Electric Vehicle User Behaviour and Demand Response

A Strive for Energy Autonomy

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Abstract—Electric vehicles are being promoted world-wide by governments to reduce dependence on oil and to mitigate greenhouse gas emissions. In addition to barriers to entry such as the cost of the new technology, convenience, and the availability of electrical energy, consumer behaviour is also a concern in developing countries such as South Africa. The Council for Scientific and Industrial Research (CSIR) has established a program aimed at promoting energy autonomy within the campus. The program focuses on the use of energy generated through renewable sources as well as initiating demand response activities to charge electric vehicles. The campus currently owns 10 electric vehicles both hybrid and battery, that can be used by staff on the campus as a means of striving towards energy autonomy. With increasing utilisation and a fast-charging system it is envisioned that more people will be keen to use these vehicles. However, the uptake of electric vehicles are tied to also consumer behaviour and the benefits of electric vehicles, hence understanding consumer awareness and behaviour will help encourage the adoption of electric vehicles. The integration of the electric vehicles to the envisioned smart micro-grid will also help the campus become smart in terms of its energy use, charging and storage. The paper focuses on understanding consumer behaviour and incorporation of demand response in the electric vehicle space to maximize adoption of electric vehicles and promote energy autonomy.

Keywords – electric vehicles, energy autonomy, consumer behaviour

I. Introduction

The development of electric vehicles (EVs) has increased worldwide and they are being considered a means to improve energy efficiency and reduce greenhouse gas (GHG) emissions [1]. It has been estimated that road transport accounts for almost 18% of CO_2 emissions, suggesting that a greater adoption of EVs by consumers could significantly contribute to the reduction of these emissions [2]. EVs are seen to have great potential, not only within the transportation sector, but also by improving energy efficiency through increasing power system flexibility through demand response [1]. However, despite these advantages, there is currently only a small proportion of EVs, on the road, across the globe. Only about 0.9% of all vehicles in the US are electric; UK offers slightly better statistics with about 1.4% of the total vehicles on the road being electric [2]. The uptake of EVs has been slow and could be attributed to concerns consumers have about the technology such as (1) driving range, (2) required charging time, (3) high costs, and (4) lack of charging infrastructure (locally and over long distances) [2].

The Council for Scientific and Industrial Research (CSIR), a multidisciplinary research-based organisation aims to fast track the adoption of EV vehicles, and in doing so strive for energy autonomy within the campus through the integration of EVs onto the envisioned smart microgrid. Since, the development of the EV market is also linked to consumer behaviour and awareness of the benefits of EVs, the institution has bought 10 electric vehicles (hybrid and battery-powered) which are available for staff to use within the campus. Through this, the objective was to understand consumer behaviour in the EV space, create awareness and employee friendliness to use an EV, as well as to understand impacts of EV on demand response measures on the campus.

This paper focusses the primary factors influencing the use of EV technology, the management protocols should be in place to increase EV adoption, and the consumer behaviour and awareness around EVs and how it can be improved to accelerate energy efficiency initiatives and drive energy autonomy.

II. Electric Vehicles

Electric vehicles have been around for centuries; in fact, electric vehicles dominated markets in the late 19th and 20th centuries [3]. Worldwide, as of 2015, almost 1.26 million EVs were in use [4]. EVs are defined as vehicles that have a batter and uses electricity that is supplied from an external power source to operate [4]. These vehicles are an important alternative to the conventional internal combustion engine driven vehicles in that they produce zero emissions (battery powered EVs). Electric vehicles comprise of three main components, (1) a battery bank wherein electrical energy is stored and ready for use, (2) a power cord, and (3) plug [3].

There are four main types of EVs, namely [3]:

1. Battery Electric Vehicle (BEV)

2. Hybrid Electric Vehicle (HEV)
3. Plug-in Hybrid Electric Vehicle (PHEV)
4. Fuel Cell Electric Vehicle (FCEV)

EVs are generally more expensive than internal combustion engine vehicles of a comparable size [5]. Also, EVs have restricted driving ranges and require longer refueling times compared to conventional vehicles [5]. The charging time of an EV is dependent on the level of charge left in the battery, technology used in the car, the type of charging cable used and the charging station itself [6]. Currently most charging stations allow charging power of up to 1.5 to 3 kW [6]. Table 1 indicates time to charge an EV battery based with a given socket type.

Table 1: Different charging modes possible. Courtesy [6]

Power (kW)	Socket type	Typical location	Time to charge up to 160 km
1-3	Domestic	Home	>10hours
1-7	Domestic	Home/Work	2-12hours
Up to 43.5	Domestic	Work/public	0.5 -1.5hours
50	CCS	Corridor	<15 minutes

A. Demand Response

An increase in EVs will result in increasing load demand of buildings – as these vehicles will be parked in, and around commercial and office buildings [7]. Also, this increases the possibility of uncoordinated charging in the residential space, which means that total demand of these building becomes potentially higher than that which is allowed by the utility [7]. However, EVs can also offer advantages like other demand response initiatives such as reserve capacity, load balancing and peak load shaving [1]. Furthermore, since data monitoring and measuring devices are already present in EVs, it will be easier to monitor and adjust charging and discharging as with other demand response initiatives. This is also advantageous as it decreases the need for investment into advanced metering infrastructure and reduces the need for demand response communication [1].

Demand response (DR) refers to a set of actions that are aimed at reducing demand. Such actions look at mainly reducing electricity consumption during peak periods [8]. DR can be classified as either price-based DR or incentive-based DR. a description of this is shown in Figure 1.

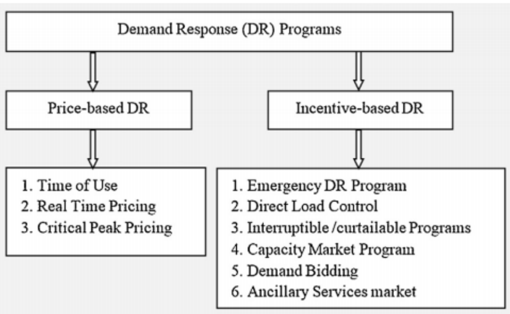

Figure 1: Categories of DR programs. Courtesy [8].

The campus is charged on time of use, i.e. falls into the PR-DR category.

If there is an increase in plug-in battery EVs, as a result of more consumer/user interest on the campus, then there will be a large accumulation of distributed energy storage [9]. The stored energy can be thus used in a way that allows the ability to shift demand, both in terms of charging of the vehicles itself, and exporting to the grid [9]. Although standard, stationary batteries would be advantageous to store excess energy produced to be used for demand response initiatives such as peak shifting, EVs are mobile devices, and users have the potential to use them as vehicles as well [9], justifying investment as well as the concept of sector coupling. However, charging capacity and transport energy needs are a constraint, hence there needs to be an alignment to consumer behaviour on the EVs to ensure effective integration of EVs for demand response.

The CSIR main campus has 52 buildings and it gets its electricity from the local municipality. It was found that the campus had a base load demand of 3MW, and a peak load of up to 7MW. The CSIR is on a time of use tariff. The three billing periods are Peak, Standard and Off-peak.

Table 2: CoT's Energy Charge (R/kWh): Courtesy [10]

Time / Day	00:00 - 05:00	05:00 - 06:00	06:00 - 09:00	09:00 - 11:00	11:00 - 17:00	17:00 - 19:00	19:00 - 21:00	21:00 - 23:00
Low Demand Season								
Sat	0.51	0.51	0.72	0.72	0.51	0.72	0.51	0.51
Sun	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51
Week-day	0.51	0.72	1.17	0.72	0.72	1.17	0.72	0.51
High Demand Season								
Sat	0.59	0.59	1.09	1.09	0.59	0.59	1.09	1.09
Sun	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59
Week-day	0.59	3.17	3.17	1.09	1.09	3.17	3.17	1.09

Decreasing electricity usage during peak times will significantly reduce the energy bill. Using renewable energy sources, and demand response measures, the campus aims at becoming energy autonomous. However, demand response measures have their limitations in that some activities cannot be shifted out of peak usage times as they will negatively affect daily operations.

B. Consumer behaviour and awarness

EV technology can provide many benefits over conventional vehicle technology, however, the uptake of EVs has been slow [2]. Many previous studies have predominantly focused on the economic and environmental impacts of EVs [11]. Often, consumer behaviour towards the adoption of EVs, especially within developing countries such as South Africa, are negative as these vehicles are more expensive, have limited driving ranges, and require longer time to refuel than the conventional vehicles [2]. The lack of public charging infrastructure further adds to the list of disadvantages. Consumers need charging infrastructure that is suited to their driving patterns and lifestyle.

On the other hand, having incentives to purchase EVs could entice consumers. For example, in the United States, EV lane access, wherein EV drivers are designated specific lanes on the roads have contributed to an increase in sales in EVs [12]. Furthermore, a study showed that consumers were inclined to adopt EVs if they had positive foundation based on the following criteria [5]:

- Brand
- Vehicle image/look
- Driving range
- Charging time
- Vehicle performance
- Environmental impact
- Lifestyle
- Operational costs

EV users have the option of feeding back to the grid or vehicle to grid (V2G). However, range anxiety and the minimum range a vehicle can provide has been proved to be the most important factors of the user's willingness to participate [13].

III. Findings and Analysis of EV Consumer Behaviour Surveys

Consumer behaviour and awareness is a key factor influencing improved adoption of EVs, which also helps achieve energy autonomy within the campus. CSIR's EV initiative allows staff members to use the EVs for their daily trips from work. To study consumer behaviour, and by doing so relate it to the general consumer, a survey was conducted to understand the challenges faced by users of the EV vehicles on the campus; the management protocols that were in place to allow smooth and optimized use of the EVs and the level of consumer awareness on EVs within the campus. Additionally, to link the study to demand response, a theoretical study was engaged in to understand the potential of battery storage as a demand response initiative, with the notion that as more EVs are adopted, there is increased battery storage available, which can then be discharged as required.

A. Brief description

Initiatives at the CSIR main campus aims to achieve a 20% reduction in energy demand by the year 2022, with the aim of eventually moving off the grid and reaching energy autonomy through the integration of a smart grid.

Enhanced EV adoption and usage means increased battery storage which could potentially assist in peak shaving. However, the user behaviour around EVs need to align to the demand response initiatives that are in place to ensure that there is seamless integration. Understanding consumer behaviour, their awareness and usage patterns of the EVs will help understand what factors need be in place to (1) improve the uptake of EVs and (2) integrate EVs as a demand response initiative.

B. Methodology

The study aimed to understand (1) user behaviour and (2) how EVs, aligned to current user behaviour, given that the shortfalls are catered for can be integrated into the proposed smart grid, i.e., using EV batteries as a storage platform.

To identify consumer behavior patterns and awareness, a survey was developed and presented to the custodians of the EVs at the CSIR main campus. The aim was to try and answer three main questions, namely:

(1) What factors influence and increase of EV challenges?
(2) What management protocols are in place to ensure smooth and optimized utilisation of the EVs?
(3) How consumer awareness on EV can be measured and improved.

The custodians of the EVs were thought to be a better alternative to surveying the staff who drove the EVs from time to time, as they engage constantly with the staff using these vehicles, deeming them more informed and aware of the trends and behaviour of these users. The questions in the survey were kept open-ended, allowing for better insights and perceptions to be drawn. The surveys did not have a ranking system, such as a Linkert-scale type ranking, however required that the custodians express their views, and opinions in writing. Similarities and commonalities were identified.

A total of 10 custodians were surveyed.

Furthermore, as there is increased adoption of renewable energy sources and improved energy efficiency and demand response measures, the focus was on how to effectively integrate, operate and monitor battery storage in EVs. As shown on Table 3, the contribution of the peak demand ranges from 16 to 26%, which increases the electricity bill significantly.

Table 3: Peak demand contribution

Month	Peak Demand (KW)	Total Electricity bill (R)	Peak Demand Cost (R)	Energy Costs (R)	% Peak Demand Contribution
May 2017	5298	2238716	550992	1687724	25%
June 2017	5676	3565697	590304	2975393	17%
July 2017	5776	3718155	612294	3105861	16%
August 2017	5331	3613267	565086	3048181	16%
September 2017	5294	2169409	561137	1608272	26%
October 2017	5273	2188692	558990	1629702	25%

In addition to the renewable energy sources, demand response initiatives could lower the electricity demands from peak to standard time of use. The battery technology market has been largely linked to the e-mobility industry, Storage capability is an added advantage of the EV, allowing for demand response, hence the battery technology market and the e-mobility industry is closely linked.

An energy audit of the CSIR campus was performed in order to identify and quantify the energy resources on the campus. This, to understand the load profiles of the business, and by doing so suggest measures, specifically energy efficiency/demand response initiatives to reduce energy use and strive towards energy autonomy.

IV. RESULTS

The survey results provided useful insight on the behaviour of EV users on the campus. Challenges faced by users ranged from a lack of technical knowledge provided during the induction to anxiety around the utilisation of these vehicles. Main findings are tabulated in Table 4.

Table 4: Challenges faced in the utilisation of EVs on campus

Question asked	Challenges faced
Challenges with EV induction / awareness?	• Custodians not sure how to answer very difficult technical questions. • Users/staff not keen to ask for induction
Challenges faced as custodian?	• Booking conflicts • Leaving vehicles uncharged by users • No recording/ incorrect recording of distances travelled by users
Why do staff prefer not to use EVs?	• Anxiety when using EV– particularly for one specific brand of vehicle. • Does not meet the driving range; staff travel longer distances • Perception that these vehicles are for a 'special group' of individuals • Slow charging infrastructure • No place to log complaints about EVs

The main themes that emerged from the findings was the fact that there is a level of anxiety faced by the users when using the EVs. This could potentially be attributed to the fact that there is not much charging infrastructure in place within the area of travel for the users, and the fact that users were not educated on the technology. Users also felt that there was not enough driving range possible; hence the vehicles could only be used for shorter trips. What is interesting note is the fact that even though price was not a shortfall, there were still other factors discouraging the use of EVs.

In terms of the second question which investigated management protocols to ensure smooth and optimized usage of the EVs, respondents were fine with the current management system that were in place. However, it was clear that with the current system a major challenge was the returning of vehicles after the allocated time of the user, resulting booking conflicts for the next user.

The third question attempted to understand how consumer awareness could be improved. Results are as shown in Table 5. As with many other studies, awareness about EVs could be increased by increasing the level of communication about the technology. This included increasing exposure to EVs using emails, banners, posters and roadshows.

Table 5: Consumer awareness

Question asked	Measurement of awareness
What is best way to create awareness?	• Informative posters/banners on corridors/reception areas and main entrances • Road shows wherein the EVs are displayed and interfaced with users • E-mails communicating about EVs
Which brand of EV is preferred (hybrid or electric)	• Hybrid is preferred over electric as refueling is an issue, with the lack of infrastructure

In total there are 10 EVs available for use on the campus. Two brands of vehicles are available, namely the Nissan leaf (6) and the BMW i3 (hybrid) (4). The total battery capacity from current EVs on the campus:

$$24\text{ kWh} \times 6 + 18.8\text{ kWh} \times 4 = 219.2\text{ kWh}.$$

The lifetime of these batteries averages around 8 years. The Nissan leaf battery, when fully charged offers a driving range if about 135 km, while the BMW i3 battery offers a driving range of about 100 km. However, since the BMW i3 is a hybrid, the vehicle can switch to fuel if longer distance trips are required. The batteries, if DC fast charging infrastructure is available, can be charged from fully discharged to about 80% charge in about 30 minutes.

The CSIR campus operates from 08:00am to 16:30pm on weekdays. However, there are laboratory activities and conferences that may occur outside of the typical business hours. Through observations of the data collected through an energy audit of the campus it was determined that building 5, out of all the 51 buildings on the campus, identified as a representative example of the typical daily load profile of the campus. The building is comprised of 48% offices, 50% laboratories and a staff canteen. It was determined that the observations and learnings from this building may be applied directly to the campus.

The annual energy consumption of the building amounted to 1 126 651 kWh in 2016, amounting to R1 120 651 (80 963 USD). The daily load profile of building 5 at the CSIR is indicated in Figure 2.

Weekdays, during business hours, the demand is the highest, baselining around 160kW shown by point A, over from 6:00am to 16:30pm. Weekend load profile shows a typical demand averaging around 120kW shown by point B.

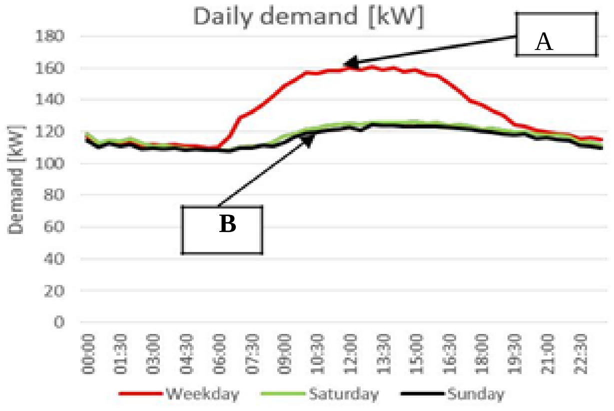

Figure 2: Daily Load Profile Building 5

When there is excess energy being generated over the weekends through renewable sources. Battery storage can be charged over the weekends – saving excess energy which can be expended during peak periods.

With the total battery storage of 219.2kWh available from the 10 EVs, it is possible to supply energy to building 5 during peak operational periods, or when the demand is high. The tariff rate plays an important role in determining the costs that are incurred for energy consumption. If there could be some form of energy supply from storage to shave of peaks, then there will be a decrease in the energy costs incurred by the campus.

Looking at Figure 2, it is evident that there is a steep increase in demand, over the weekdays, from about 06:00am to 09:00am. The tariff table, Table 2, shows that costs in peak times are R1.17/kWh in the low demand season (summer), and about R3.17/kWh in the high demand season (winter). Adding the V2G could create value as now charging can be postponed or even reduced if electricity prices are high. However, the issue becomes whether the battery can be charged quickly enough to meet short-term mobility requirements.

With the current number of vehicles on campus, the total energy storage capacity is around 219.2 kWh. This means at any given time, there is capacity to discharge about 219 kWh of energy into the campus grid system. This, on the basis that there are provisions in place for V2G, and fast charging facilities available to ensure that cars can be charged to meet short-mobility requirements, and excess energy available for charging from renewable sources. From the results, it is evident that users do not use the vehicles for long trips due to their limited driving ranges; hence the potential for V2G is aligned with current user behaviour on the campus. Potential savings that could be achieved are based on the following assumptions:

1. EVs are charged thrice in 24 hours – once at night (off-peak); once in twice during standard rate.
2. EVs are discharged twice – during morning peak and evening peak hours.
3. There are fast charging systems/infrastructure in place (30 minutes per full charge).

Based on this scenario, looking at a typical weekday in low demand season as per tariff structure on Table 2, savings potential using EV batteries as storage, and integrating with DR is:

Cost of charging vehicles:

- $\mathrm{R0.51/kWh} \times 219\,\mathrm{kWh/day} + 2 \times \mathrm{R0.72/kWh} \times 219\,\mathrm{kWh/day} = \mathrm{R}\,427/\mathrm{day}$

Savings because of discharging during peak:

- $\mathrm{R1.17/kWh} \times 219\mathrm{kWh/day} \times 2 = \mathrm{R}\,512/\mathrm{day}$

Total savings per day using EV:

- $\mathrm{R}\,512/\mathrm{day} - \mathrm{R}\,427/\mathrm{day} = \mathrm{R}\,85/\mathrm{day}$.

It is predicted savings, in the case of the High demand season will be higher.

The awareness concept will become quite important when considering the willingness of users to participate in DR using battery storage. Studies [13] show that users are generally unaware of the concept of V2G, and of the different types of charging strategies present to optimise DR and reduce energy. A main limitation is the fact that there is no direct projectability on the trips or usage of EVs, hence there will be difficulty in dispensing EVs for V2G.

V. Analysis of Results

The driving range provided by the EV and the fact that many people use vehicles not just for short trips make EVs less attractive to the users. Based on the results, there is a perception amongst users that EVs are limited or better suited to certain types of individuals or a 'special group' than others. Consumers also feel more at home with certain brands of EVs compared to others purely based on the ease of use of these vehicles and the technological offerings the brand provided. In fact, users for one specific brand, users were concerned that the charge of the vehicles was used up before it met the driving range indicated – creating anxiety in users.

Another behaviour exhibited by the users were that they were more inclined to purchase or consider hybrid EVs over purely electrical ones. This as mentioned could be attributed to the 'anxiety' users felt when driving EVs due to their limited driving ranges and the lack of infrastructure in place for charging. What should be noted, is that, even though price was not a factor, users were still discouraged from using EVs mainly because of the current charging infrastructure in place, or rather the lack thereof, as well as the driving ranges of these vehicles. In fact, a major concern is that users forget to re-charge their vehicles after usage. From a DSM point of view, if the concept of V2G is to gain traction on the campus, this could have adverse effects as the vehicles always need to be fully charged to allow discharge when needed, i.e. during peak shaving etc. This can attribute to the slow charging infrastructure in place. By upgrading to fast chargers, there is a likelihood, based on the findings of the survey, that consumers would be more pro-active towards using the EVs.

From a demand response point of view, there is a potential to link EV technology to storage, if users are willing to limit use during peak periods. One limitation is the fact that there is a general lack of understanding of V2G, and types of charging strategies in place. There are strong concerns on the actual projectability of trips in EVs, which could also potentially affect DR initiatives such as peak shaving if not controlled with a proper feedback charging system. In a standard connection there is unidirectional flow of power – from the grid to the vehicle. Potentially, by building in an inverter into the electric vehicle supply equipment it will be possible to achieve bi-directional flow of current. Furthermore, to ensure effective utilisation of EVs and their stored energy, there needs to be enough communications systems in place. Hence, the campus needs to focus on developing suitable algorithms that discharge the vehicle, based on the grid needs. Ideally, using renewable energy resources, setting up a solar charging facility will eliminate dependence of EVs from the grid, hence increasing the magnitude of energy cost savings. Overall, there needs to be more investigation into smart energy trading, and the use of renewables to charge EVs. Since vehicles are parked for most of the time when not in use, or when trips ends, setting up V2G applications are helpful given there is adequate supply equipment.

The integration of E-mobility, its storage to the electrical system, in a smart micro-grid system, is a promising technology if users take initiative in the technology and align their usage and behaviour to saving energy. Although results indicate the need to create more awareness within the EV space, there is also a need for consumers themselves to take interest in the technology.

Further studies, looking at predicting trips and charging times could contribute to setting up a smart microgrid system that uses EVs in an energy efficient manner helping reduce energy costs. Also, the development of adequate feedback software, integrating renewables, consumer/user behaviour, i.e. charging patterns etc. could result in the coming together of a virtual power plant that has minimal dependence on the grid.

VI. CONCLUSION

The number of registered EVs have increased worldwide. The EV market has the potential to grow larger and at a faster scale, if there is expansion on EV infrastructure as well. There are still a few challenges to overcome; the main one being the seeming lack of initiative by consumers (in this case, staff) on investigating and understanding EV technology better. By studying the user behaviour, and aligning these with the energy usage patterns, it could be possible to utilize battery storage to reduce the CSIR energy bill by implementing peak shaving and energy price arbitrage. V2G capabilities could assist to balance renewable peaks, provide extra capacity and bulk storage. Although the battery storage available from these vehicles will not be able to meet the energy needs of the entire campus; it may be possible to use the available battery storage to alleviate some energy usage within specific buildings, and by doing so continue the strive towards energy autonomy on the campus. A model summarizing key findings is shown in figure 4.

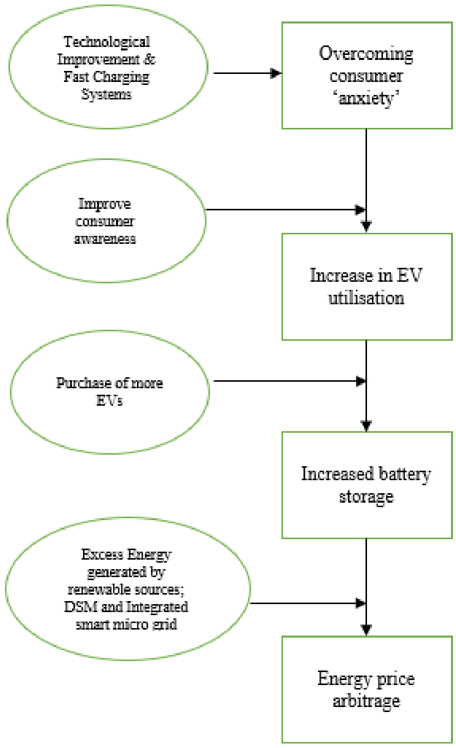

Figure 4: EV user and DR model – achieving energy autonomy

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