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# AN ANALYSIS THE ENHANCING ELECTRIC VEHICLE AGGREGATOR SCHEDULING IN ELECTRICITY MARKETS

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**ABSTRACT**

Electric vehicles (EVs) are emerging as the fastest-transforming sector globally, owing to the clamour to mitigate emissions and fossil fuel dependency. In leveraging its volume, EVs have increased pressure on the electricity markets, and their paradigm needs innovation to balance the supply and demand scales. The recent innovation of electric vehicle aggregators (EVAs) has been a key step in incorporating vehicles into the system and driving efficient supply, demand, and energy storage. Managing the charging and discharging cycling allows the grid to run efficiently without burdening the EVA owner or leaving profits in the dust.

However, the deemed implementation of integrating the EVAs into the electricity markets is fraught with several challenges: technical, such as the grid constraints exemplified by congestion and voltage management; economic, such as cost balancing; and policy-based, whereby there still an insufficient legal and policy, framework architecture for standardisation and underpinning policy support. To overcome these challenges, there is a need to provide a solid solution that broadly spans sophisticated scheduling of RESs, integration of innovative grid systems, and responsive policies.

## 2. Scope of Electric Vehicles in Global and Indian Context

### 2.1 Global Perspective

The interest in the employment of electric vehicles has increased steadily across the globe as an effort to address environmental impacts and shift towards energy-efficient systems. National and company stakeholders are at the forefront of advocating for EVs to decrease greenhouse emissions, increase energy efficiency and reduce fossil fuel use. According to current projections, the advancement of electric cars will see a figure of over fifty per cent of new car sales worldwide by 2040, with Europe and China leading the change (Nazari-Heris et al., 2022). The expectation for Europe and China's market share in the coming years is 70% and over 50% sequentially due to robust policies and the realisation of industrial updates.

| Region | EV Market Share (2022) | Projected Market Share (2040) |
|---|---|---|
| Europe | 22% | 70% |
| China | 15% | 55% |
| United States | 8% | 50% |
| India | 2% | 30% |
| Global Average | 10% | 50% |

Many developed countries have witnessed rapid EV market penetration because of strong charging infrastructure and technological and policy factors. For instance, Norway is an example where 100 per cent plus new car sales have been achieved due to subsidies, tax exemptions, and sufficient charging infrastructure (Strach, 2024). The United States and European Union have also established emission control norms and buyback programs for EV manufacturers and users.

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### 2.2 Indian Perspective

In EV, India has vast potential and actively encourages government plans and requirements that force it to consider environmental problems. While NEMMP has provided the charge for formulating an embryonic structure, FAME schemes have enhanced EV acceptance. After the roll-out of the FAME II program, the government has included large sums for EV incentives, charging infrastructure and innovation (Jin et al., 2020). The state governments have also developed policies like tax credits, capital subsidies, and right of way for electric vehicles.

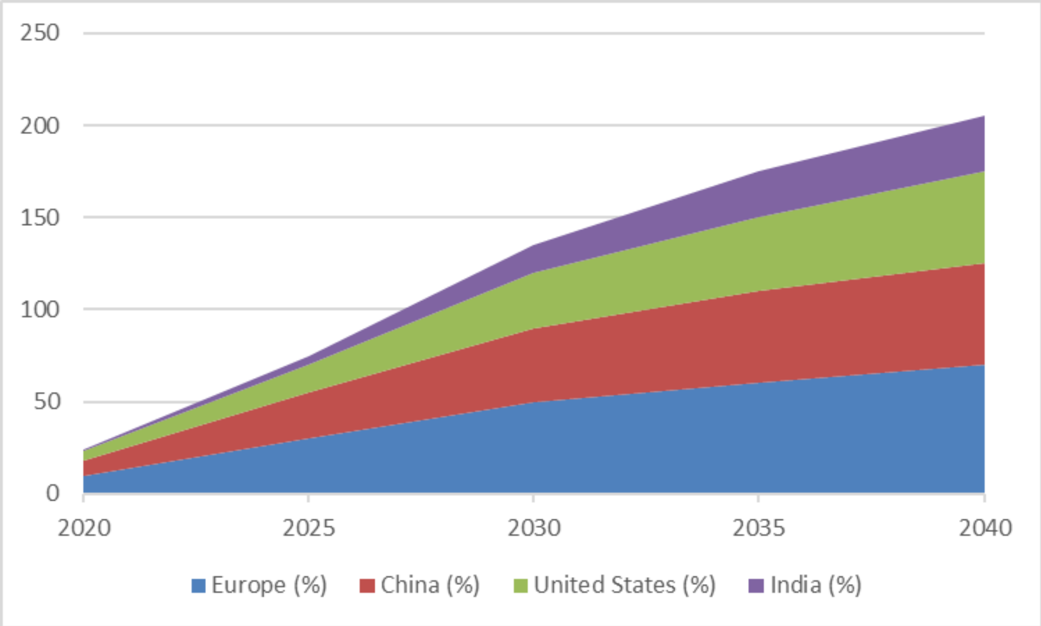


**Figure 1: Global EV Adoption Trends**

Nevertheless, a few drawbacks exist as barriers to the transition of EVs in India. It should, however, be noted that the absence of outrageously accessible charging points is still a fundamental inhibitor. There is a problem of inadequate availability of charging stations, and the existing ones are highly centralised, with few or none in rural and semi-urban regions. Also, due to battery expenses, their prices remain high and are still affordable to many vehicles.

The second critical issue that needs solving is the integration of renewable energy sources. India has been adding more renewable capacity in its environment-friendly approach, but integrating electric vehicles with green power still needs to be improved. Owing to the high reliance on conventional electricity produced from coal-fired power plants, the positive impact of EVs on the environment may be questionable if clean, renewable energy is not used to charge them.

## 3. Electric Vehicle Aggregator (EVA): Concept and Role

### 3.1 Definition and Functions of EVA

Electric Vehicle Aggregators (EVA) are essential in managing electric vehicle integration into electricity markets. An EVA or an Energy Vehicle Actor functions operationally as a middleman, incorporating the variable load requirements of many EVs and acting as their agent in energy markets. This aggregation enables small-scale EV owners to gain a market advantage since they may need help to engage the market individually.

The main objectives of an EVA are as follows: Providing the system with the charging and discharging schedules of EVs, negotiating the electricity prices with other market players, and optimal energy handling (Sharma et al., 2020). By accessing actual electricity tariffs and grid status, EVAs can correctly determine when to charge the batteries, or at least the significant shares, at optimal times or during periods of renewable resources availability. They also accommodate Vehicle to Grid (V2G) functionality that allows the batteries in electric cars to feed power back to the grid at the maximum demanded times.

### 3.2 Role in Electricity Markets

**Grid Stability**

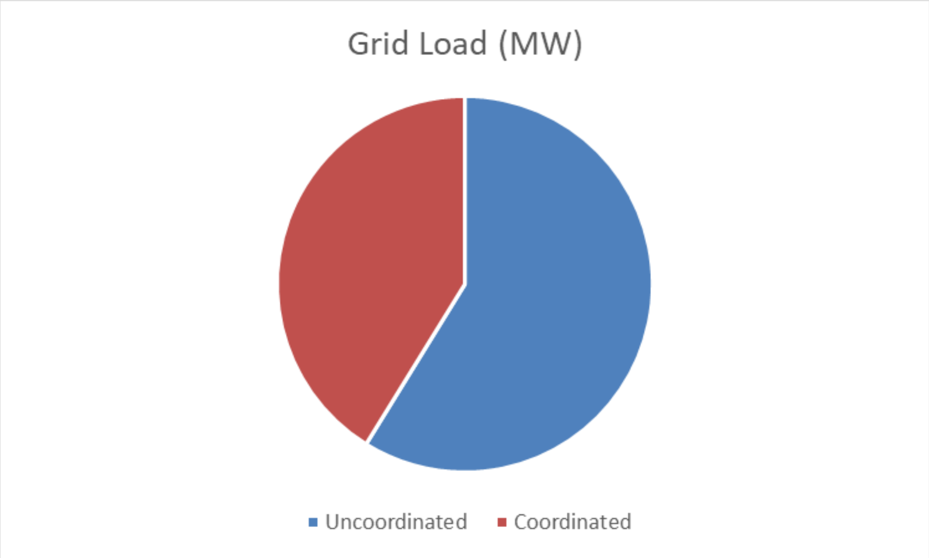


**Figure 2: Grid Load**

EVAs assist in reducing the effects of the unsynchronised connectivity of EVs, which may cause congestion in the grid, voltage instabilities, and overloading of transformers. Through a compelling charging profile, EVAs relieve distribution network pressure and maintain service quality by providing constant electricity availability. V2G operations add to the improvement of the grid's stability by enabling the utilisation of EVs as distributed energy storage systems, offering other services such as frequency management and voltage control.

**Efficient Energy Utilization**

By integrating dynamic scheduling with EV charging times, EVAs ensure that charging is executed when demand is low or renewable energy is abundant. This reduces energy waste or saves energy and helps eliminate nonrenewable energy use. Through demand response programs, EVAs intimidate EV owners to charge during times of low demand, when TOU is high, for maximum electrical usage efficiency.

**Renewable Energy Integration**

Since renewable energy sources such as solar and wind power cannot always generate power, EVAs help manage supply and demand at any time (Eltamaly, 2023). As mobile energy storage, EVs stand to receive excess energy each time there is an abundance of RENs and supply energy every time there is low energy application or peak demand.

**Economic Benefits**

EVAs earn money by buying and selling electricity in electricity markets and charging and discharging at appropriate times. Since low electricity prices can be procured at night, the intention to coordinate the charging of EVs with the low pricing results in a positive feedback cycle. Moreover, being legally empowered to collectively bargain for multiple EV owners while aggregating demand guarantees a competitive price and the highest possible economic utility.

## 4. Challenges in EV Aggregator Scheduling

### 4.1 Technical Challenges

Electric Vehicle Aggregates (EVAs) in electricity markets are problematic from a technical viewpoint. This is because the charging of many EVs happens at once because of high demand during the day, which, in most cases, leads to congestion. This puts stress on the distribution networks, which leads to transformer loading and the reliability of the utility grid (Naja et al., 2023). The other technical challenge is voltage ripple due to the unpredictability of electric vehicles' charging and discharging. Voltage imbalance in 3ph systems is due to inefficiencies and power quality issues in almost all electrical circuit equipment. Further, the large-scale integration of EVs leads to harmony in the grid due to the use of power electronic converters in the EV chargers. These harmonics can cause high-frequency interference, affecting the operation of some equipment and decreasing the whole system's efficiency.

**4.2 Economic Challenges**

From an economic point of view, it becomes a problem to adequately compensate EV owners for their costs while simultaneously optimising the revenue generated by the same owners through the sale of electricity to EVAs. EVAs have to maximise charging strategies to reduce electricity costs for consumers while ensuring their survival from participation in the electricity market. However, this requires unique and complicated pricing structures and marketing strategies.

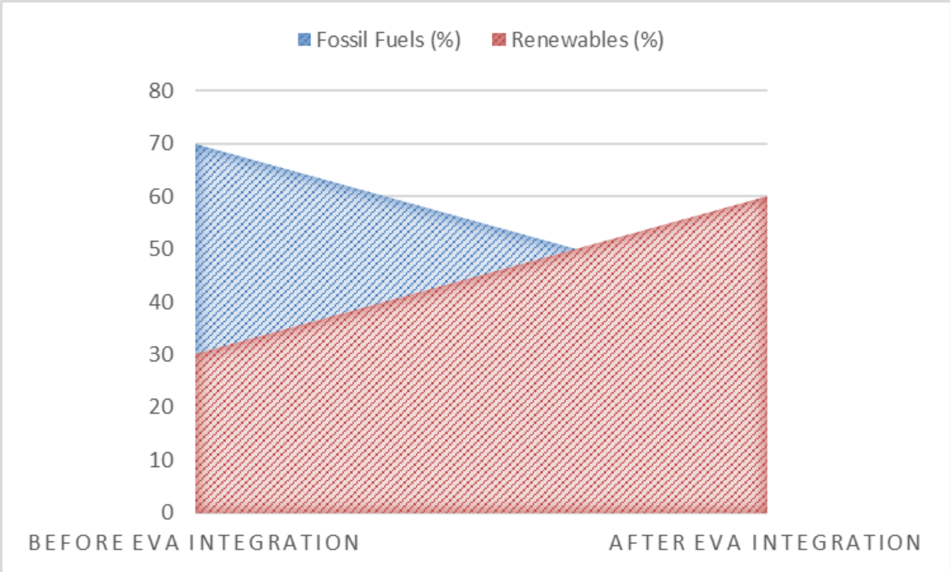


**Figure 3: Renewable Energy Utilization with EVA Scheduling**

The initial capital cost for charging infrastructure and the recurring fees for communication infrastructure stretch the economic feasibility of EVAs even more. Moreover, the owners of EVs that are not compensated or not compensated enough for the energy they sell back to the grid through net metering may not be inclined to join aggregator programs, thus restricting the EVA business.

**4.3 Regulatory Challenges**

First, high regulatory restraints heavily impede the efficient functioning of EVAs. Most charging service delivery is done without harmonised connection interfaces or communication protocols between the EV chargers, aggregators, and grid operators. Process integration and proper coordination remain problematic when no internationally set standards exist (Xu et al., 2024). Moreover, the absence of appropriate policies to support EV aggregation, such as subsidies or other incentives, does not encourage innovations and companies to enter this market. Current regulatory models must capture EVAs' evolving nature, such as their use in connection with renewable energy resources and their operation as active providers of ancillary services. This is so given that the above-described regulatory loophole hinders EVAs from realising maximal effectiveness in stabilising and decarbonising the grid.

## 5. Strategies for Enhancing EVA Scheduling

### 5.1 Coordinated Charging and Discharging Strategies

Scheduling the EVA requires coordinating charging and discharging agendas for optimum results while avoiding grid problems. Flexible tariffs allow EVAs to charge the client's car during off-peak times or when more renewable electricity is available. This reduces the strain on the grid system and enhances energy use.

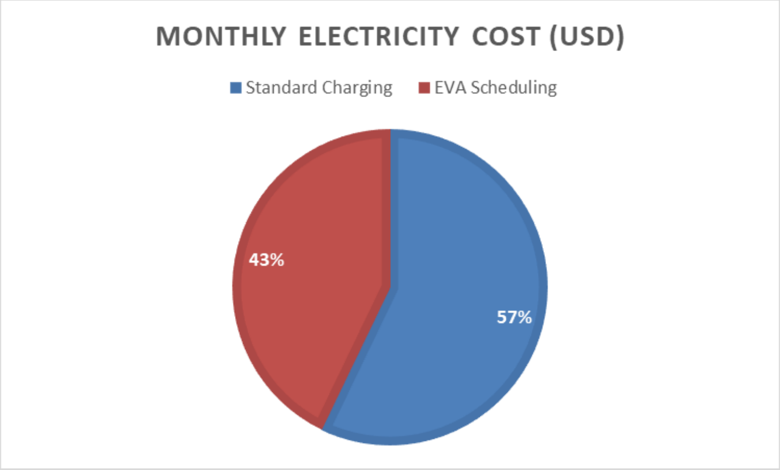


**Figure 4: Economic Savings for EV Owners**

V2G technology takes the above measures a notch higher in providing grid stability. V2G enables the storage and disbursal of power to other EVs during peak hours, thus making them micro power storage stations (Muqbel et al., 2024). This interchange assists load frequency control and minimises the need for expensive transmission grid reinforcement.

Further, the type of pricing, such as time-variant prices, may also encourage EV owners to charge at other than peak times and, therefore, align the market demand with what the grid requires. Thus, synchronised approaches are beneficial for improving EVAs' functional performance and incurring extra value for EV owners.

### 5.2 Smart Grid Integration

Innovative grid technologies are crucial in advancing this agenda and improving EVA schedules. IT real-time monitoring and control solutions allow EVAs to change their charging and discharging plans according to grid conditions and electricity tariffs. These systems utilise sophisticated Command, Control, and Communication networks and sophisticated data analysis to effectively synchronise operations between EVs, Aggregates, and the Grid.

### 5.3 Risk Averse Scheduling Models

RF scheduling models employing a risk aversion strategy incorporate elements of electricity price volatility, EV mobility patterns, and grid facilities. As with traditional EVAs, stochastic programme assistance entails adding variation to allow for framework scheduling by optimising profit rather than risk (Azizivahed et al., 2024). Another type is time-of-use tariffs, which help charge EVs when they are used least frequently. This reduces the pressure on the electricity network, especially during peak hours, and further checks consumer electricity tariffs.

EVAs are integral to the operation of demand response programs, allowing for leveraging charging demand sufficiently to cover price change or grid fluctuation signals. The programs above incentivise EV owners to manage the grid actively, and, of course, those owners make money in the process.

## 6. Impact Analysis of EV Adoption on Electricity Markets

### 6.1 Grid Stability and Reliability

Moreover, they point out that electric vehicle aggregates (EVAs) are equally critical to ensuring the grid's balance and stability. Therefore, with the precise coordination in charging and discharging of the EVs, the EVAs help avoid grid loading several times during the demand surge (Afshar et al., 2021). Namely, EVAs turn electric vehicles into distributed storage thanks to the synchronised charging behaviours and bidirectional power flow, which is V2G enabled. This reduces the chances of loading the transformer heavily and variation in voltage regulation, enhancing the standard power delivery.

### 6.2 Economic Impact

The adoption of EVA as a business model has massive economic implications for the owners of EVs and for all the stakeholders who operate in the market. As part of the service, TOU and demand response programs assist the owners of the EVAs to charge their vehicles during off-peak times to reduce the cost of electricity. This cost efficiency thus helps to push the electric vehicle uptake rate and generate a positive feedback effect on market growth (Patanè et al., 2024). On the other hand, EVAs earn revenues and manage charging and discharging cycles concerning electricity market prices. This double advantage creates the conditions for making EVAs financially sustainable while reducing the cost of owning an EV. Moreover, the use of revenues can again be repeated to roll out charging equipment and enhance aggregator business models.

### 6.3 Environmental Impact

EVAs contribute significantly to a sustainable environment by incorporating renewable power supply in the electricity market. Through achieving a causal link between EV charging and periods of sustainable energy generation, EVAs decrease the consumption of fossil fuels, resulting in lower carbon emissions. V2G technology makes it possible for electric vehicles to store renewable energy by charging back the grid during periods of high consumption. Incorporating clean energy into EVs provides the needed cover for achieving global decarbonisation targets in a way that complements the positive effect of EVs in reducing greenhouse gas emissions.

## 7. Future Directions and Research Opportunities

### 7.1 Advancements in EVA Scheduling Algorithms

The specific area that should be studied in the future is integrating AI and ML to improve EVA scheduling algorithms. Real-time prices, grid, and EV mobility data can be considered and predicted through AI-assisted scheduling models to help schedule more efficiently. The use of machine learning in smoothening the charging profile and cost savings are also possible in addition to the effectiveness of V2G activity (Deng et al., 2020). That way, more significant progress could be made to continuously update EVAs or enable them to become more effective in the face of fluctuating market prerequisites and contribute much more effectively to the ability of the grid to hold up.

### 7.2 Infrastructure Development

It is crucial to develop the SC network to develop the EV market and meet the corresponding needs. Further steps should involve widespread distribution of fast-charging and charging stations using renewable energy sources. Combining renewable energy resources with charging infrastructure will improve the sustainability of EV use and decrease the threat of grid reliance on fossil fuel resources. Future investments in smart-grid integration and AMI will also enhance the communication of EVAs and grid operators in optimal energy usage for sound and stable grid conditions.

## Conclusion

Therefore, electric vehicle aggregators, or EVAs, disrupt electricity demand and energy infrastructure interrelation. Through EVAS, EV charging and discharging benefits include balancing load, cost, and renewable energy in the grid. Nonetheless, such technologies must leverage technical, economic, and regulatory hurdles to achieve optimal implementation through emerging technologies and favourable policies.

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