Economics of Electric Mobility: Utilities and Electric mobility

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List of Abbreviations

TSO	Electricity transmission system operator
DSO	Electricity distribution system operator
IPCC	Intergovernmental Panel on Climate Change
EV	Electric Vehicle
PV	Solar Photovoltaic panel
SPV	Special Purpose Vehicle
BSP	Balance Service Providers
CPO	Charging Point Operator
EMSP	Electric mobility Service Providers
ICEV	Internal Combustion Engine Vehicle
IEA	International Energy Agency
EVSE	Electric Vehicle Supply Equipment
SOH	State of Health
SOC	State of Charge
V2X	Vehicle-to-Anything
IPP	Independent Power Producer

Basic Definitions

Electric Utilities	Electricity generation, transmission, distribution, and retail companies or an SPV in the value chain
Electric Mobility	Vehicles that are powered by an electric motor and primarily get their energy from the power grid
Megatrend	The contemporary issues challenging the electricity industry (decarbonization, decentralization, demand disruption, digitalization & disintermediation).
Battery Electric Vehicle	Vehicles that exclusively use chemical energy stored in rechargeable battery packs, electric motors and motor controllers instead of internal combustion engines (ICEs), with no secondary source of propulsion.
Smart Charging	Charging system where electric vehicles, charging stations, and charging operators share data connection
Battery State of Health (SOH)	Measurement that reflects the general condition of a battery and its ability to deliver the specified performance compared with a fresh battery
Battery State of Charge (SOC)	The available capacity of a battery expressed as a percentage of some reference, sometimes its rated capacity but more likely its current capacity
Frequency Regulation	To stabilize the power frequency at the required threshold and prevent it from becoming too high or too low.
Energy Arbitrage	To buy electricity during low price period and to sell at a later high price period
Spinning reserve	The amount of unused capacity in online energy assets which can compensate for power shortages/frequency drops within a given period of time

Executive Summary

This report analyses the topology, ecosystem, opportunities, and challenges (economic and technical) of electric mobility. Furthermore, it analyses the interaction of electric utilities with the increased uptake of electric mobility in the context of the megatrends of decarbonization, digitalisation, decentralization, demand disruption and disintermediation in the developing countries.

- **Electric Mobility topology**

V1G means unidirectional charge control that is also referred to as smart charging. Vehicle-to-Anything (V2X) topology means bidirectional charge/discharge capability and can be classified as Vehicle-to-Grid (V2G), Vehicle-to-Building(V2B), Vehicle-to-Home(V2H) and Vehicle-to-Load(V2L).

V2L means an individual EV battery providing energy to a load. For example, in case of emergency back-up energy during an electric grid outage or as an energy source in rural areas with limited grid connections.

V2H consists of optimizing home energy consumption or using one or several EVs as emergency back-up power for residential homes. It could involve the combination of Photovoltaic (PV) power generation and EV for a home. The EV could use the PV energy for charging while the PV systems could use the bidirectional flexibility of the EV batteries to maximize its self-consumption.

V2B operates much like V2H but at a larger scale with a few EVs or aggregate of a fleet to optimize the building or site energy consumption at commercial or industrial buildings.

V2G refers to using the EV batteries to interact with and to provide value back to the electric grid in the form of one or more energy services. Energy services refer to selling this dynamic charge control in the form of aggregated flexible capacity in wholesale and ancillary services markets to provide flexibility services for the technical operation of the electric grid. Therefore, apart from the use of the EV for transportation, it can be enabled to serve additional purposes by integration with the electric grid, a building, home or to meet a power need (load).

- **Electric mobility Ecosystem**

Electric mobility is a part of a wide and intertwined ecosystem that involves both transport and electric systems as well as regulatory authorities etc. First, it consists of the EV users. Second, the manufacturers - car manufacturers, battery and BMS (control logic) and the charging infrastructure manufacturers. Third, the electricity grid operator (TSO and DSO). Fourth, the energy providers, Charging Point Operators (CPOs) and Balance Service Providers (BSPs) to properly manage the charging process and to support proper data exchange. Fifth, the aggregator that has a role to balance the communication and power sent between the grid and the vehicle. Sixth, the government and its regulatory authorities (bilateral decision makers, national /local decision makers, regulatory authorities, standardisation bodies, urban planning authorities, transport authorities etc.). Seventh, the electricity providers (power generation utilities and traders). Eight, the energy/flexibility markets operators to ensure the proper functioning of the ancillary services market. All the actors in the ecosystem need to be properly coordinated to facilitate the smooth functioning of the EV market.

- **Electric Mobility Opportunities for the utilities**

Apart from the fact that EVs do not release emissions when driven and thus help to mitigate climate change. EV can also provide benefits to the electric grid, such as to provide flexibility services to the grid via smart charging approaches. For the distribution networks, the EV's flexibility can help to defer or avoid costly reinforcements in highly uncertain scenarios. Additionally, the EV's

flexibility can help to achieve an efficient use of the existing infrastructure, by providing peak shaving services. The table below summarizes the opportunities of EV.

			Aggregated		Singular			
Sector	Value Stream	Definition and Value Derivation	V2G (10+)	V2B (1-30)	V2H (1-3)	V2L (1)	Topology Scale	
Wholesale	Resource Adequacy	Provides capacity through ability to discharge electricity (V2G) or ability to reduce demand (V1G/V2G) at future peak load hours. Value through RA mechanisms or Capacity Payments.	✓				Power	In-Front-of-the-Meter
	Frequency Regulation	Either fluctuate charge rate (V1G) or charge and discharge (V2G) to follow a 4 second regulation signal. Value through Ancillary Service markets or mechanisms.	✓					
	Demand Response-Wholesale	Reduce charge rate or delay charge (V1G) or in addition to previous, discharge to grid (V2G) in response to grid conditions. Value through wholesale market DR mechanisms.	✓				Energy	
	Energy Arbitrage	Buy electricity (charge) during low price hours and sell (discharge) at later high price hours (V2G only). Value through wholesale market in hourly price difference.	✓					
	Spinning Reserves	Maintain electricity balance by immediately discharging to grid (V2G) or by interrupting charge (V1G) in response to grid contingencies. Value through Ancillary Service markets/mechanisms.	✓					
	Load Following	Due to solar peak or wind fluctuation, discharge (V2G) to control system demand ramp rate. Value through Ancillary Services market.	✓					
	Excess RES generation	Charge to absorb excess wind and/or solar generation. Value through reduced RES curtailment.	✓					
	Peak Shaving	Charge at peak hours to reduce demand. Value through wholesale market.	✓					
	Generation Pairing	Paired with RES to control ramp rate of large energy fluctuations or with thermal generator to improve flexibility and allow faster response time. Value through ancillary services markets, bi-lateral contracts, and forgone retro-fit upgrade costs.	✓	✓				
	Reactive Power Support	Adjust Reactive Power output to provide PFC, RPC, or VR (V2X only). Value through Ancillary Services market or through forgone investment to reduce inductive loads.	✓	✓				
Utilities/SO	Network Deferral	Reduce demand (V1X/V2X) or increase supply (V2X) at peak to meet projected load growth in capacity-constrained areas for the purpose of delaying, reducing, or avoiding Trans/Dist. build-out. Value via TSO/DSO direct payments or infrastructure deferral mechanisms.	✓	✓			Power	
	Demand Response-Utility	Reduce charge rate or delay charge (V1X) or in addition to previous, discharge to grid (V2X) in response to grid conditions. Value through utility operated DR mechanisms.	✓	✓	✓		Energy	
	Site-located RES firming	Discharge (V2X only) to firm site solar or wind generation capacity to improve RES utilization rates. Value through reduced RES curtailment and/or payments for meeting RES targets.	✓	✓	✓			Behind-the-Meter
Customer	Bill Management	Reduce demand charges and adapt EV battery charge (V1X)/discharge (V2X) depending on tariff or TOU rates to minimize electricity costs. Value through cost savings.		✓	✓			
	Emergency Back-up	Provide emergency energy to buildings in the case of outage (V2X only). Value through costs savings of forgone diesel fuel or through VOLL estimation.		✓	✓			
	Non-Emergency	Mobile source of electricity for recreational activities or rural areas: camping, concerts, construction sites, parties, etc (V2X only). Value through pricing for capability.			✓	✓		

V2G presents the largest overall revenue potential with direct access to the wholesale energy and ancillary services markets. However, it constitutes the most complicated topology due to the need for grid-significant capacity acting in response to real-time grid conditions. Therefore, V2G services are provided by an aggregator coordinating a multitude of individual vehicles or by operating a fleet of vehicles. To determine which of the opportunities has the highest economic potential is challenging due to the complexities arising from the locational characteristics, differing market conditions and regulation. Different tariff structures, local and regional energy technology mix, and demand growth also make drawing conclusions applicable to all markets nearly impossible. Therefore, analyses of EV economic viability must be taken in the context they are performed and may not be transferrable to other markets.

- **Electric mobility challenges for the utilities and the potential solutions**

First, the technical challenges that include increased battery degradation, charging efficiency, implementing effective algorithms to aggregate resources, metering accuracy, cybersecurity risks and data privacy concerns and lack of a uniform communication system/protocol. Minimizing battery degradation, optimizing charger efficiency, and implementing effective algorithms to aggregate resources can be achieved through increased R&D and demonstration projects. For V2G, common standards should be developed and adopted to guarantee the interoperability of charging networks. Moreover, control systems for EV charging should be designed in such a manner that data failure or manipulation does not lead to a substantial change in the system balance (cyber-resilience) and emergency situations should be properly managed.

Second, the economic challenges include the investment costs that may be required to extend and reinforce the existing grids. Others are the market design and regulatory challenges that include the integration challenges with the subsisting market designs and how to manage the ensuing regulatory complexities, entry barriers to storage-based actors, double taxation, curtailment requirements of renewable energy and the capacity markets to support baseload capacity. To address the market design and regulatory challenges, this report develops an iterative framework that entails: 'the analysis of the market rules', 'improvement of the market rules', 'the review the regulators' evaluation criteria' and 'change of the market rules' that can be applied in case studies.

- **Electric utilities interaction with electric mobility in the megatrends context**

First, decarbonization entails reducing the carbon emission by phasing out fossil fuels from the generation of electricity. The use of EVs as a flexibility resource via smart charging approaches would reduce the need for investment in carbon-intensive, fossil-fuel power plants to balance renewables generation. Second, digitalization can increase flexibility and enable integration across entire systems. It can play a key role in the optimisation between EV transport service and the grid services, in both the planning and operation stages. Furthermore, digital technologies and data analytics will make it possible to match mobility demand with power supply patterns, to be as compatible as possible and to identify the most optimal locations for charging points. Third, decentralization brings more players providing supply, storage and energy management services. EV battery storage can empower consumers to participate in the production of electricity and in demand response services, generating reverse flows along power networks and introducing the possibility of trade at the retail level.
Fourth, disintermediation is the process of removing the middleman or intermediary from future transactions. Peer to peer technology can facilitate the payment and billing for EV services as well as simplify the provision of EVs flexibility services to the grid. It can facilitate smart charging by connecting different parties and facilitating monetary transactions between aggregators and customers through a form of open-source standards, replacing proprietary solutions. Peer to peer technology can also be used for customer-to customer charging solutions such as the sharing of a private charger when not in use with someone else for a fee. Fifth, a spike in the number of EVs can put large power demand burdens on the grid system that may affect the performance of the power system and leads to power failure. Centralized coordination can be effective to solve the EV integration to grid issues to avoid demand disruption. The optimal power, energy capacity and location of EVs can accurately be solved by optimizing the system/interaction between the EV and the grid variables.

Finally, this report develops a framework that can support in-depth case studies of the interaction of electric utilities and electric mobility in the megatrends' context in the developing countries. It makes a longlist of 16 countries to apply the framework in future studies. The countries are - [Latin America (Argentina, Brazil, Chile, Guatemala, Peru, Colombia); Eastern Europe (Romania, Russia, Turkey, Ukraine, Poland)**;** Asia (India, China, Philippines, Kazakhstan); and the Caribbean (Dominican Republic)].

Takeaway for Policy Makers

- Electric mobility is a part of a wide and intertwined ecosystem that involves both transport and electric systems and requires proper coordination among the different actors.
- Beyond meeting transportation needs that help to mitigate climate change, EV also presents other economic opportunities. EV can provide benefits to the electric grid, such as the provision of flexibility services via smart charging approaches.
- Analyses of the EV economic viability for flexibility services must be taken in the context they are performed and may not be transferrable to other markets due to the market intricacies that make drawing general conclusions applicable to all markets nearly impossible.
- Increased battery degradation, charging efficiency, implementing effective algorithms to aggregate resources, metering accuracy, cybersecurity risks and data privacy concerns and lack of communication system/protocol are the key technical challenges to use EV for flexibility services. They can be addressed through increased R&D and demonstration projects.
- Grid extension and reinforcement investment costs and the market design and regulatory challenges are the key economic challenges to use EV for flexibility services. This report proposes an iterative framework that entails: 'analysing the market rules', 'improving the market rules', 'the review the regulators' evaluation criteria' and 'changing the market rules' that can be applied to case studies.
- This report develops a framework and makes a longlist of 16 countries where it can be applied for in-depth case study of the interaction of electric utilities and electric mobility in the context of the megatrends in the developing countries. The countries are – Latin America (Argentina, Brazil, Chile, Guatemala, Peru, Colombia); Eastern Europe **(**Romania, Russia, Turkey, Ukraine, Poland**);** Asia **(**India, China, Philippines, Kazakhstan) and in the Caribbean (Dominican Republic) in no particular order.

1. Introduction

Electric mobility is fundamentally changing the traditional interaction between technology, market dynamics, production capacity, government policy, supply chains and manufacturing [11]. According to the IEA, there are over 10 million electric cars, 290 million 2 and 3 wheelers, 378,000 light commercial vehicles, 600,000 buses, 31,000 trucks and 230 million micromobility e-scooters, e-bikes, electric mopeds globally in the year 2020 [13]. Moreover, there is an expected increase in end-users' electric mobility acquisition in the coming years due to declining battery costs, mass production of battery cells, and energy density increase that allows the reduction of the battery pack size. EV market penetration is quickly increasing, driven by progressive improvements in the driving range and purchase price that is reducing the competition gap with fossil-fuelled vehicles. For instance, in 2020, the weighted average range for a new battery electric car was about 350 kilometres (km), up from 200 km in 2015 [13]. Besides, the most recent environmental policies and the industrial efforts in this sector have clearly paved the way for a significant electrification [17].

If energized with decarbonized electricity and smart charging, electric mobility should provide a partial solution to protecting collective public goods like local public health (via reduced urban air pollution). It should also help to reduce NOx and CO_2 emissions, thus helping to stabilize the climate, reducing domestic consumption of transport fuel, thus increasing energy security and independence [5]. In 2019, electric vehicles in operation globally avoided the consumption of almost 0.6 million barrels of oil products per day. Moreover, the electricity generation to supply the global electric vehicle fleet emitted 51 MtCO2-eq, about half the amount that would have been emitted from an equivalent fleet of ICEV, corresponding to 53 MtCO2-eq of avoided emissions [25].

Electric mobility operates in a wide ecosystem with many actors from both the transport (vehicle, battery, charging infrastructure manufacturers etc.), and electric systems (utilities, regulatory authorities, market traders, service providers etc). At the heart of electric mobility is the Electric Vehicle (EV). EV can be V1X (unidirectional charge) or V2X (bidirectional charge and discharge) where X refers to multiple topologies or is replaced by the specific topology referenced i.e. V1G (smart charging), vehicle to grid (V2G) etc. The V2X topology is the umbrella term to explain the use of EV batteries to derive additional value during the times of non-use [1]. This implies the interaction of electric mobility with electric utilities.

There are some major trends impacting the interaction of electric mobility with the electric utilities and also transforming the subsisting modus operandi of the traditional electric utilities. These megatrends include: (i) decarbonization, (ii) digitalization (iii) decentralization, (iv) demand disruption and (v) disintermediation. Decarbonization is the removal of carbon emissions from energy sources to mitigate the impact of climate change. For electric utilities, decarbonization implies a change in power generation source and EVs as a flexibility resource via smart charging approaches can reduce the need for investment in carbon-intensive, fossil-fuel power plants to balance renewables power generation. Digitalization is the growing application of information and communications technologies (ICT) in the energy systems [19]. Digitalisation will make it possible to go beyond simple time-of-use charging for EVs and enhance EV use. It will play a key role in optimisation between EV transport service and the grid services, in both the planning and operation stages [28]. Disintermediation is the process of removing the middleman or intermediary from future transactions [23]. For example, the blockchain technology can facilitate the payment and billing for EV services as well as simplify the provision of EVs flexibility services to the grid [28]

The plummeting cost of solar photovoltaic power and new developments in battery storage, combined with digitized power grids, are creating possibilities for the decentralization of energy services, with power provided by a variety of actors. EV battery storage will empowers consumers and other decentralized actors to participate in the production of electricity and in so-called demand-response services, generating reverse flows along power networks and introducing the possibility of trade at the retail level. These technological trends are disrupting frontier markets where some are even calling into question the need for a traditional, centralized utility [24]. Demand disruption creates new risks and opportunities with the potential to transform the traditional electric utilities service delivery model, reshape the stakeholders' landscape, and redefine the way that government agencies and consumers engage with the energy markets [20].

Large fractions of EVs can impact the load profile of utilities by overloading the electric generation capacity (regionally) or electric distribution systems (locally) [5]. In some cases, EVs may also require extending and reinforcing the existing electricity grids. For example, the electrification of gas stations (urban or on highways) for fast charging. High powered recharging stations are usually needed for personal or collective long distances and/or heavy loads trips. As EVs become a significant fraction of the fleet, (and if they are implemented along with intelligent systems), would lead the whole electricity system to undergo an important paradigm change [5]. The need to match generation and load becomes more challenging as the variable generation (e.g. wind and solar power) increase to represent a larger fraction of the generation mix. Thus, large-scale EV introduction along with the possibility of charging and discharging these vehicles in an intelligent way, will facilitate real-time management and greatly reduce the short term need to precisely balance generation with load [5].

This paper analyses the EV topology, ecosystem, opportunities and challenges that the electric utilities (currently faced with the megatrends) are facing with the increased uptake of electric mobility in the developing countries. It provides insight on how to overcome the market design and regulatory challenges for the electric utilities faced with the increased uptake of electric mobility. Moreover, it analyses the transformation of the electric utilities with electric mobility in the context of the megatrends in the developing countries. Finally, it provides a long list of developing countries that can be potentially viable for electric utilities integration with electric mobility for further studies.

Section 2 is the discussion of the electric mobility topology, ecosystem and opportunities. Section 3 is the discussion of the technical, market design/ regulatory challenges. Section 4 is the discussion of the electric utilities' interaction with electric mobility in the megatrend's context. Section 5 presents a framework for the interaction of the electric utilities with electric mobility in the context of the megatrends for the developing countries. Section 6 is the conclusion.

2. Electric mobility topology, ecosystem and value streams(opportunities) framework

2.1 Electric mobility topology

V1G means unidirectional charge control, it is also referred to as smart charging. Furthermore, there is the Vehicle-to-Anything (V2X) topology. The V2X topology can be classified as Vehicle-to-Grid (V2G), Vehicle-to-Building (V2B), Vehicle-to-Home (V2H) and Vehicle-to-Load (V2L)**.** V2L is the least complex and smallest scale topology and constitutes any instance of an individual EV battery providing energy to a load. The primary envisioned operation of V2L is in providing emergency back-up energy in the case of an electric grid outage or serving as a source of energy in rural areas with limited grid connections. V2H is the next least complex topology and consists of optimizing home energy consumption or using one or several EVs as emergency back-up power for residential homes. V2H offers a clear value proposition which has already garnered industry support and is the second most commercially developed V2X topology to date. For example, V2H could involve the combination of Photovoltaic (PV) power generation and EV for a home. In this case, the EV could use the PV energy and benefit from cheap carbon- free electricity for charging [6]. Also, the PV systems could use the bidirectional flexibility of the EV batteries to maximize its self-consumption.

V2B operates much like V2H but at a larger scale which may employ only a few EVs or aggregate an entire fleet to optimize the building or site (microgrid) energy consumption. As the V2B is aimed at the commercial and industrial buildings, the benefits are more pronounced and the V2B technology can reach grid-significant capacity through aggregation which opens other avenues that V2H cannot access. Industrial and commercial consumers are not only subject to much higher capacity charges but also charged for line phase imbalances caused by large inductive loads which increase line power losses and require expensive corrective actions. These capacity charges, additionally referred to as demand charges, can comprise over half of a monthly commercial/industrial electricity bill yet are induced by only a few brief spikes in the load. Therefore, a V2B resource that can reduce these occasional peaks can deliver significant cost savings and provide a valuable service for a low capacity and time commitment [1].

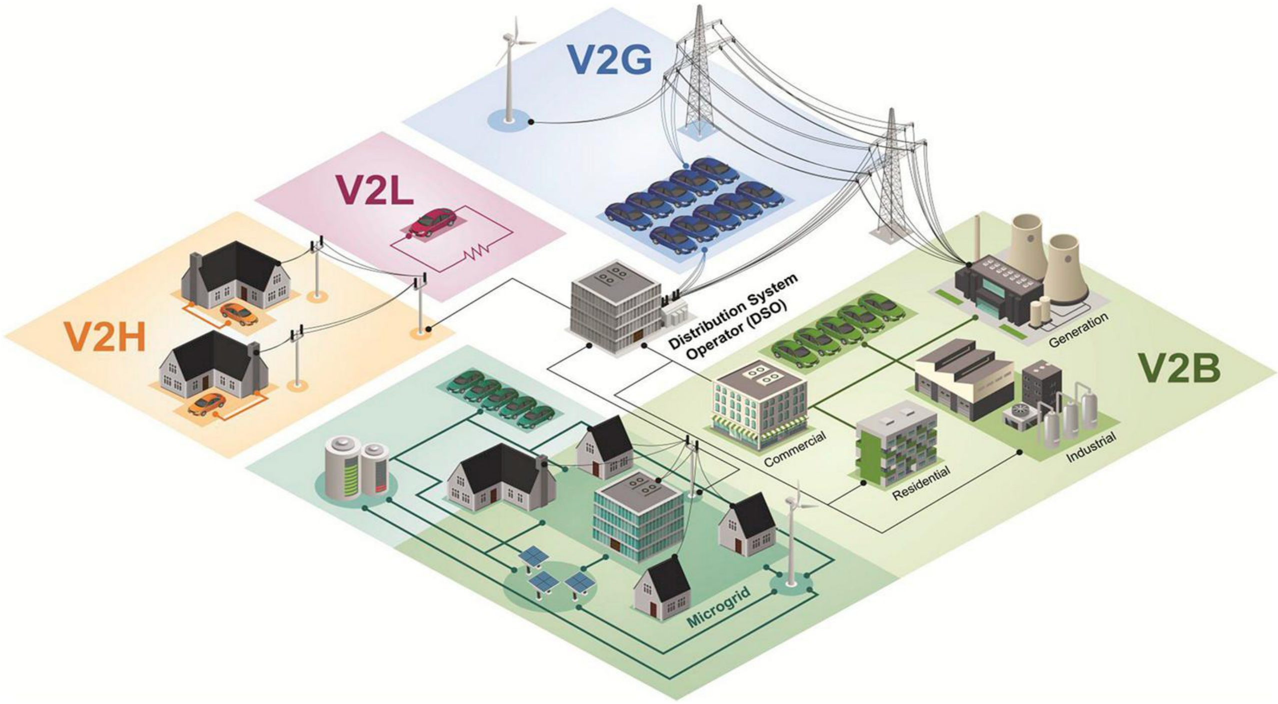

Figure 1: V2X Topology. Source: Ref. [1]

V2G is the most well-known V2X topology and refers to using the EV batteries to interact with and to provide value back to the electric grid in the form of one or more energy services [3]. Energy services refer to selling this dynamic charge control in the form of aggregated flexible capacity in wholesale and ancillary services markets to provide the much-needed flexibility to the system operators and the other relevant parties for the technical operation of the electric grid. To build a V2G system, the EV thus requires three things: a specialized charger, power bidirectionality, and communication capacity.
Both V1G and V2G operating modes require telecommunication and controls infrastructure that can receive signals and respond to the real-time grid conditions by either varying charge power (V1G) or by varying both charge and discharge power (V2G) [1].

To have a connection to the grid, the EV needs to have a charger to connect with. There are several important attributes of a charger, including its power capacity, whether the charger is on-board the vehicle or off-board within the charging station, and its communication and bidirectional capabilities. If the bidirectional charger is on-board, it is manufactured by the vehicle manufacturers and paid for by the vehicle owner. If the charger is off board, it is paid for by the facility owner (home/building/networks). With a bidirectional power connection and a means to receive communication signals, the EV is ready to participate in a V2G system. The V2G framework also requires a precision meter. Since the fastest electricity markets require reliability within the individual second-time frame, the meter needs to have high precision and granularity. This level of energy metering, sometimes referred to as Advanced Metering Infrastructure (AMI), provides practically real-time data and information to the aggregator and the electricity grid operator [2].

2.2 Electric mobility ecosystem

Electric mobility is a part of a wide and intertwined ecosystem that involves both transport (vehicle, battery, charging infrastructure manufacturers etc.) and electric systems (utilities, regulatory authorities, market traders, service providers etc.), as well as urban planners, regulatory authorities, research institutions etc.

First, the EV users (such as the private car users, company and logistics fleets mobility managers, sharing fleets companies, local public transport managers, trucks drivers/owners etc.) play a vital role in the electric mobility ecosystem [17]. Depending on the vehicle capabilities, the owner's driving behaviour and the charging opportunities, the vehicle owner can play an active role in the V1G and V2X markets [2]. Figure 2 shows the data and energy interactions among electric mobility ecosystem actors.

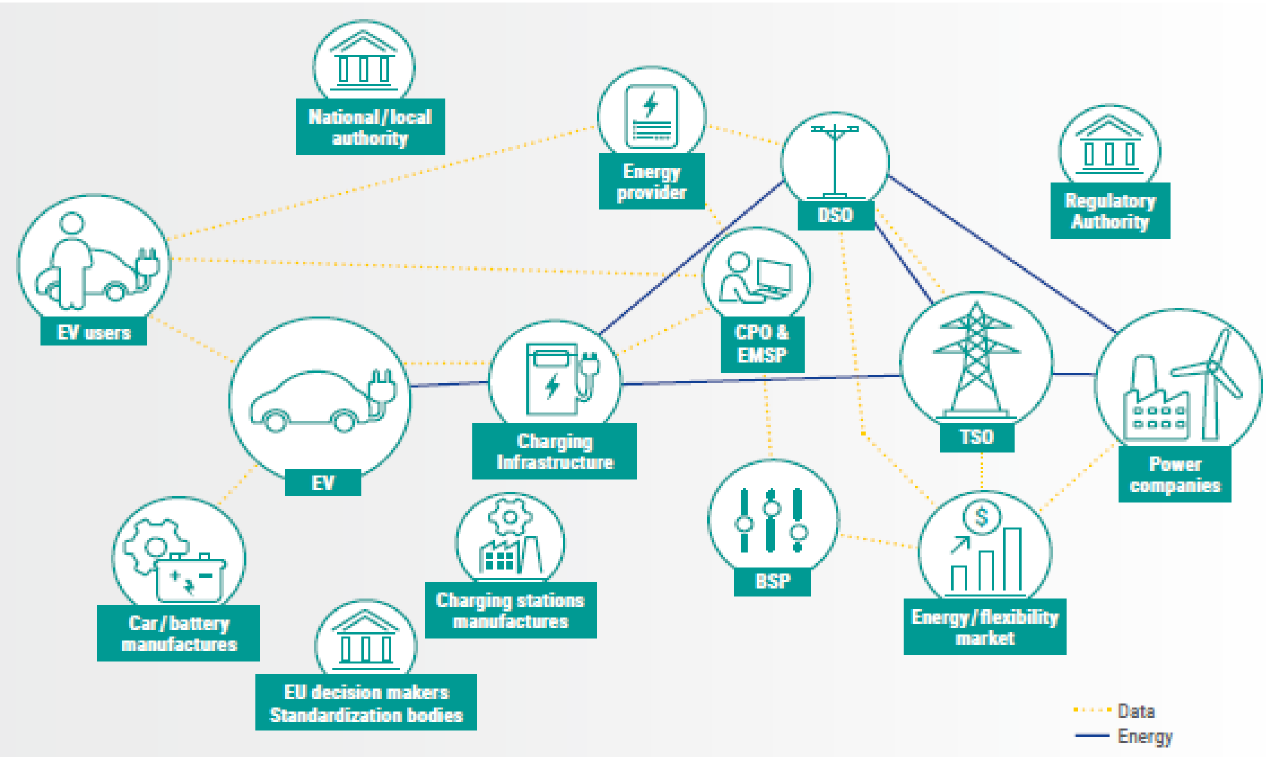

Figure 2: Data and energy interactions among electric mobility ecosystem actors. Source: ENTSO-E, Ref. [17]

The next actors are the manufacturers - vehicle manufacturers, battery and BMS (control logic) and the charging infrastructure manufacturers [17]. The EV industry manufacturers participate in the operation of the V1G and V2X system in the following ways. (i.) they invest in the manufacturing of vehicles with uni- and bidirectional charge/discharge capabilities. (ii.) some car manufacturers are participating in the management of their car fleet [2]. For instance, Tesla in the UK, Renault-Nissan alliance in France or Stellantis in Italy among others [14]. (iii.) they invest in public charging infrastructures [2].

The third primary actor is the electricity grid operator. The larger regional or national electricity grid operator, that is known across regions and nations as either a transmission system operator

(TSO), an independent system operator (ISO), or a regional transmission organization (RTO). Their primary role is the transmission of large-scale electricity production to the demand areas through high voltage transmission lines, and balancing of the power generation and load, typically over large regional areas. Depending on the state of the grid, the electricity grid operator will purchase ancillary service capacity and subsequently send the signal to all participants, including the aggregator.

The other grid operator is the local utility, also known as a distribution system operator (DSO). The main purpose of this organization is to receive the electricity transmitted by a TSO or ISO and then distribute it to the end-users, such as industries or households. Although ancillary service markets will typically be conducted at the TSO level, the EVs must also use the DSO network as the EVs in the V1G and V2X system will be situated at the end-use of electricity (i.e., houses, etc.) and therefore both impact and interact with the local grid [2].

The technical impacts of EVs diffusion and the benefits of providing flexibility for the distribution grids have been widely studied in the literature. The studies have focused mostly on developing new control algorithms and the architecture for the EV fleets. Moreover, the findings have been tested in different use scenarios mostly in the low voltage residential grids. For the distribution networks, the EV's flexibility can help to defer or avoid costly reinforcements in highly uncertain scenarios, thus reducing the risk of stranded assets. Additionally, the EV's flexibility can help to achieve an efficient use of the existing infrastructure, by providing peak shaving services and voltage support, as well as fault resolution or island services to reduce non-served energy. Nonetheless, using EVs will require the DSOs to be involved in the active management of the distribution grids (such as in forecasting and operating the grids), as well as putting in place the mechanisms to procure flexibility in a cost-efficient way. Furthermore, EVs will require increased need for coordination between DSO-TSO to enable flexibility from all levels of the grid and to maintain a secure and reliable operation of the power system. Moreover, it will require the deployment of smart meters to allow the implementation of dynamic tariffs that will allow users to adopt smart charging strategies [15].

To properly manage the charging process, proper data exchange is required, involving actors such as the energy providers, Charging Point Operators (CPOs) and Balance Service Providers (BSPs) [17]. The aggregator has a role to balance communication and power sent between the grid and the vehicle. The aggregator, likely operated by a third party (though on rare occasions may be owned by the electricity grid operator) manages the system in a variety of ways. There are two types of aggregators: 1. The "EV only" aggregators that only manage the vehicle fleet. 2. The smart grid aggregators that manage multiple and diverse sources of flexible power sources including EVs, battery energy storage systems, renewable energies etc. The aggregator decides what electricity markets to participate in and when to do so, which may depend on the available resources aggregated across the EV owners. Once the aggregator has bid in a certain market, the aggregator must then be capable of receiving the communication signal for the services they agreed to provide from the electricity grid operator [2].

The next actor is the government and its regulatory authorities (bilateral decision makers, national /local decision makers, regulatory authorities, standardisation bodies, urban planning authorities, transport authorities etc.) [17]. The government policymakers can encourage the TSOs and DSOs to develop their own policies and regulations on the decarbonisation, decentralisation, and digitalisation of storage [2]. The regulator is structurally important because it regulates the storage markets and develops the regulatory framework for the aggregators to exist and participate in the electricity markets.

The next type of actors are the electricity providers (power generation utilities and traders) [17][2]. Electricity generation is a key determinant of the ancillary services required by the grid operator. Moreover, renewable electricity developers may work in tandem with the advent of V1G and V2X systems and other energy storage options to ensure the reliability of the electricity grid [2]. To ensure the proper functioning of the ancillary services market will involve actors such as the BSP and the energy/flexibility markets operators.

The increasing number of EVs that will interact with the power grid in the coming years will certainly require special attention from the grid operators and regulators. EVs will both represent an additional load and a distributed flexible resource for the grid services. Only through an optimal management of the charging process will it be possible to solve the potential system challenges and take advantage of all the potential opportunities [17].

2.3 Electric mobility opportunities

This section discusses the opportunities that EVs offers to the utilities in terms of the value stream framework developed in Thompson and Perez (2020) [1]. This framework presents the economic potential of EVs in terms of the value streams where value can be derived from the wholesale energy market through: (i.) the use of products or mechanisms.

(ii.) the interaction with the utilities and network system operators by providing value in terms of capital cost deferment and greater efficiency of existing network assets.

(iii.) through the interaction with the customers by providing value to the residential/commercial or industrial consumers in terms of cost savings and reliability.

The framework categorizes the full range of the energy services EVs can provide, designates what topology can provide each service, and identifies where value is derived while providing some insight into the economic scale of each value stream. It is summarized in the Table 1.

Each value stream description expands upon both unidirectional (V1X) and bidirectional (V2X) operations, where X refers to multiple topologies or is replaced by the specific topology referenced (i.e. V1G, V2G). Where no distinction is made indicates that both V1X and V2X operate in the same manner. Additionally, Table 1 highlights what value stream is accessible by each V2X topology, whether the service is provided by an individual or aggregated resource, if the service is power or energy based, and designates where each physically operates in the electric grid either In-front-of or Behind-the-Meter.

It is noteworthy that V2G presents the largest overall revenue potential with direct access to the wholesale energy and ancillary services markets. However, it constitutes the most complicated topology due to the need for grid-significant capacity acting in response to real-time grid conditions. Therefore, V2G services are provided by an aggregator coordinating a multitude of individual vehicles or by operating a fleet of vehicles.

			Aggregated		Singular			
Sector	Value Stream	Definition and Value Derivation	V2G (10+)	V2B (1-30)	V2H (1-3)	V2L (1)	Topology Scale	
Wholesale	Resource Adequacy	Provides capacity through ability to discharge electricity (V2G) or ability to reduce demand (V1G/V2G) at future peak load hours. Value through RA mechanisms or Capacity Payments.	✓				Power	In-Front-of-the-Meter
	Frequency Regulation	Either fluctuate charge rate (V1G) or charge and discharge (V2G) to follow a 4 second regulation signal. Value through Ancillary Service markets or mechanisms.	✓					
	Demand Response-Wholesale	Reduce charge rate or delay charge (V1G) or in addition to previous, discharge to grid (V2G) in response to grid conditions. Value through wholesale market DR mechanisms.	✓				Energy	
	Energy Arbitrage	Buy electricity (charge) during low price hours and sell (discharge) at later high price hours (V2G only). Value through wholesale market in hourly price difference.	✓					
	Spinning Reserves	Maintain electricity balance by immediately discharging to grid (V2G) or by interrupting charge (V1G) in response to grid contingencies. Value through Ancillary Service markets/mechanisms.	✓					
	Load Following	Due to solar peak or wind fluctuation, discharge (V2G) to control system demand ramp rate. Value through Ancillary Services market.	✓					
	Excess RES generation	Charge to absorb excess wind and/or solar generation. Value through reduced RES curtailment.	✓					
	Peak Shaving	Charge at peak hours to reduce demand. Value through wholesale market.	✓					
	Generation Pairing	Paired with RES to control ramp rate of large energy fluctuations or with thermal generator to improve flexibility and allow faster response time. Value through ancillary services markets, bi-lateral contracts, and forgone retro-fit upgrade costs.	✓	✓				
	Reactive Power Support	Adjust Reactive Power output to provide PFC, RPC, or VR (V2X only). Value through Ancillary Services market or through forgone investment to reduce inductive loads.	✓	✓				
Utilities/SO	Network Deferral	Reduce demand (V1X/V2X) or increase supply (V2X) at peak to meet projected load growth in capacity-constrained areas for the purpose of delaying, reducing, or avoiding Trans/Dist. build-out. Value via TSO/DSO direct payments or infrastructure deferral mechanisms.	✓	✓			Power	
	Demand Response-Utility	Reduce charge rate or delay charge (V1X) or in addition to previous, discharge to grid (V2X) in response to grid conditions. Value through utility operated DR mechanisms.	✓	✓	✓		Energy	
	Site-located RES firming	Discharge (V2X only) to firm site solar or wind generation capacity to improve RES utilization rates. Value through reduced RES curtailment and/or payments for meeting RES targets.	✓	✓	✓			Behind-the-Meter
Customer	Bill Management	Reduce demand charges and adapt EV battery charge (V1X)/discharge (V2X) depending on tariff or TOU rates to minimize electricity costs. Value through cost savings.		✓	✓			
	Emergency Back-up	Provide emergency energy to buildings in the case of outage (V2X only). Value through costs savings of forgone diesel fuel or through VOLL estimation.		✓	✓			
	Non-Emergency	Mobile source of electricity for recreational activities or rural areas: camping, concerts, construction sites, parties, etc (V2X only). Value through pricing for capability.			✓	✓		

Table 1: V2X Value Stream Framework: Value Streams are presented by sector category (Wholesale, Utilities/SO, Customer) along with definitions and indication of where value is derived in the energy industry. Green indicates Power Value Streams while blue indicates Energy Value Streams. Additionally, it shows which V2X topology can access each Value Stream, whether the service is provided by an Aggregated or Singular resource, the scale/number of vehicles needed for each topology, and where each operates physically, either In-front-of or Behind-the-Meter.

The most important power-based service of V2G is Frequency Regulation which fundamentally is derived from the charge/discharge power flexibility i.e. the ability to vary charge power quickly to follow a grid signal from the system operator. For frequency regulation or control, *Regulation up* is used when sources are providing power to the grid, or when the loads are reducing their demand. Conversely, *regulation down* allows sources to reduce power fed to the grid or loads to increase their demand [5]. Then, EV that would participate in *regulation up* will discharge into the grid, and they will charge during *regulation down*. EVs can provide fast response (possibly within a second) for regulation purposes, faster than typical power plants now providing this service [5].

Resource Adequacy or Capacity Payments are compensatory mechanisms to develop new capacity to maintain safety margins above projected future peak demands. Network Deferral mechanisms are to develop capacity (or the ability to alleviate load at peak hours) in specific capacity-constrained locations in the distribution and transmission grids to avoid infrastructure investments and build-out.

The remaining energy based V2X services (in the Table 1) must be balanced with their respective degradation costs within the confines of the energy capacity of the aggregated or individual resource. To determine which of the value stream or opportunities has the highest economic potential is challenging due to the complexities arising from the locational characteristics, differing market conditions and regulation. Different tariff structures, local and regional energy technology mix, and demand growth also make drawing conclusions applicable to all markets nearly impossible. Therefore, analyses of EV economic viability must be taken in the context they are performed and may not be transferrable to other markets [1].

The engineering rationale and economic motivation for the V2G power are compelling [5]. Nevertheless, the penetration of EVs will affect the operations of the distribution grids and to a lesser extent the transmission grids. Therefore, on the one hand, cooperation between the TSOs and DSOs, and the DSOs and other market parties need to be improved [4]. On the other hand, market design rules, regulations and government policies should proactively address the new challenges of the V1G and V2G interactions with the grid. Even without a proactive public policy towards EVs diffusion, policymakers, regulators, and the utilities need to plan ahead into the era of EVs, to prepare for future challenges and opportunities related to the electric power system faced with new decentralized storage opportunities [3].

3. Electric mobility challenges for the utilities

Following the description of the EV topology, ecosystem and the value streams (opportunities) in section 3, this section focuses on the challenges of the interaction of the electric utilities with electric mobility.

3.1 The technical challenges

Battery degradation: Battery degradation can cause loss of capacity over time, which impacts an EV’s range capability [2]. The factors influencing battery degradation are measured as capacity fade [31]. The overall life capacity fade of a battery is the contribution of both the calendar and cycle aging effects [32]. Calendar ageing is a function of time and temperature, and cycle ageing is mainly dependent on the number of charge/discharge cycles. The degradation mechanism occurs faster when there is a high energy density in the battery, which means that it increases with higher SOC and temperature. For V1G applications, calendar ageing is the dominating effect because EVs are generally idle more than 90% of the time [31]. Moreover, the fear of battery degradation may make EV owners unwilling to participate in rendering V2G services to the utilities and prevent the utilities from accessing the valuable flexibility services the battery can provide [2]. Current V2G pilot projects focus on services that require seconds to minutes worth of storage time, but future storage markets like renewable energy integration may require storage time of days to weeks.

The result from a five-year study in Denmark on battery degradation shows that after 5 years the battery SOH is reduced by 15.73%, only about 5% of this reduction is due to the charge cycles.

Year	Cal	Cycle	total	$\sum$Cal	$\sum$Cycle	$\sum$total
1	4.51%	0.81%	5.32%	4.51%	0.81%	5.32%
2	1.97%	0.88%	2.85%	6.48%	1.69%	8.17%
3	1.58%	0.96%	2.54%	8.06%	2.66%	10.72%
4	1.40%	1.05%	2.45%	9.46%	3.71%	13.17%
5	1.37%	1.18%	2.55%	10.83%	4.89%	15.73%

Table 2: Capacity loss due to cycle degradation and calendar ageing as well as the total capacity loss; both per year and accumulated in the first five years of the EV lifetime. Source: Ref [31]

Furthermore, the result on the impact of V2G frequency regulation services on battery degradation for a 24 kWh EV shows that there is a 1% capacity loss per year due to the added energy throughput [31]. Assuming a battery cost of 180 €/kWh, a 24 kWh EV would cost €4,320 and using a minimum SOH of 50% of a second-life application where the battery has lost all value. The yearly cost of battery degradation due to frequency regulation services is found as $\frac{1\%}{50\%} \cdot €4{,}320$ = €86. The energy consumption for conversion losses is found to be 11.1 kWh per day or 4.1 MWh per year. Using the average electricity price for mid-sized industrial customers in Denmark of 0.08 €/kWh, will result in a yearly electricity cost of €324. When compared to a capacity payment of €1100 per year, will result in a profit of 1100 − 324 − 86 =€690. For a 40 kWh EV, the degradation due to V2G frequency regulation services is found to be an additional 1-2% to the 7-12% capacity reduction over 5 years [31].

The second key technical challenge is the overall efficiency of sending energy to and from the grid, particularly from the Electric Vehicle Supply Equipment (EVSE). The aggregators face two central challenges, the first is with implementing algorithms that can handle the growing complexity of V2G systems, and the second is with the communication system. In addition to the challenges of aggregation, algorithms and scaling of a V2G system, a related challenge is the communication standard that is used in the V2G system to transmit messages to and from the EVs/EVSEs and the electric utilities. Across the various existing V2G projects, no single standard has taken hold, with projects around the world using different communication protocols. Other technical issues are the cybersecurity risks, managing data privacy concerns and metering accuracy and reconciliation among different actors [2]. With respect to metering, a key challenge is to clearly define who is metering what and how to manage/prevent a metering dispute. For instance, the vehicle has a meter, the charger has one, the distribution and transmission grids also have their meters. If all the meters give the same readings, there is no dispute, otherwise a conflict resolution mechanism must be implemented.

Regulatory and market design challenges

V2G needs to be integrated in the regulatory system in a manner that is non-discriminatory and guarantees equitable access to the variety of electricity markets that V2G can participate in [2]. Current market rules in several wholesale markets have been shown to be insufficient and need to be modified to better accommodate aggregators offering V2G [4][11]. Apart from defining and clarifying the regulatory complexities of V2G and energy storage, the next challenge for V2G is that the markets that they participate in often have barriers to storage-based actors. As the V2G capacity grows, it has the potential to participate in several markets at once, providing “stacked” services, but the current market design inhibits simultaneously bidding into multiple markets. In a nutshell, there are a variety of regulations within current and emerging ancillary services markets that need to be resolved both in the short and the long run to increase the value of V2G and decrease the barriers to entry [2].

In addition to the ancillary services market design that are inhibiting the V2G participation, there are also other market design elements that reduce the economic viability of a V2G system. These elements include double taxation, curtailment requirements of the variable renewable energy and the capacity markets to support baseload capacity in the presence of ever-increasing levels of renewable energy. With respect to double taxation, the aggregators of V2G services are required to pay fees and taxes when they charge and discharge electricity. This can have substantial economic implications for V2G when providing services like frequency regulation, where electricity frequently flows in and out of the battery. Curtailment requirements stipulate the maximum amount of renewable energy supply allowed into the grid to manage the intermittency without jeopardizing the security of supply. Moreover, the capacity markets undervalue behind-the-meter resources like V2G since capacity markets are geared toward traditional electricity generation market actors. These market design elements prevent the proper valuation of V2G systems, particularly in the long-term, and inhibit its investment stability and diffusion process [2].

Moreover, the tariff design has an influence on the V1G and V2X charging and discharging strategies. For example, our recent research findings show that for California, the compensation of the EV owners for energy services depend on the type of tariff applied. Energy-based tariffs during the peak periods synchronized with solar PV production brought the highest private gains, but with high cost-shifting. On the other hand, the capacity-based tariffs reduced the economic benefits and cost-shifting during the peak periods [14].

3.2 Overcoming the technical, regulatory and market design challenges

I. The technical challenges

Minimizing battery degradation, optimizing charger efficiency, and implementing effective algorithms to aggregate resources pose significant challenges, but the V1G and V2X system needs to do all the above while also scaling up in the near future. There is also a need to regulate the privacy and security aspects of the data streams. While lawmakers and regulators are increasingly enforcing privacy by design principles, the actual regulation is only just beginning and sometimes actually resisted. Nonetheless, privacy and security of data collection during V1G and V2X operations may become an increasingly pressing challenge that requires further regulation [2]. Common standards should be developed and adopted to guarantee the interoperability of charging networks. Moreover, control systems of EV-charging should be designed in such a manner that data failure or manipulation does not lead to a substantial change in system balance (cyber-resilience) and emergency situations are properly managed (e. g. restoration after black-outs) [17]. The solutions to the technical challenges will require increased R&D and demonstration projects.

II. The market design and regulatory challenges

The V1G and V2X potential depends on the availability of electric vehicles or vehicle fleets to participate in such services at suitable times, consumer acceptance, and the ability of participants to generate revenues, as well as other technical constraints related to battery discharge rates or impacts on battery lifetime. To fully unlock the flexibility potential of electric vehicles through dynamic controlled charging (V1G) and vehicle-to-grid services (V2G) to reap synergies with variable renewable generation and reduce electricity generation capacity needs would require the adaptation of regulatory and market frameworks. Currently, flexible electric vehicle integration is not on track for power systems to accommodate the distributed loads that electric vehicle batteries represent in a co-ordinated way and on a large scale. Specific stakeholders such as aggregators, along with business models that make use of new regulatory frameworks to reward electric vehicle owners for providing flexibility services are needed for electric vehicle batteries to contribute to the power system stability on a significant scale [25].

This section discusses an iterative framework to address the market design and regulatory challenges as follows: (i.) analyse the market rules (ii.) improve the market rules (iii.) review the regulators' evaluation criteria and (iv.) change the market rules.

i. Analyse the market rules

The framework (Figure 3) to analyse the existing rules in the V2G frequency regulation markets to (i.) identify the barriers to entry for the aggregators and to (ii.) identify some options to overcome the barriers.

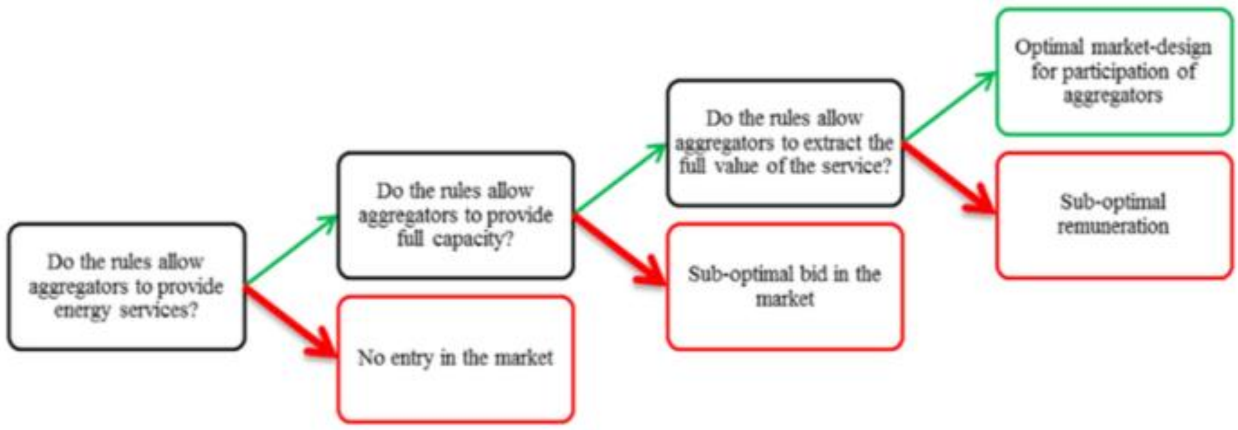

Figure 3: Analytical framework for existing rules in frequency regulation market. Source: [9]

This framework attempts to identify a combination of rules that could facilitate EVs reserve provision in the frequency regulation market. It argues that opening the market to new players such as the aggregators should not imply introducing great complexity to the existing market design that could introduce uncertainty and hamper investments. Ultimately, a unified market design should be implemented to procure reserves at the least possible cost [9].

ii. Improve the market rules

The TSO market rules could be improved by (i.) creating a legal framework and a formal status for distributed storage units in the TSO rules and by (ii.) easing the rules to encourage the building of coalitions of small, distributed units. Such aggregation would have a single-entry point from the TSO perspective which would enable them to dispatch the power flows among the distributed units as they wish, thus maximizing the aggregators' ability to bid in the electricity markets [10]. For example, the former rules in the EU Frequency containment reserve (FCR) market were constraining for “EV only” aggregators - temporal granularity was limited (products of 168 h), as assets with varying availability could provide a limited fraction of their available reserves [8]. The future EU market for reserves (under construction) will be organized among standardized 15 minutes for 1MW product definition. With this new definition, the EVs and other flexibility providers will be able to compete in the market. The smaller the granularity, the more the possibility to offer more reserve different actors. Depending on the reserves market conditions, potential revenues and business cases could be viable. Increasing the granularity restriction would make it possible to offer more reserve, thus increasing potential revenues and allowing business cases to be more viable [8]. Nonetheless, any market design correction should not result in other unexpected market disruptions such as causing uncertain impact on the security of supply while attempting to improve competitiveness or sustainability [10].

iii. Review the regulators' evaluation criteria

The EV industry is a complex system within which firms choose among competing organisational architectures and regulatory institutions emerge from the interaction between firms' choices and rule-makers' beliefs. The main drivers to change regulatory institutions are the ‘evaluation criteria’ applied to outcomes. Evaluation criteria are the rule-makers' simplified models against what outcomes are evaluated. The emergence of a dominant organisational design may be crucially affected by those criteria, and the organizational design affects the path of technological evolution. Consequently, rule-makers' beliefs might determine the technological path chosen by the EV industry [7]. Therefore, it is critical to review the evaluation criteria of the regulators.

iv. Change the market rules

Using EVs as TSO reserve providing units have been demonstrated as being both a feasible and a profitable solution. Nevertheless, the TSO market rules have potentially a great impact on the EV's expected revenues for the aggregators and vehicle owners [10]. It is necessary to adapt the frequency-regulation reserve market design to allow the EVs to participate through the new market players "aggregators" [9]. Since the subsisting rules are made for existing actors in the electric power industry, introducing the EVs to the market requires changing some of the subsisting rules to facilitate money (revenue) flow from the grid operator (TSO or ISO) to the Aggregator and from the Aggregator to the EV owners.

Based on the preceding arguments, we provide an analytical framework for the market and regulatory challenges in figure 4.

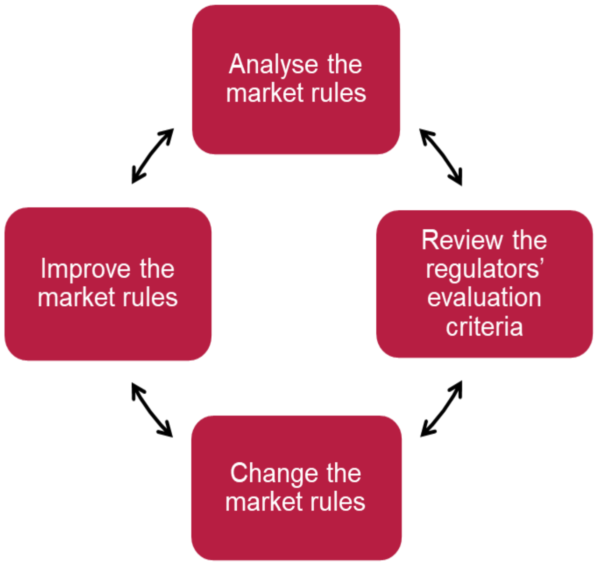

Figure 4: Analytical framework for the market design and regulatory challenges.

This framework can help to provide insight and guide decision making in a methodical manner to address the market and regulatory challenges of the EV interaction with the utilities. It should be useful for the regulators and other stakeholders to understand the market rules and to facilitate informed decision making on the market design. It is noteworthy that this framework is iterative and not necessarily a step after the other (fig. 4). Its application will depend on the state of the market design at any point in time. For example, a review of the regulator's evaluation criteria may require a need to improve the market rules that may subsequently require a change of some market rules. In this case, it may be logical to start with the review of the regulator's evaluation criteria.

4. Electric utilities interaction with electric mobility in the megatrends context

Decarbonization

Decarbonization entails reducing the carbon emission by phasing out fossil fuels from the generation of electricity. This involves shifting the generation to carbon neutral electricity sources. This will help to limit the effects of climate change and contribute to sustainable economic development. For example, by replacing coal and gas plants with variable renewable sources of energy such as wind and solar power. Variable sources of energy bring new challenges for the utilities in ensuring system reliability and the security of supply to instantly balance supply and demand of power generation. In addition, it brings new market actors such as IPPs and increases the need for coordination and management of the grid.

In terms of demand planning, future energy demand forecasts rely on models that contain uncertainties about forthcoming needs for the installed capacity. The model results vary broadly depending on the institution and the considered scenarios. While improvements in efficiency would decrease the final energy demand; the electrification of other sectors (for example transport via electric mobility), however, will increase the electricity demand and, therefore, the total energy demand. Moreover, complexity increases with increasing variable renewable energy shares while in parallel phasing out fossil fuels.

Another challenge decarbonization brings to the utilities is the possibilities of stranded assets. Changes in the market structure could lead to a situation in which technical units are unable to earn money before the end of their lifetime and thus become stranded assets. Stranded assets can also occur in the renewable sector when, for instance, supporting schemes expire. Moreover, since renewable technologies have zero marginal cost, they reduce the average electricity prices. Thus, renewables can amplify market design flaws, leading to negatively priced periods at times. This calls for well-designed and flexible electricity markets. Besides, the concern about making (the right) investments in the energy sector during an uncertain period can result in a reduction of electricity generation capacity and incapability to cover the demand. In the developing countries, utilities have to deal with high interest rates, less robust credit markets and high currency risk, which make the conditions for investment in decarbonization less favourable. The need for investments in developing countries is high and will continue to increase with the growing demand for energy. The main challenge remains how to overcome the capital scarcity in those markets [27]. Nevertheless, for developing countries, the pursuit of a low-carbon transition must be integrated into the overall development agenda: the goal is not just to decarbonize, but to decarbonize development [18].

EV fleets can create vast electricity storage capacity to support decarbonization. However, the optimal charging patterns will depend on the precise energy mix. EV integration differs in systems with high shares of solar-based generation compared with systems where wind power prevails. The use of EVs as a flexibility resource via smart charging approaches would reduce the need for investment in flexible, but carbon-intensive, fossil-fuel power plants to balance renewables. Nonetheless, while EVs do not release emissions when driven, they use electricity that often still comes largely from fossil fuels, although the overall emission is lower than ICEV. To reap the full benefits of both, electrification of transport must go hand in hand with the decarbonisation of the power sector [28].

Digitalization

Digitalization can be thought of as the increasing interaction and convergence between the digital and physical worlds. The digital world has three fundamental elements: data (digital information), analytics (the use of data to produce useful information and insights) and connectivity (the exchange of data between humans, devices and machines (including machine-to-machine), through digital communications networks. Digitalization holds the potential to build new architectures of interconnected energy systems, including breaking down traditional boundaries between demand and supply. Digitalized energy systems in the future may be able to identify who needs energy and deliver it at the right time, in the right place and at the lowest cost. The greatest transformational potential for digitalization is its ability to break down boundaries between energy sectors, increasing flexibility and enabling integration across entire systems. Aggregated and anonymised individual energy use data can improve understanding of energy systems, such as the load profiles, and help lower costs for consumers [19]. Digitalisation will make it possible to go beyond simple time-of-use charging for EVs to enhance EV use. First with automated V1G and then increasingly, V2X applications should also boost synergies with renewables. Digitalisation will play a key role in the optimisation between EV transport service and the grid services, in both the planning and operation stages. Digital technologies and data analytics will make it possible to match mobility demand with power supply patterns, to be as compatible as possible and to identify the most optimal locations for charging points [28].

Decentralization

Decentralization brings more players providing supply, storage and energy management services and requires increased coordination [29]. This impacts the electric utilities power generation, systems operation, demand planning, investment, network asset management etc. Centralized, asset-heavy production of electricity may not disappear in the near future, but utilities must explore new horizons in clean energy, downstream markets, and digitally enabled, customer-centric business models [20].

The current wave of innovations including decentralized renewable energy, battery storage (such as from EVs), and digitalization empowers consumers and other decentralized actors to participate in the production of electricity and in so-called demand-response services, generating reverse flows along power networks and introducing the possibility of trade at the retail level [24].

Disintermediation

Disintermediation is the process of removing the middleman or intermediary from future transactions [23]. A good example of disintermediation in the energy sector is the peer-to-peer transactions enabled by the blockchain technology. Blockchain introduces a database that functions like a distributed network, hence the term 'distributed ledger' with the promise of near friction-free cooperation between members of complex networks that transfer value to each other without central authorities or middlemen. Its ability to provide disintermediation, improve transparency, and increase auditability can significantly reduce transaction costs, introduce efficiency into existing value chains, challenge revenue models, and open new markets [21]. Disintermediation can reduce cost and increase efficiency, but it usually requires more due diligence work [23]. For instance, blockchain technology facilitated disintermediation in the energy system will avoid: the operating costs of the retailer, meter reading, billing, payment reminders, debt collection process, banking costs amongst others [22]. It can essentially remove the retail utilities from the energy supply value chain in many markets with active retail utilities [21]. Normally, where prosumers generate their own electricity, they can deduct this from the energy they purchase from their retailer. However, with direct access to market through a peer-to-peer platform they would have the opportunity to sell their energy directly to other users. This cuts out intermediaries and potentially eliminates costs while creating arbitrage opportunities [22].

Blockchain technology can facilitate the payment and billing for EV services as well as simplify the provision of EVs flexibility services to the grid [28]. Blockchain can facilitate smart charging by connecting different parties and facilitating monetary transactions between aggregators and customers through a form of open-source standards, replacing proprietary solutions. This technology can also be used for customer-to customer charging solutions: the sharing of a private charger when not in use with someone else for a fee [28]. As the potential of blockchain is immense, so is the uncertainty surrounding it. The technology is not a complete solution to be applied ubiquitously, but instead is one piece of a well-articulated digital transformation strategy that probably includes artificial intelligence and big data management, among other emerging technologies [21].

Demand disruption

The rise of distributed energy resources has introduced a risk that both retailer platforms and the platform provided by the grid operator might be bypassed causing demand disruption for the utilities. Retailers can be bypassed either by consumers opting to buy and sell through a different intermediary (e.g. an aggregator) or trading directly over a platform. However, a bypass risk also exists for grid operators. For example, since prosumers can self-supply they can become increasingly self-reliant, particularly where they can supplement their generation capability with storage capability. This potentially takes them off-grid, either entirely or at least for a large proportion of their needs. In addition, prosumers and consumers can set up local micro-grids that again have the impact of taking them off-grid for a large proportion of their needs, and potentially for long periods of time. As consumers defect, the grid is increasingly left to spread its largely fixed costs of maintaining its infrastructure across a smaller number of consumers. This increases the cost of remaining on the grid and makes defection an increasingly attractive proposition. This can create a potential death spiral that threatens the viability of the utilities. Moreover, consumers that use the grid only as a fall-back option may attach less value to the grid and so might not be willing to make the same level of contribution as those consumers that rely continuously on the grid [22].

Business models that disconnect people and instead bet on the localisation of electricity markets might allow consumers and local communities to become self-sufficient by generating and storing their own electricity, enabling them to cut their costs by going off-grid. Also, rising electricity prices have made it more attractive for consumers to begin generating their own electricity, both to reduce the quantity they purchase from the grid and in order to sell to the grid at a higher price. Apart from the peer-to-peer platform that can cause demand disruption for the utilities, there is also the prosumer-to-grid models where prosumers sell their electricity to a central (local) market, from which other prosumers and consumers purchase. Alternatively, groups of prosumers might aggregate their generating and storage capability to create a virtual power plant that can provide both generated energy and flexibility to the market. Indeed, by adding the generating and storage capacity of these prosumers to the capacity of consumers willing to adjust demand (particularly when enabled through automated IoT appliances), these virtual power plants might become key players that can either meet all the energy needs of their constituents or can demand significant discounts on fixed tariffs from retailers [22]. It may be that storage, local trading and demand response will drive some prosumers to defect from the grid.

To address the challenges of demand disruption, the use of Integrated Resource Planning (IRP) modelling tools that account for the integration of demand side resources will become increasingly important as new ICT and clean energy technologies including cloud and data services, power storage in distributed energy applications, and electric vehicles penetrate the markets and prosumers emerge as active market participants [20].

Furthermore, a spike in the number of EVs can put large power demand burdens on the grid system. This enormous power demand may cause serious issues (such as overloading, voltage instability, frequency fluctuations and power losses) that can affect the performance of the power system and leads to power failure. Centralized coordination can be effective in solving the EV integration to grid issues. Centralized coordination reduces load variance, voltage variations, power losses, computational complexity and helps in determining the EVs charging locations. The optimal power, energy capacity and location of EVs in centralized coordination can accurately be solved by optimizing the system/interaction between the EV and the grid variables [30].

5. Framework for the megatrends (developing country context)

The classic industrial organization models of the electric utilities have experienced fundamental changes with the increasing impact of electric mobility in the megatrends' context. In this section, this report attempts to understand this change. Building upon the works of Hunt [26] and Foster and Rana [24], it discusses the representative industrial organization models of the electric utilities and provide new ones to depict the contemporary state of the electric utilities. Thereafter, it presents a framework to analyse the impact of the megatrends on the utilities based on their current state both in the developing and the developed countries.

Traditionally, power systems have developed around centralized infrastructure designed to reap economies of scale and achieve simultaneous balancing of supply and demand through the one-way flow of power to passive consumers. The vertically integrated utilities have characteristics such as the central planning of generation and network, cost-of-service remuneration of each vertically integrated utility (regulated tariffs) and have social policy obligations [24]. The vertically integrated utility operates as a monopoly responsible for the generation, transmission, and distribution/retail of electricity to the end-users. This is depicted below in Fig 5.

Model 1: Vertically integrated electric utility (monopoly at all levels)

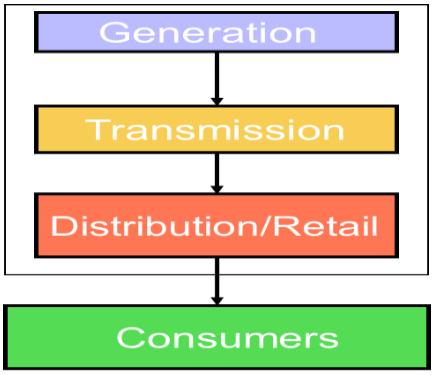

Figure 5: Vertically integrated utility industrial organization

The challenges with the vertical integrated utility include poor accountability since the government agency is not directly accountable to consumers or shareholders, the lack of sufficient incentives to improve customer service or to engage in technology innovation and the taxpayers bear most of the investment risks. For the developing countries, a key challenge is the lack of sufficient resources from the government to invest resulting in chronic power outages and poor service quality [12].

During the 1990s, a new paradigm for power sector reform was put forward that emphasized the restructuring of utilities, the creation of regulators, the participation of the private sector, and the establishment of competitive power markets [24]. Consequently, the electric utilities have faced a continuous series of changes. Technical changes to electricity generation, and information technologies cost decline have allowed competition to be introduced in a lot of countries willing to reduce the cost of electricity provision. Moreover, many developed countries have liberalized the power sector and established the wholesale electricity market. This is depicted in Fig 6.

Model 2: Wholesale Competition

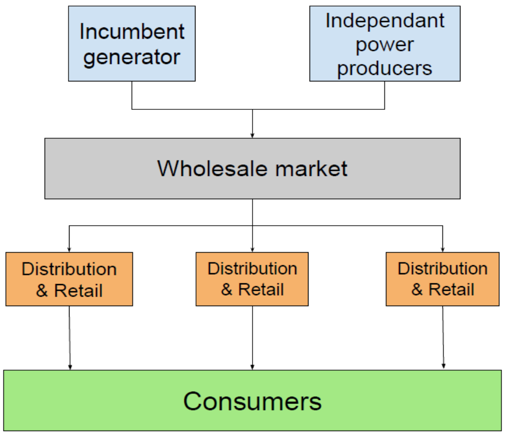

Figure 6: Electric utilities wholesale market industrial organization

In this model, the vertical integrated utility is unbundled and new wholesale market players are introduced (such as the system operator, market operators, traders and other market intermediaries) in the new organisation. The goal is to mitigate market power, achieve performance improvement and to ensure the wholesale markets yield competitive results etc. Consequently, many developed countries established wholesale electricity markets. However, only few developing countries have introduced a wholesale power market, reflecting the formidable list of preconditions that must be met before such markets become possible or meaningful [24].

Moreover, some developed countries went a step further to establish and create competition in the retail market. This is depicted in Fig 7. In the wholesale and retail market model, there is full access to the markets for all the participants. Consumers are eligible to purchase their power supplies from competing retail suppliers [12]. Power markets (wholesale only and wholesale and retail) are mostly found in developed countries where the power systems are relatively large and financially viable. Across the developing world, reforms were adopted rather selectively, resulting in a hybrid model in which elements of market orientation coexist with continued state dominance of the sector.

Model 3: Wholesale and Retail competition

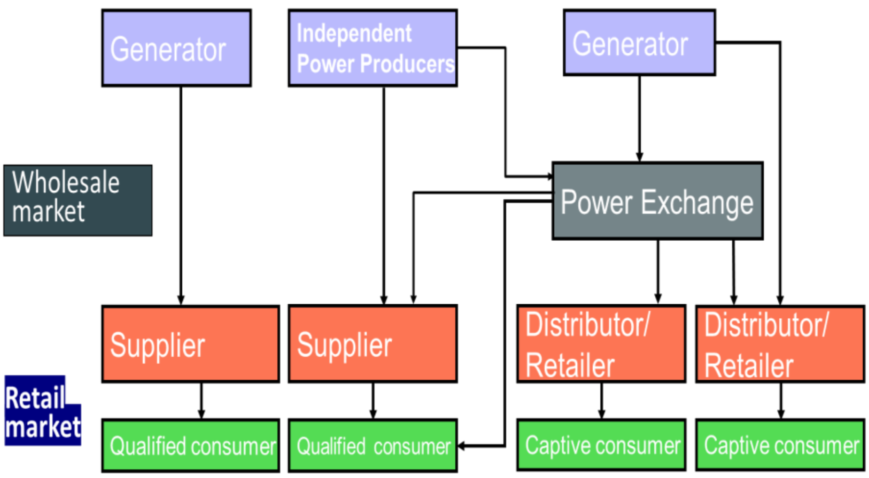

Figure 7: Electric utilities wholesale and retail market industrial organization

The rarity of wholesale power markets in the developing world reflects the demanding preconditions for viable competition. For example, not one wholesale power market can be found in Africa and the Middle East. Many of the largest power systems in the developing world - such as those of the Arab Republic of Egypt, Indonesia, Pakistan, and South Africa have not yet introduced wholesale power markets. A key concern is that the long-term take-or-pay arrangements that are often required to induce IPP investments in emerging markets can introduce distortions into power dispatch and build contractual rigidity into the power system - both of which significantly limit the scope for competition when a wholesale market is eventually introduced [24].

Close to half of the developing countries have adopted the hybrid single buyer model as a (sometimes indefinite) step toward wholesale competition. The single buyer model occurs after some vertical and horizontal unbundling of the sector, the IPPs compete alongside incumbent generators to supply power to the publicly owned single buyer, which is typically the transmission (and sometimes also distribution) utility [24]. At other times, the single buyer is neither the transmission nor distribution utility but a publicly owned SPV. For example, in the Nigeria case (Nigeria Bulk Electricity trading Plc). This is depicted in Fig 8.

Although the single buyer often conceived as a transitional model toward a competitive market, in practice, many developing countries have remained stuck at this stage [24].

Model 4: The Single Buyer Model

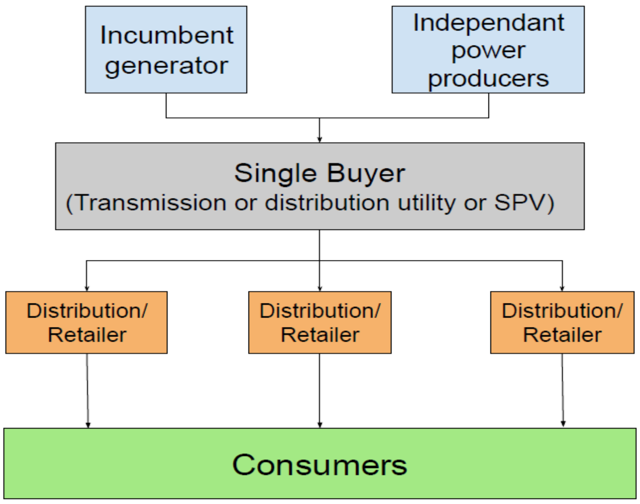

Figure 8: The single buyer model industrial organization

Peer-to-Peer innovation with electric mobility

With the combined impact of the megatrends transforming the electric utilities (see Section 4), there is a progressive peer-to-peer innovation with electric mobility unfolding in the developed and developing countries alike. This contemporary and burgeoning innovation is an unorganised local market based on peer-to-peer energy services. This is depicted in Fig 9.

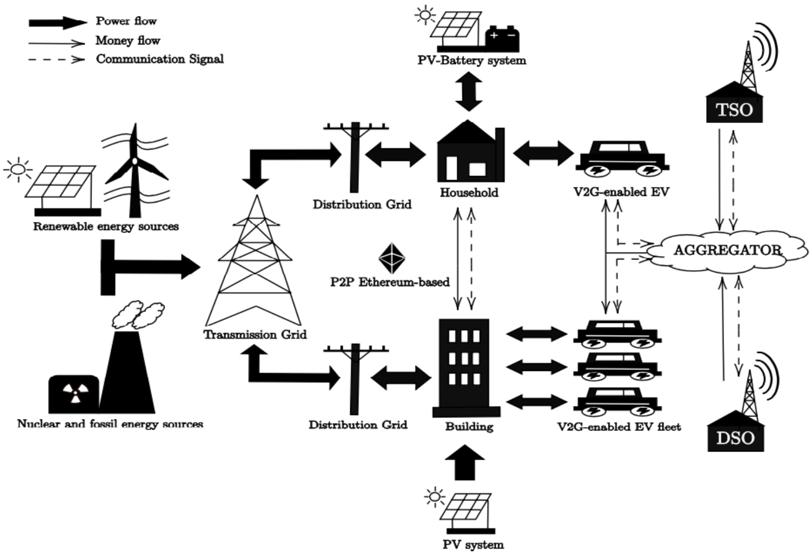

Figure 9: Peer to peer innovation with electric mobility. Source: Ref [16]

This innovation is under development in many countries, and it includes new decentralised storage solutions (such as electric mobility and battery energy storage systems), new communication protocols and the coupling of local renewable energies (solar PV and wind). It also includes new market actors such as aggregators, vehicle manufacturers etc. and a high impact of the megatrends. For example, there is power flow from the renewable enegy sources such as Solar PV system directly to homes and buildings (decentralization), electric mobility supported by advanced technologies and flow of communication signals (digitalization), renewable energy sources of generation (decarbonization), bidirectional power flows from vehicle to households and buildings that will lead to (demand disruption) and disintermediation for the utilities. Consequently, there is a gradual transformation of the electric utilities in the developed and developing countries from Model 1, 2, 3 and 4 to include features of the peer to peer innovation with electric mobility. This is depicted in fig. 10.

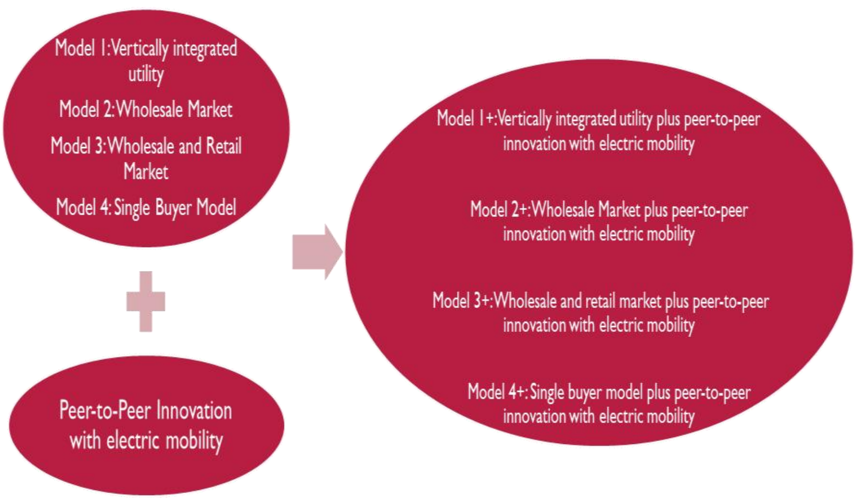

Fig 10: Utilities transformation by peer to peer innovation with electric mobility

This transformation of the electric utilities industrial organisation is coined as Model 1+, Model 2+, Model 3+ and Model 4+.

Based on the foregoing analysis, this section presents a newly developed framework to explain the transformation of the electric utilities as a result of the megatrends (Table 2). Many utilities in the developing countries are still in the Model 1+ (vertical integrated utility plus peer-to-peer innovation with electric mobility) classification. The framework (Table 3) explains this transformation of the utilities with electric mobility. The plus sign represents the order of magnitude of the increasing impact of the megatrends on the electric utilities depending on their industrial organization.

Countries	Electric Utilities industrial Organization Model	Digitalization	Decentralization	Decarbonization	Demand disruption	Disintermediation
Developing countries	Full Vertical integration + Peer to Peer innovation with electric mobility (Model 1+)	+	+	+	+	+
Developing Countries	Single buyer + Peer to Peer innovation with electric mobility (Model 4+)	++	++	++	++	++
Developing Countries Developed countries	Wholesale Market + Peer to Peer innovation with electric mobility (Model 2+)	+++	+++	+++	+++	+++
Developing countries Developed countries	Wholesale & Retail market + Peer to Peer innovation with electric mobility (Model 3+)	++++	++++	++++	++++	++++

Table 3: Electric Utilities and the megatrends (framework)

For the developing countries, the magnitude of the transformation of the utilities with electric mobility caused by the impact of the megatrends is highest in those with functional wholesale and retail markets (Model 3+). It is followed by the countries with the wholesale market only (Model 2+), then the Single buyer model (Model 4+) while it is the lowest in the developing countries still operating state owned vertically integrated utilities (monopoly) represented as (Model 1+). Many countries in Sub-Sahara Africa appear to fall in this Model 1+ category. In a situation where a developing country moves to the next model, for example from the vertical integrated utility (Model 1+) to the single buyer hybrid (Model 4+), the impact of the megatrend should increase as new players enter into the market. For the developed countries, the impact of the megatrends is highest in countries with wholesale and retail markets plus peer to peer innovation with electric mobility (Model 3+).

This framework can be useful to gain further insight on the transformation and impact of the megatrends on the utilities with electric mobility in different developing countries. It can be further enriched with qualitative or quantitative indicators for comparative analysis among developing countries and the developed and developing countries. The results of the comparative analysis should help as an additional tool that provides insight on the electric utility and electric mobility interaction in developing countries to facilitate decision making or policy design.

Finally, this report makes a long list of the developing countries in the Model 2+ and Model 3+ (table 4). These are those with functional wholesale and/or retail electricity market with well-functioning electric utilities. Indeed, most of the developed countries where electric mobility integration with the electric utilities is gaining traction are also in this category.

List of some developing countries in Model 2+ and 3+	
Latin America	Argentina, Brazil, Chile, Guatemala, Peru, Colombia
Eastern Europe	Romania, Russia, Turkey, Ukraine, Poland
Asia	India, China, Philippines, Kazakhstan
Caribbean	Dominican Republic

Table 4: Long list of developing countries in Model 2+ and 3+. Source: Authors' elaboration and Foster et al. (2017)

The framework can be applied for in-depth country case studies and analyses of the electric utilities and electric mobility interactions in the context of the megatrend or for comparative analysis among countries to support decision making or policy design for developing countries.

6. Conclusion

This report discusses the opportunities and challenges faced by the electric utilities with the increased uptake of electric mobility and the impact of the megatrends of decarbonization, digitalisation, decentralization, demand disruption and disintermediation in the developing country context.

First, it discusses the electric mobility topology, ecosystem and the value streams (or opportunities) of electric mobility. Second, it discusses the electric mobility (technical, market design and regulatory) challenges for the electric utilities and the potential solutions. Third, it discusses the transformation of the electric utilities with electric mobility in the context of the megatrends.

Fourth, it develops a framework to understand the transformation of the classic industrial organization models of the electric utilities with the impact of electric mobility in the context of the megatrends in the developing countries. Thereafter, it makes a list of some developing countries for electric utilities integration with electric mobility to apply the framework for further studies.

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