REVIEW OF EMERGING ADVANCED SMART CHARGING FLEXIBILITY BUSINESS MODELS

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ABSTRACT

Electric vehicle sales across all transport modes have had a steady growth over the last decade, and mass electric mobility will soon become a reality. In Europe, this represents an opportunity to introduce higher shares of variable renewable energy into the generation mix. However, a shift to mass electromobility needs to be accompanied by extensive integration of advanced smart electric vehicle charging, which could serve growing mobility needs while supporting the power system through a series of possible flexibility services. Such services need yet to mature, and its synergistic business models to be better understood in terms of value streams they will deliver and to whom. This paper investigates a group of such business models, particularly linking EV and/or homeowners, building managers, and network operators.

INTRODUCTION

Global electric vehicle (EV) sales have grown steadily over the last decade. Sales of electric cars doubled in 2021 to reach a new record of 6.6 million, and by the end of the year, there were over 16 million EVs on the road, triple the amount of 2018 [1]. A leader segment among these increases has been passenger light duty vehicles (e-PLDVs). In 2020 only, there has been a 41% increase in e-PLDVs registrations, despite the COVID-19 pandemic, multiple supply chain disruptions, and a resulting 16% drop in overall car sales during that period [2]. In Europe, mass EV deployment carries a game-changing decarbonization potential, due to the opportunity to introduce higher shares of variable renewable energy (VRE) sources into the generation mix [3,2]. This is aligned with ambitious European Union policies aimed at reducing greenhouse gases (GHG) emissions in half by 2030, and at reaching climate neutrality by 2050 [4,5,6]. However, the forthcoming mass EV deployment is not without challenges; if scaled up to mass-market levels, the mainstream approaches to EV charging, dominated by uncontrolled or time-of-use pricing-driven on/off control, are likely to create an unsustainable upsurge in power system peak demand [3,7,8,9]. Depending on context, this could either be deemed technically unfeasible or lead to prohibitive grid infrastructure upgrade requirements [3]. Thus, an effective shift to mass electromobility needs to be accompanied by advanced, bidirectional, "smarter" EV charging, characterized by vehicle-to-building (V2B), vehicle-to-home (V2H), and vehicle-to-grid (V2G) strategies, which could unlock unprecedented levels of flexibility in future VRE-rich power systems [3]. As a result, bidirectional charging is often colloquially termed "vehicle-to-everything", or simply "V2X".

V2X flexibility services

It is estimated that by 2050, around 14 TWh of flexible EV battery capacity would be available to provide grid-supportive services [11]. If properly exploited, this flexibility could minimize the need for costly grid infrastructural upgrades. Yet, it remains paramount to consolidate the market instruments and the business cases that incentivize the synergistic cooperation between EV users and the power system, while enabling stacking of various grid services and their value streams [3]. The technical flexibility service potential from V2X ranges from higher-level participation in electricity markets to balancing and system-level services to transmission and distribution network operators. Because the development of V2X business models needs to be supported by more than one revenue stream, it is imperative that its value proposition is clarified. This paper investigates a triangle of commercial interactions between EV owners (or prosumer-EV owners), building managers and network operators. It reviews and individually depicts six families of emerging V2X business models deemed to be dominant based on project surveys and literature research

The V2X marketplace

Bidirectional charging is part of an overarching marketplace concept where EV users and prosumers/homeowners, building managers, and distribution network operator entities (which could be traditional DSOs or other types of operators, such as energy communities) can interact and openly trade EV charging flexibility under different contexts (Figure 1). The marketplace incorporates various "scenarios" of EV user participation in the market, namely:

- A *V2G scenario*, where EVs connect directly to network operators through public charging stations (BM1, public charging case).
- A *V2B scenario*, where EVs connect to building parking lots and lend their battery capacity to the building manager's control (BM2, BM4, BM5).
- A *V2H scenario*, where EVs are connected within the distribution board of individual homes (BM1, home charging case, and BM3).

ADVANCED SMART CHARGING BUSINESS MODELS

The following section will depict the bidirectional charging business models BM1-BM6, by visually highlighting stakeholder roles and their interactions, and clarifying the unlocked value streams in each case.

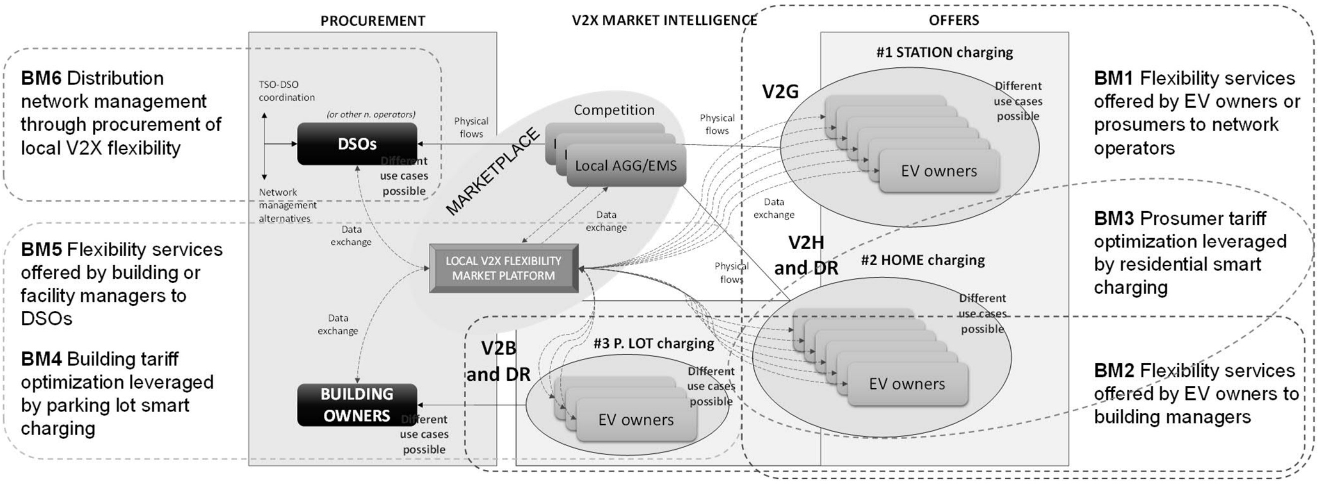

Figure 1 – Overarching bidirectional charging flexibility marketplace concept and respective portfolio of possible business models.

Flexibility services offered by EV owners or prosumers to network operators (BM1)

This business model covers possible commercial arrangements based on which individual EV owners contribute to providing some level of grid support services to formal distribution system operators or other eligible network operators managing specific branches of the distribution grid. Such services could be aimed at maintaining power quality parameters related to frequency and voltage under specific limits, or at improving the technical and economic operation of the grid by increasing renewable energy integration (avoiding curtailment), providing demand and supply balancing support, or offering congestion relief. Due to the small scale of the EV assets, this activity must take place through the involvement of intermediary aggregator agents.

This business model could possibly materialize under two distinct scenarios:

1) **Home charging**, through demand response (Figure 2): In this scenario, flexible EV charging is handled by a home energy management system (HEMS) along other connected assets the EV owner/electricity customer/prosumer may have at its disposal. The HEMS also coordinates customer participation in the balancing markets through demand response events.

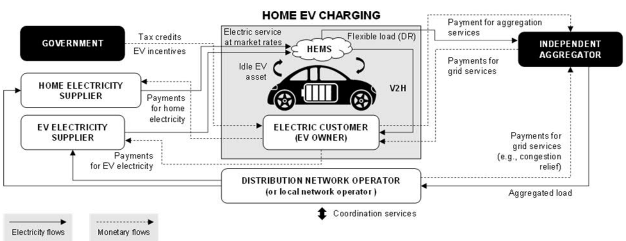

Figure 2 – Representation of financial and commodity flows in flexible services provided by EV owners to network operators, mapped in overarching marketplace as BM1 (home charging).

2) **Station/public charging**, directly through charging point management activities (Figure 3): In this scenario, the flexibility services to network operators are intermediated by charging point operators (CPOs), who can act as aggregators due to their direct connection and control of large portfolios of individual EV charging sessions. CPOs can also outsource that activity to other aggregator entities in the market.

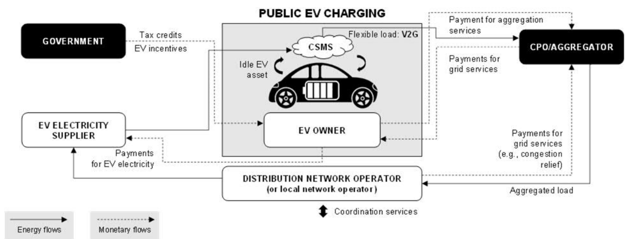

Figure 3 – Representation of financial and commodity flows in flexible services provided by EV owners to network operators, mapped in overarching marketplace as BM1 (station charging).

The different circumstances of the above scenarios result in that EV owners are positioned as direct flexibility service providers when in public charging stations, but not when connected at home. In home charging, the EVs are one additional flexible asset controlled by the HEMS, which manages demand response events on behalf of the residential electricity customer – the flexibility service provider in that case, being the EV role here an indirect one. Regardless of who receives it, service compensation from network operators is due in both models through the aggregator/CPO intermediaries. However, aggregation activities are also remunerated, and as a result EV owners/electricity customers must give up part of their revenue, as a condition for accessing these services. In context of HEMS, EV assets can also be optimally managed for capturing energy savings from V2H, which could compete with the revenues from demand response. Lastly, depending on the regulatory context in question, various capital subsidies and/or tax credits may be available to new EV owners, which could help offset some of the running costs and stack up with other value streams.

Flexibility services offered by EV owners to building managers (BM2)

If rather than at home or along the public way EVs are parked inside large commercial building facilities, they become idle energy assets that can be made available for performing V2B in context of energy management contracts established between EV owners and building managers (Figure 4). If efficiently managed with BEMS, the collective battery capacity of parked EVs can offer benefits to facility energy management, such as reduction of time-of-use electricity and power costs through peak shaving and energy arbitrage, in addition to intelligent and safe charging through dynamic load balancing.

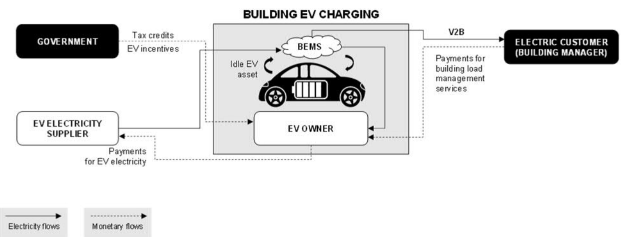

Figure 4 – Representation of financial and commodity flows in flexible services provided by EV owners to building managers, mapped in overarching marketplace as BM2.

This type of arrangements could pertain to short-term (e.g., supermarkets) or long-term charging (e.g., employee parking in offices, passenger parking in airports…), which will influence the constraints and contractual conditions of the energy service. Through digital identifiers at the connection point, an integrated BEMS could recognize the EV unit and contracted service possibilities before acquiring the available capacity, whereas connection/disconnection times would be introduced manually each time by the EV owner/driver. The BEMS ensures that the EVs are ready to drive at the designated exit times, by liaising with EV electricity suppliers. The building manager will then provide EV owners with compensation or charging credit for the service of accessing their idle battery capacity for energy management purposes. That compensation may suffer some level of penalties in case the EV owner fails to comply with the planned connection/disconnection times. As with other EV owner-centric business models, certain government subsidies and tax credits could help EV owners in making financial sense of EV investments. As to the building managers, they have the additional chance of participating in demand response markets, whose revenues can be appropriately balanced and/or stacked with savings from V2B-leveraged energy management.

Prosumer tariff optimization leveraged by residential smart charging (BM3)

When the EV is connected at home and is being controlled by a HEMS alongside other distributed flexible assets, such as heat pumps, electric boilers, and air conditioning units, potentially together with some type of renewable energy generation, it can support the optimization of residential energy costs via V2H (Figure 5). Inevitably, that ability will depend substantially on individual working and driving habits and must be studied at a case by case basis. For example, in a remote working situation, the EV battery could be charged with solar PV during peak-sun hours, virtually at no cost for the EV/homeowner. In another possible case, a fully charged EV battery could support home electricity demand during expensive evening “shoulder hours” and be recharged along the early morning hours, when electricity is cheap. In other words, V2H does not necessarily require renewable energy integration to deliver monetary value, due to the price difference between the peak and off-peak periods of time-of-use (TOU) electricity tariffs. Furthermore, the coupling of V2H with stationary electric storage can enhance flexibility even further, since EV energy injected to the home’s distribution board can be appropriately stored for later internal distribution, if the HEMS optimization so dictates.

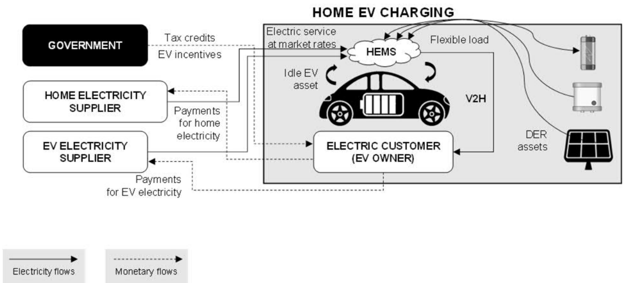

Figure 5 – Representation of financial and commodity flows in prosumer tariff optimization leveraged by residential smart charging, mapped in overarching marketplace as BM3.

Government subsidies and tax credits are often available to strengthen the value proposition of pure-V2H business models for EV owners. However, just like with the commercial buildings, potential revenue streams from involvement in balancing markets could also be accessible and considered under a stacked value logic by the HEMS.

Building tariff optimization leveraged by parking lot smart charging (BM4)

This business model mirrors the scenario of collective EV charging in building parking lots from BM2, being however established from the point of view of the building manager and/or large electricity customer. Here, building management facilitates EV charging services in the building’s premises in exchange for provisional access to idle battery capacity through a V2B setup (Figure 6). Such large customers are often plagued by not only extensive electricity consumption during peak tariff periods, but also by high monthly power usage bills. The ability of a BEMS to connect dynamically to each individual EV charging session allows for balancing of charging needs and optimizing of the collective power draw at each instant, which effectively results in peak shaving and helps reduce overall demand charging costs.

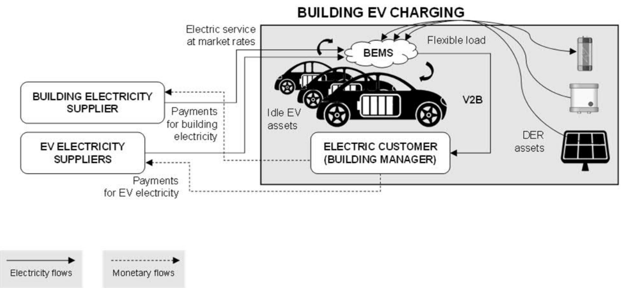

Figure 6 – Representation of financial and commodity flows in building tariff optimization leveraged by parking lot smart charging, mapped in overarching marketplace as BM4.

In addition to this, the BEMS will operate the aggregated mobile storage capacity of idled EVs a "virtual battery", optimally combining its use with the flexible use of other distributed heat and power assets of the facility, such as HVAC units, renewable energy, and stationary storage. In conditions of time-of-use electricity pricing, this joint asset optimization could be geared towards capturing as much cheap and/or green electricity as possible and direct it for consumption during price-peak periods, resulting in substantial reductions of electricity costs for the building. While performing these operations, the BEMS also needs to ensure that the requirements of each individual EV charging session (e.g., disconnection times and minimum SOC at exit) are strictly complied with. According to contracting rules between the building manager and the EV owners, monetary compensation is due for the temporary use of the idle mobile storage capacity (to cover for proportional battery degradation and ensure a profit margin for EV owners), which in absence of any service revenues, and otherwise subsidies or incentives could hinder the viability of this business model alone. As mentioned earlier, to fully capture and maximize value, building managers may have to consider combining V2B energy management savings with revenues from participation in the balancing markets (BM5).

Flexibility services offered by building/facility managers to DSOs (BM5)

While BM4 envisions the case when a portfolio of building distributed energy assets (notably including portfolios of parked EVs) is managed for electricity tariff optimization (i.e., for the purpose of *minimizing energy costs*) this business model contemplates the case when the same assets are managed for electricity market participation optimization (i.e., for the purpose of *maximizing flexibility service revenues*). Large building customers can engage with intermediary agents to allocate their load flexibility to the grid balancing markets, known as explicit demand response. In fact, due to still prevalent high minimum bids required for participation in these types of markets across various European countries, it is in principle easier to do so for these customers than it is for smaller residential prosumers (BM1). Yet, regardless of scale, aggregator parties will play the part of capturing the individual loads and operate with collective grid support services towards distribution system operators or others (Figure 7).

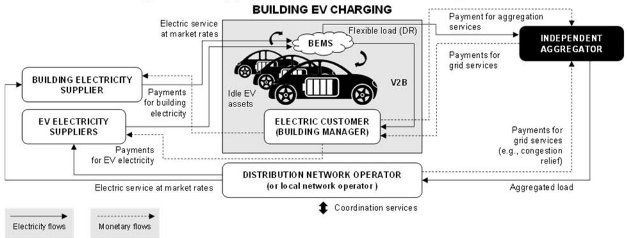

Figure 7 – Representation of financial and commodity flows in flexibility services offered by building/facility managers to DSOs, mapped in overarching marketplace as BM5.

Similar to BM1, the aggregators will channel the payments for technical grid support services from the DSOs to the building managers, after aggregation service fees have been appropriately factored in. Please note that just like in the "home charging" scenario for BM1, the EV assets take the role of mere enablers and have here an indirect involvement in the flexibility services since both the BEMS operations and the demand response are technologically neutral. Yet, as explained before, building managers have to follow their contractual obligations with EV owners and take in the operational costs of monetary compensations for use of idle EV battery capacity. Lastly, this business model focuses on generation of service revenues, but in a realistic situation where the building manager may wish to capitalize on multiple value creation opportunities, it could be combined with energy management of the flexible assets, including the idle EVs, for capturing tariff-related savings, as in BM4.

Distribution network management through procurement of local V2X flexibility (BM6)

This business model is markedly different from other business models studied in this paper in that it focuses exclusively on the perspective of distribution network operators accessing local flexibility to solve technical grid constraints and/or energy balancing issues (Figure 8).

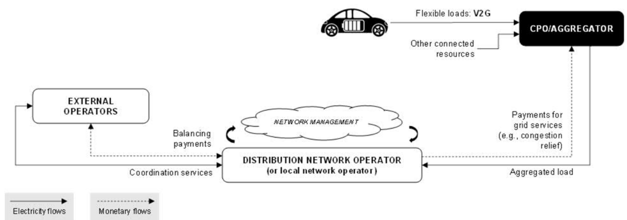

Figure 8 – Representation of financial and commodity flows in distribution network management through procurement of local V2X flexibility, mapped in overarching marketplace as BM6.

Traditionally, day-to-day problems in electric distribution would be handled by using network management infrastructure and through the coordination with external network operators, most notably the TSO. The emergence of aggregator agents with the ability to gather flexible load contributions from large amounts of dispersed assets and deliver it to the distribution system operators changed this paradigm, most notably reducing their dependency from external agents. As the previous models have shown, regardless of charging scenario circumstances, bidirectional charging flexibility is among the distributed resources that operators can access and/or procure locally, either directly or indirectly (via demand response), through aggregation intermediaries (which could be independent aggregators or CPOs). The procurement of localized resources allows for a more cost-effective handling of grid constraints and balancing challenges, which results in savings benefits for distribution system operators.

BUSINESS MODEL COMBINATION AND VALIE STACKING

While the analysis of possible bidirectional charging flexibility business models is facilitated by their discrete consideration and analysis, it is likely that in realistic conditions and whenever possible they could be combined and/or their value streams could be stacked (or both), in order to best recover mobility or infrastructure investments. None of the two options is possible for all the business models studied in this paper. For example, it is unlikely that BM6 could be combined with other bidirectional charging-based models, even though this is possible for other flexibility exploitation models available to DSOs (e.g., linked to different sources of local flexibility). As a rule-of-thumb, business models centered on delivering value to the same stakeholder (e.g., EV owner-centric models) could be combined. On the other hand, value stacking requires that for the considered business models, the charging scenarios are maintained. Table 1 describes the different possible combinations and value stacking possibilities among the six studied models.

Table 1 - Possible business model combinations and value stream stacking possibilities among the studied business models.

	EV owner-centric	**Building manager-centric**
Models' combination	BM1 home and station charging, BM2, and BM3	BM4 and BM5
Value stream stacking	BM1 home charging and BM3	BM4 and BM5

As Table 1 suggests, nothing prevents EV owners from adopting different types of business models in different contexts, in that way tapping different value creation opportunities brought by bidirectional charging. Because mobility is an individual and uncertain phenomenon with many possible driving and charging patterns possible at home, public charging stations, and inside buildings, this combination is expected to take place in a realist context. As to value stream stacking, it is fully dependent on the charging scenario, and for that reason, for EV owners, only the revenues from BM1 in home charging environment and the home energy savings from BM3 could be stacked for maximum capturing of bidirectional charging value. Such stacking is only made possible through real-time techno-economic optimization performed by the HEMS and is not necessarily always concurrently triggered. For building managers, the business model combination and value stacking possibilities resemble those for EV owners. In a building charging environment, BM4 and BM5 could be combined and the value streams they deliver pertaining to building energy savings and flexibility service revenues, respectively, could also be stacked with the expert decision support from BEMS optimization.

CONCLUSIONS

Mass electric mobility will soon become a reality and it is paramount to deepen the knowledge of bidirectional charging strategies and the grid support services they enable. This paper reviewed six bidirectional charging flexibility business models, studying also potential model combinations and its value stream stacking opportunities.

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