can be limited.

28. During the initial rollout of charging infrastructure, it is essential to incorporate requirements related to smart charging and V2G capabilities. By including these features, a foundation for contributing to a flexible and intelligent energy system is developed.

III. Vehicle and charging infrastructure security

29. As EV adoption continues to increase, it is important to assess the safety advantages and potential hazards associated with these vehicles. This section examines the safety considerations related to electric vehicles, highlighting their advantages and potential risks.

By understanding these factors, stakeholders can make informed decisions and develop appropriate safety measures and policies for a safe adoption of electric vehicles.

A. Safety advantages of electric vehicles[9, 10]

30. Crash tests indicate that electric cars are comparable to conventional cars in terms of safety. Electric vehicles are subjected to the same safety standards as their traditional counterparts. The safety of pedestrians and cyclists in the event of an incident depends on factors such as car design and the implementation of built-in safety systems.

31. One of the significant safety advantages of electric vehicles is their lower centre of gravity. This advantage stems from the placement of the battery pack, typically located on the bottom of the vehicle. By distributing the weight evenly across the car, electric vehicles provide a stable base, reducing the risk of tipping or rolling over, even in high-speed collisions. In contrast, traditional gasoline-powered cars have their heavy components, such as the engine and fuel tank, located at the top, making them more prone to tipping over. The lower centre of gravity also enhances the handling and performance of electric vehicles. With improved weight distribution, these vehicles can turn and corner more quickly and smoothly, minimizing the risk of losing control. Ultimately, this contributes to overall road safety.

32. Electric vehicles offer instant torque, which refers to the ability of the electric motor to provide maximum torque from a standstill. This feature has several safety benefits. Firstly, it enables drivers to accelerate quickly and merge onto highways, helping to avoid accidents caused by slow acceleration. Additionally, instant torque enhances the ability to respond promptly to obstacles in the road, such as debris or animals, further enhancing safety.

33. Regenerative braking is a technology unique to electric vehicles that allows them to capture and store energy during the braking process. When the driver applies the brakes, the electric motor runs in reverse, converting kinetic energy into electrical energy, which is then stored in the battery pack. Regenerative braking offers several safety advantages. Firstly, it can help prevent accidents caused by brake failure or malfunction. By utilizing the electric motor to slow down the vehicle, regenerative braking reduces the wear and tear on the traditional braking system, extending the brakes' lifespan and preventing overheating or failure.

34. Unlike traditional internal combustion engine vehicles, electric vehicles are powered by an electric motor running on electricity stored in a battery pack. This distinction yields various safety benefits. Firstly, electric vehicles do not possess a fuel system, eliminating the risk of fuel leakage or ignition during an accident. Consequently, the potential for fire hazards is significantly reduced. Electric vehicle battery packs are designed to be safe and incorporate built-in safety features that further mitigate fire risks.

B. Potential safety risks[11]

35. Battery damage. While the risk of thermal runaway in damaged EV batteries appears low based on practical testing, it is a potential hazard to consider. Thermal runaway refers to the uncontrolled increase in temperature within a battery cell, often resulting in hazardous thermal events such as fires or explosions. Internal damage or short circuits can trigger thermal runaway.

36. Fire safety. The risk of fire in electric cars is not higher compared to conventional cars. The release of substances during fires is largely similar, but electric cars may emit more hydrogen fluoride, which can cause skin irritation. However, the battery packs in electric vehicles are designed to be safe and incorporate safety features to prevent fires. When faced

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[9] https://www.agendalaadinfrastructuur.nl/ondersteuning+gemeenten/documenten+en+links/documenten+in+bibliotheek/handlerdownloadfiles.ashx?idnv=1930035

[10] https://steerev.com/steer-vs-other/8-reasons-why-electric-vehicles-are-safer-than-traditional-cars/

[11] https://www.agendalaadinfrastructuur.nl/ondersteuning+gemeenten/documenten+en+links/documenten+in+bibliotheek/handlerdownloadfiles.ashx?idnv=1930035

with thermal runaway or fires in EVs, firefighters encounter unique challenges due to the construction and characteristics of lithium-ion battery cells. Various methods have been explored to address these situations, but it is important to understand their limitations and potential risks. Here are different approaches that have been considered:[12]

- Firefighting foams are commonly used to smother fires and cool the surrounding area. However, foam is ineffective in stopping a thermal runaway event in an EV. The cells are located inside a watertight, fire-resistant box, making it difficult for the foam to reach them. Additionally, lithium-ion battery cells do not require external oxygen to burn, rendering foam ineffective in extinguishing the fire.
- Fire blankets are traditionally used to smother fires and deprive them of oxygen. However, attempting to smother a fire in a lithium-ion battery cell is ineffective since these cells do not rely on atmospheric oxygen to burn. Fire blankets can be used to contain the fire and provide exposure protection, but care must be taken due to the harmful and flammable gases emitted by the battery cells.
- A piercing nozzle is a specialized firefighting tool used in electric vehicle (EV) fires. It is designed to puncture the battery box or compartment of an EV to deliver water directly to the fire source. The nozzle's sharp tip creates an opening, allowing firefighters to cool down overheating battery cells and prevent the fire from spreading. However, using piercing nozzles poses risks such as electrocution and the potential for additional cell failures. EV manufacturers advise against attempting to access the inside of the battery box, as it is hazardous and can cause further damage. Considering the limitations of these considered approaches, the best approach is to let the battery burn itself out.

37. No sound. EVs produce less noise compared to traditional internal combustion engine vehicles, raising concerns about pedestrian safety, especially at low speeds. To address this, the Acoustic Vehicle Alert System (AVAS) has been introduced, as detailed in United Nations Regulation No. 138 on Quiet Road Transport Vehicles (QRTV). AVAS generates artificial sounds resembling a traditional engine, providing an audible cue to pedestrians and other road users, enhancing safety, particularly in urban environments. However, beyond certain speeds, the difference in sound between electric and conventional cars diminishes, with tire noise becoming the primary sound. At higher speeds, the sound difference disappears entirely.

38. Water immersion. Electric car batteries are designed to operate even when fully immersed in water. Distinctions exist between full and partial immersion scenarios, with the lack of oxygen being a potential difference. Guidelines are in place to address situations involving flooding or exposure to salty/polluted water. However, complete submersion in flood events is not always expected.

C. Safety management[13]

39. This section focuses on safety management for electric vehicle incidents, covering training programs for fire departments, incident management strategies, safety considerations for maintenance personnel, and safety measures for charging infrastructure.

40. Training. It is highly recommended that fire departments prioritize specialized training programs for responding to incidents involving electric vehicle fires. Training programs should cover a range of topics, starting with the identification of different types of EVs and understanding their specific battery chemistries and characteristics. This knowledge forms the foundation for implementing safe firefighting strategies tailored to EV incidents. Emphasis should be placed on educating firefighters about the potential hazards associated with high-voltage systems, as well as the risks of thermal runaway events and the release of harmful gases. Practical exercises and simulations should be incorporated into the training

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[12] https://www.firerescue1.com/electric-vehicles/articles/developing-sops-for-electric-vehicles-incidents-CbHhgn5759QnLDv3/

[13] https://www.osti.gov/biblio/1877784

curriculum to provide hands-on experience in safely managing and extinguishing EV fires. These exercises should underscore the proper usage of personal protective equipment, incident management techniques, and effective coordination with other relevant agencies.

41. Incident management. Incident management for electric cars differs due to their unique fire behavior and the risk of reignition. Identifying electric vehicles and locating battery packs pose challenges for incident managers. Thermal imaging cameras and vehicle information applications can assist in identifying the position of the battery pack. Collaboration between salvage companies, insurers, and fire services is ongoing to develop protocols for safely handling unstable or burning electric cars.

42. Safety for maintenance. Proper training is required for roadside assistance, emergency services, and garage personnel to work safely with electric cars. These training courses are based on guidelines concerning the safety risks associated with high-voltage systems.

43. Safety for charging infrastructure. The charging infrastructure for electric vehicles presents challenges in mitigating risks. Charging systems are considered safe due to built-in safety features and adherence to existing regulations and technical standards. Collision detection sensors and safety systems are designed to minimize risks during charging. Proper installation and capacity considerations are crucial for ensuring safe charging infrastructure.

D. Cybersecurity

44. Potential impact of cyber-attacks: A successful cyber-attack on high-power EV chargers could disrupt the charging process, compromise user data, or even cause physical damage to the charging infrastructure itself. Cyber-attacks targeting EVs and charging infrastructure can result in the theft or unauthorized access to financial and personal data of EV owners or users. This can lead to identity theft, fraud, and financial loss. A cyber-attack on EV charging infrastructure can disrupt the charging process, leading to a failure to charge vehicles. In more severe cases, a sophisticated cyber-attack can lead to the complete shutdown of an entire charging network. This can inconvenience EV owners and users, limit their mobility, and hinder the adoption and acceptance of electric vehicles. Cyber-attacks on EVs or charging infrastructure can undermine consumer confidence in the security and reliability of electric vehicles. The perception of EVs as vulnerable to cyber threats may discourage potential buyers from adopting electric mobility solutions, slowing down the transition to a sustainable transportation system.

45. EV charging stations are commonly found in workplaces, public areas, and other accessible locations. Due to their connectivity to the internet and other networks, they provide an entry point for potential hackers to exploit vulnerabilities and gain unauthorized access. Cyber- attacks targeting EVs or charging infrastructure may exploit vulnerabilities to gain unauthorized access to linked IT systems. This could enable hackers to get access to sensitive data within organizations or government entities. In the context of critical infrastructure sectors, including transportation systems, emergency services, and manufacturing, the consequences of cyber-attacks can be severe. An attack on transportation systems could disrupt the flow of traffic, impacting the movement of goods and people. Similarly, targeting emergency services could compromise their ability to respond effectively to crises and emergencies. Attacks on manufacturing facilities could disrupt production lines, leading to significant economic losses.

46. The integration of EVs with smart-grid technologies offers numerous benefits, including optimized charging, load balancing, and efficient energy management. However, this integration also introduces new attack vectors and potential risks. Smart-grid technologies rely on communication networks and data exchange between EVs, charging infrastructure, and the electricity grid. Any vulnerability in this interconnected system can be exploited by cybercriminals to compromise the electricity grid's integrity or disrupt its operations. Cyber-attacks may target specific components of EVs, such as batteries, with the intent to cause damage or compromise their functionality. Manipulating battery charging parameters or overriding safety mechanisms can result in battery degradation, reduced performance, or even safety hazards for the drivers.

47. Inadequate logging or lack of alarm systems when internal compartments of EVs or charging infrastructure are accessed creates a vulnerability. This means that unauthorized physical access to critical components, such as the battery or control systems, may go undetected. Attackers could exploit this weakness to tamper with or compromise the integrity of the components, potentially leading to unauthorized control of the vehicle or disruption of charging infrastructure operations. Storing sensitive data, such as personal information and credentials, in an unencrypted format poses a significant security risk. If attackers gain access to the data storage systems, they can easily retrieve and exploit this information for identity theft, financial fraud, or unauthorized access to linked systems and networks. Encryption is a fundamental measure to protect data confidentiality and integrity, and its absence increases the likelihood of data breaches and compromises. The placement of malicious hardware or software within EVs or charging infrastructure can have severe consequences. Attackers may install unauthorized devices or software to manipulate or exploit the systems, such as compromising financial transactions or redirecting funds to false accounts. This can result in financial losses for individuals or organizations involved in EV-related transactions and undermine trust in the security of financial processes within the EV ecosystem.

48. PLACEHOLDER: [Cybersecurity measures, governance, and policies to be elaborated further.]. This section is to be finalized and to include information on:

- Implementation of secure communication protocols to protect data transmission.
- Integration of strong authentication mechanisms to prevent unauthorized access.
- Utilization of encryption techniques to safeguard sensitive information.
- Incorporation of intrusion detection and prevention systems to identify and mitigate cyber threats.
- Adoption of secure over-the-air (OTA) software updates for timely security patching.

49. PLACEHOLDER: [Cybersecurity governance and policies]

- To be finalized and to include:
  - Role of regulatory bodies and industry standards in establishing cybersecurity frameworks
  - Development of comprehensive policies to address cybersecurity risks in EV manufacturing, deployment, and operation.
  - Collaboration between government entities, industry stakeholders, and cybersecurity experts to formulate robust policies.
  - Regular audits and assessments to ensure compliance with cybersecurity guidelines and regulations.

50. PLACEHOLDER: [EV data management to be further elaborated]. This section is to be finalized and to include information on:

- Relevance of data management for EV optimization across the EV value chain such as state-of-charge.
- Reliance of EV services such as smart charging and V2G on data.
- The need for good data quality and calibration elements.
- Data architecture elements across the EV charging value chain including planning data; construction and realization data; operational data; metadata; usage/transaction data; configuration management data; data on service & maintenance; reporting data; as well as standardization and harmonization requirements (including single IDs for charging points; single semantics across actors and monitoring efforts across sectors, including the energy sector.

IV. Conclusions, recommendations and next steps

51. The need and urgency for sustainable transport is clear. The transition towards sustainable transport has been broadly embraced to reduce CO2 emissions and improve air quality. The rationale and urgency have been proven by science and acknowledged by many United Nations member States. This has been translated into commitments with specific targets, captured in Nationally Determined Contributions (NDCs) for every country.

52. Governments are making use of their policy instruments to support the NDCs, but face uncertainties. Meanwhile, governments and policymakers have made use of regulatory, tax and financial incentives to stimulate supply and demand of electric vehicles and charging infrastructure to reach the NDCs. These policy and regulatory frameworks are often part of a broader energy transition movement, including reduced consumption, sustainable generation and moving away from gas and oil in every segment, from heating in houses to industrial production methods. Each country faces different challenges and is looking for an optimal balance to achieve their NDCs; there is a lot that can be learned from each other.

53. Battery-electric transportation is the optimal pathway. To move towards zero-emission mobility, the electrification of inland transport with batteries has proven to be the most promising and efficient pathway to date. Multiple low carbon alternative fuels have been researched and are being developed, but when taking efficiency and carbon footprint into account, battery-electric transportation has demonstrated to be the best business case in most cases to reach climate goals. Considering all modes of transport, there are areas where alternative fuels and/or energy carriers are still considered useful. Also, a lot of research is still going on to further improve efficiency of alternative fuels use. While the value chain for battery-electric drivetrains still has some significant challenges to be resolved (fully sustainable generation, use of critical materials, recycling, and waste management), but the general scientific consensus is that electrification via batteries is currently the optimal pathway towards zero-emission transport.

54. Battery-electric transportation has become a mature part of the energy transition. The state of the industry reflects this development: car manufacturers have globally invested in the production of battery-electric vehicles (BEVs), generation companies have demonstrated strong businesses case improvements of solar and wind farms, battery development is moving away from cobalt and demonstrating e.g. silicon-based solid state batteries with impressive specifications, and numerous battery-recycling initiatives are being developed to prepare for second-life and reuse of scarce materials. Also, bidirectional interaction between BEVs and the electricity grid remains to be deployed at large scale, but the potential for BEVs to support the transition to renewable power generation, both in volume and in daily offtake profiles, is enormous.

55. The EV battery is part of a larger energy transition towards a fully flexible system; both as a consumer but also as a storage solution. A unique aspect of the electrification of transportation, is the collaboration with (and impact on) the energy system. The presence of a battery-electric fleet has impact on both generations, the distribution grid and consumption. Not only the amount of kWh's increases, but also the usage profile shows drastic changes. Combined with the generation curve of solar and wind generation and other initiatives such as moving away from gas heating to heat pumps, the electricity grid and the utility companies face an unheard-of challenge. It is therefore crucial to provide predictable figures on the electrification of transport, for all modes, in order to add these to the forecasted generation and distribution needs. It is equally important to provide solutions to limit peaks in the grid and thereby prevent costly investments. Smart charging (V1G) is considered a default functionality for this, to reduce charging capacity at peak hours, or move charging sessions to off-peak moments. Vehicle-to-grid (V2G) is the more advanced solution where the vehicle can provide electricity back to the grid. These are very successful capabilities to not only reduce the impact of EVs on the grid, but even to have a positive contribution to grid balance and usage profiles. Current markets will need to develop business models and adequate regulation to optimally develop this functionality. Both the energy value chain as well as the transportation value chain are involved in smart charging and will need to be more interconnected to fully capture this value. Also, new issues will arise from the scale-up of electric transport: what are optimal charging infrastructure models when BEVs are a

significant part of transport fleets? how to deal with data ownership, the exchange of privacy-sensitive data and other cybersecurity issues? Every country is facing these questions, and UECE can support governments in exchanging best practices and providing guidance towards harmonizing regulatory and market frameworks.

56. Given the significant size and importance of multimodal transport in the ECE region, which reflects diverse economies, the electrification of this sector remains crucial for enhancing connectivity. Achieving electrification in multimodal transport and between the different actors involved, necessitates the development of interoperable charging infrastructure and standardized protocols. While addressing this formidable challenge is no simple feat, it can also be viewed as a catalyst to promote the adoption of EV and enable a consistent and harmonized approach.

57. In the inland water transport (IWT) sector, electrification emerges as one of the key strategies in the greening of its fleets. Powering inland waterway vessels using batteries is identified as a viable solution for achieving a zero-emission fleet. Hybrid solutions combining battery power with hydrogen fuel cells, offer promising solutions to overcome challenges associated with extended voyages and energy storage limitations. However, the success of electrification depends heavily on sufficient shore-side electricity supply at ports. The ongoing implementation of shore power systems, in particular in the European Union, signifies a positive trend towards this requirement. Moreover, projects aimed at developing and testing these technologies are underway, indicating a growing momentum in the industry. To ensure safety and efficiency, it is imperative to establish relevant harmonized norms and standards governing the deployment and operation of these systems. Consequently, recommendations encompass not only a proactive pursuit of vessel electrification and infrastructure development but also a focus on establishing robust standards to guide this transition. Government bodies, international organizations, shipping companies, and technology providers should collaborate to accelerate these efforts and transform the vision of a zero-emission IWT fleet into a tangible reality.

58. Sharing best practices and the adoption of globally harmonized open standards and regulatory tools is the best way to counter uncertainties and prepare for any future market design. The transition towards sustainable transport affects every actor in the value chain, and even affect other sectors such as electricity and spatial development. As transitions go, the definite future market model is not prescribed. To re-use best practices, assure cross-border harmonization and compatibility and support different market models in different countries, it is of the utmost importance to introduce globally harmonized open standards, protocols and regulatory tools. This will assure the most efficient route in this transition, and the flexibility to move to an optimal future market model that connects the ECE region and beyond. Many standards and protocols are in development, and some are already in use to support the current electrification initiatives. UNECE can play a valuable role in exchanging best practices, help build a harmonized regulatory landscape and introducing the fundamentals for the energy transition.

59. A harmonized and driver-centric approach of charging infrastructure is fundamental for a successful transport electrification. Cross-border harmonization and its need for open standard and protocols can be translated into specific use cases that address ease of payment, access to every charging station, transparent prices, high-quality navigation and information services. ECE can address the convergence of regulatory frameworks to assure this driver-centric approach and can additionally address implementation challenges in this innovative space where regulation has not yet been formulated.

60. Potential roles of ECE moving forward. To facilitate progress in electric mobility, it is strongly recommended that ECE establishes a dedicated task force focused on driving and coordinating efforts related to EV development both within ECE and in collaboration with other institutions. The task force should be granted a specific mandate to address key challenges and opportunities within the EV sector, including standardization, regulatory frameworks, infrastructure deployment, and market incentives. By taking on this role, the task force can significantly contribute to the alignment of evolving market models and the role of public governance in facilitating market-driven deployment. Additionally, it should prioritize promoting cross-sectoral collaboration and actively engaging with industry representatives to foster knowledge exchange and innovation. While the exact resource

requirements would depend on the scope and scale of the task force activities, it is recommended to allocate at least one full-time equivalent staff member to lead and coordinate the task force initiatives.