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Final report - Leicester City Hall Operational Pilot

Subtitle: V2B and V2G at Leicester City Hall – case study

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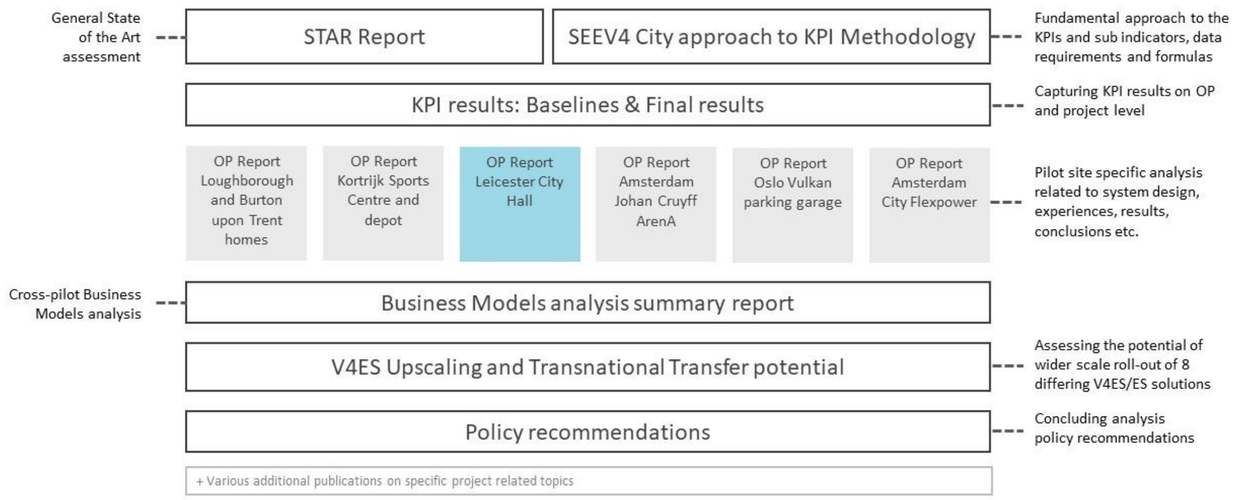
Executive Summary

This report provides evaluation of the SEEV4-City Operational Pilot at Leicester City Hall, in the city of Leicester, U.K. In cooperation with Cenex UK, a demonstration project was set up to evaluate the technical requirements and commercial benefits of V2B (Vehicle to Building) technology at Leicester City Hall, U.K. It is part of a collection of reports published by the project covering a variation of specific and cross-cutting analysis and evaluation perspectives and spans 6 operational pilots. This report is dedicated to the analysis of the pilot itself. Below an indication of the set of repots is provided, including an indication where this OP report fits in.



A large council building in Leicester, its central HQ called City Hall, aims to link on site renewable energy (PV) generation to electric vehicles (EVs) used by the Council staff. Leicester City Hall based staff are utilising four EVs for their work and charging these, when possible, from local renewable energy (PV) generation. This study presents the analysis of the use of four such EVs and their charging profiles that take place at the City Hall.

This is a relatively small-scale operational pilot (OP) studied by the EU Interreg North Sea Region (NSR) funded SEEV4-City project. It aims to demonstrate the benefit of smart (controlled) charging to better integrate renewable energy generation and EV charging in order to reduce carbon footprint, alleviate low voltage (LV) grid stress and achieve an economically viable solution to sustainable electrical transportation and renewable energy supply. The different aspects mentioned in this report constitute the key elements of a viable/successful business model, which is essential for a wider implementation of this concept in real-life applications beyond that of a financially assisted innovation and demonstration one.

This report explores these different dimensions of the business model by making use of smart charging of electric vehicles (EVs). Four Nissan Leaf electric vehicles are used in this pilot. The SEEV4-City project uses three key performance indicators (KPIs), namely energy autonomy, CO_2 emission savings, and grid investment deferral, to measure the environmental and economic benefits achieved by providing Electric-Vehicle-for-Energy-Services (eV4ESs).

The results are summarised in the table below, showing the degree to which the OP was able to address the various KPI dimensions. Owing to circumstances beyond the control of the participants, no V2B equipment was installed prior to the end of the pilot / SEEV4-City Project, thus the available outputs were less comprehensive than had been originally intended. Nevertheless, analysis could be performed using actual and available data to assess results of the OP for the achieved set-up. This show the OP exceeds its target for CO_2 reduction through different measures, mostly as result of ICE vehicle replacement. Because most of the PV generation was absorbed by the energy use of the building, the ZE km increase did not meet its full target, although the connection capacity indicates there is room to increase the amount of PV which could be dedicated to EV charging. The current set-up, where the planned V2B has not yet been implemented, also indicates no Energy Autonomy increase. However, using existing data to assess the V2B in the 'virtual carport' model shows an achievable result of Energy Autonomy for the site increases to 41%,

Analysis, using NPV techniques, of potential eV4ES provided by this OP shows that for the proposed V2G installation to be profitable, the investment cost per V2G charger/controller should not exceed £11,015.90.

Leicester City Hall Operational Pilot - KPIs			
KPI		***Target***	***Results***
A	CO_2 Reduction	2-5 tonnes	7.19 tonnes/year
	Sub-KPI: ZE km increase factor	1.3 x increase	26793.66 km/year (1.07 x increase)
B	Energy Autonomy increase	1% increase (36 to 37%)	N/A (future achievable indication 39% increase)
C	Grid Investment deferral (by peak demand reduction)	N/A	N/A

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Glossary

Abbreviations	Terms
BEV	Battery Electric Vehicle
BESS	Battery Energy Storage System
CCGT	Combined Cycle Gas Turbine
CCS	Combined Charging System
CHAdeMO	CHArge de MOde: e-mobility collaboration platform around the CHAdeMO system
C-Rate	Battery charging/discharging rate relative to its maximum capacity (1 C refers to charging of a battery from flat to full capacity in 1 hour).
DFFR	Dynamic Firm Frequency Response
Do **DESS**	Depth of Discharge Energy Storage System
EA	Energy Autonomy
EV	Electric Vehicle
FCR	Frequency Containment Reserve
FFR	Firm Frequency Response
FiT	Feed-in Tariff
ICE	Internal Combustion Engine
ICT	Information and Communication Technology
KPI	Key Performance Indicator
LCOE	Levelised Cost of Energy
LV	Low Voltage
NPV	Net Present Value
OCGT	Open Cycle Gas Turbine
OCPP	Open Charge Point Protocol
OSCP **OEM**	Open Smart Charging Protocol Original Equipment Manufacturer
OLEV	Office of Low Emission Vehicles (UK)
OP **OSCP**	Operational Pilot Open Smart Charging Protocol
PV	Photovoltaic
RE	Renewable Energy
SFFR	Static Firm Frequency Response
SoC	State of Charge
USD	US dollar
V2G	Vehicle to Grid
V2H	Vehicle to Home
V2X	Vehicle to Anything
V4ES	(electric) Vehicle for Energy Service (eV4ES)

1. About the pilot

1.1. Background

1.1.1. Local context and Energy Profile

In 2014, following a refurbishment, Leicester City Council (LCC) offices returned to their premises in Charles Street, Leicester, originally built in 1938, making City Hall (as the building is now called) its new headquarters.

The Leicester City Hall operational pilot is based on an office building already provided with roof-top Photovoltaic (PV) system. LCC runs a fleet of 800 vehicles delivering a number of services. Prior to commencement of the project LCC had 17 Ultra Low Emission Vehicles; 7 electric vans and 10 electric cars, of which 4 Nissan Leaf EVs are studied as part of this project.

1.1.2. Local partners

In cooperation with Cenex UK, a demonstration project was set up to evaluate the technical requirements and commercial benefits of V2B and V2G technology. A large council building in Leicester, its central HQ called City Hall, aims to link on site renewable energy (PV) generation to electric vehicles. Leicester City Hall based staff are utilising four electric vehicles for charging, when possible, from local PV renewable energy generation. This study deals with the use of four such EVs and their charging that takes place at the City Hall. In addition, Western Power Distribution (WPD), the local distribution network operator, is another key project stakeholder; they need to assess the grid impact due to EV charging requirements before tendering takes place for the associated equipment and integrating the energy generation/consumption. From communications between LCC and WPD, it emerges that a formal application with reference to the proposed V2B system is being made via the Energy Networks Association website. LCC’s installer seeks authority to potentially export electricity to the grid on LCC's behalf, with a letter of authority giving them permission to discuss LCC’s supply with WPD. WPD will work to provide G99 approval once the formal application is received. It appears that no WPD equipment will be required. This V2B system is a behind the meter project with no intended export to the grid.

Cenex UK advise that energy export can be avoided by steering the charging/discharging profiles from the vehicles to match the building's demand. CT clamps will provide the V2B control interface with mains import and solar generation data, which will permit the controller to work out what power to discharge to avoid any export to the grid beyond the parameters to be agreed with WPD. WPD want LCC's existing generating capacity agreement to be increased to cover both the PV and the V2B system, which they state has the potential to export.

1.1.3. Objectives and SEEV4-City KPI targets

This is a relatively small-scale operational pilot studied by the EU Interreg North Sea Region funded SEEV4-City project. It aims to demonstrate the benefit of smart (controlled) charging to better integrate renewable energy generation and EV charging in order to reduce carbon footprint, alleviate low voltage (LV) power system stress and achieve an economically feasible solution to sustainable electrical transportation and renewable energy supply. The different aspects mentioned in this report constitute the key elements of a viable/successful business model, which is essential for a wider implementation of this concept in real-life applications beyond that of a financially assisted innovation and demonstration one.

This report explores these different dimensions of the business model by making use of smart charging of electric vehicles (EVs). Four Nissan Leaf full battery electric vehicles (BEV) are used in this pilot, which is referred to as EV in the rest of this report. The SEEV4-City project uses three key performance indicators (KPIs), namely energy autonomy, CO_2 emission savings, and grid investment deferral, to measure the environmental and economic benefits achieved by providing Electric-Vehicle-for-Energy-Services (eV4ESs).

The objectives for the location system design therefore focused on using eV4ES solutions to:

1. Increase the level of Energy Autonomy as defined by the concept of energy self-sufficiency discussed hereafter;
2. Create CO_2 emission savings by substituting ICE vehicle miles by EV use, and to a degree using PV to charge the EV rather than charging from the fossil fuel rich energy mix when power is drawn from the Grid;
3. Investigate the possibility of postponing the need for grid reinforcement by minimising the system load at times of peak system demand.

The Leicester OP's SEEV4-City KPI targets as stated at the start of the project were:

KPI		***Target for OP***
A	CO_2 Reduction	2 – 5 tonnes yearly
		(sub-KPI) ZE km increase factor: 1.3
B	Energy Autonomy Increase	From 36 to 37% → Δ +1

1.1.4. Operational Pilot V2B/V2G System design

The pilot site of Leicester City Hall combines a number of components for the (eV)ES solutions. Those currently in place or in the process of being adopted are visualised in Figure 1.

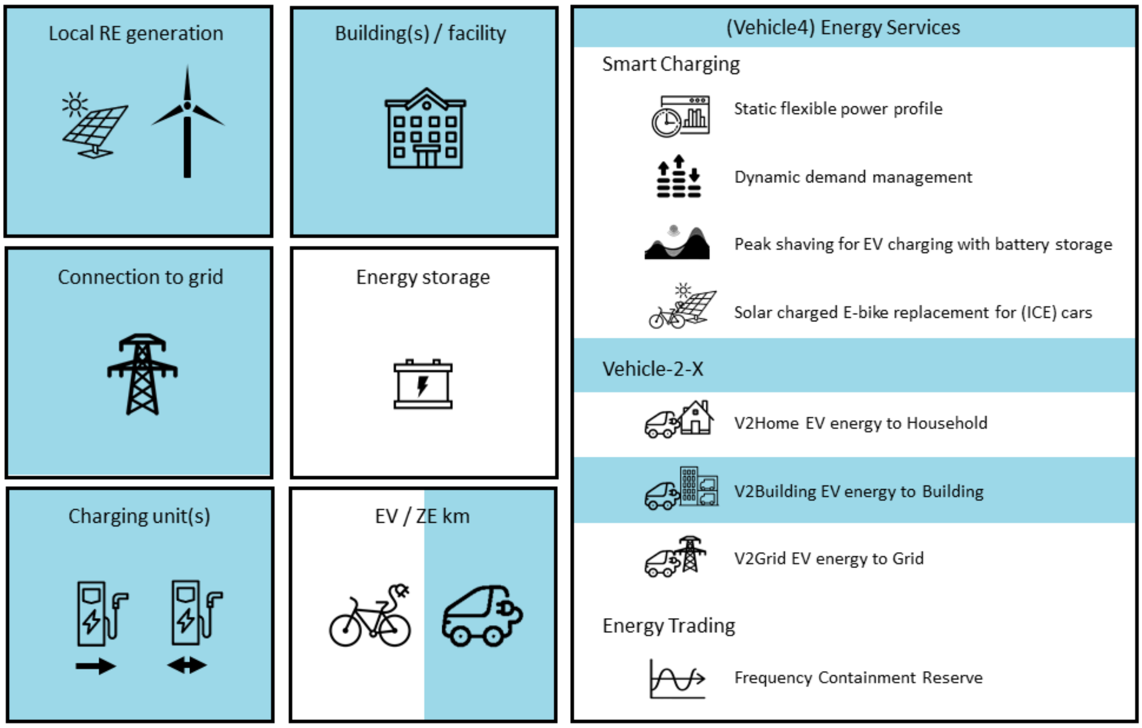

Figure 1: Pilot site overview - design components

The outline of the system is shown in Figure 2. The system under consideration comprises 4 X 7 kW EV chargers connected to the City Hall's main distribution board, with charging sockets. A 23 kWp PV system had been installed prior to the inception of this project. In the future, it is proposed to install bidirectional chargers to enable energy stored in the EVs to be used for V2B or V2G service, as required [1]. A summary of the system components is given in Table 1.

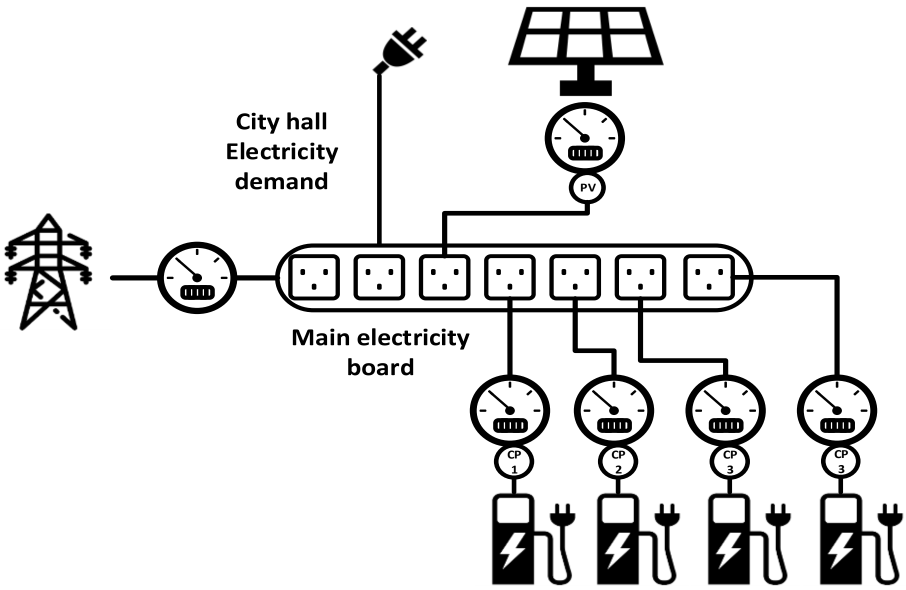

Figure 2: System schematic

Table 1: Summary of system components

Overview		Initial stage
Number of EVs	known vehicles	4
	by RIFD	4
	by charging events	4
Est. Average Annual Mileage (per EV) (km)		#7241 8111 km/year; #7242 5627 km/year; #7243 5,865 km/year; for the 4th EV mileage is not available, and hence is estimated.
No. of existing unidirectional EV Charge Points		5 x 7 kW
Size of PV/ PV generation		24 kWp (16,622 kWh/annum in 2017)
Size of Battery Storage		None
Other generation		None
Total Annual Electricity Consumption - kWh*		894,910 kWh/annum in 2018/2019
Number of smart charging points		0
Number of proposed V2B units		4
Charging protocol for proposed V2B units		CHAdeMO
V2B Charging output (variable)		7 kW maximum per unit
V2B Discharging output (variable)		10 kW maximum per unit
Plug connector		JEVS G105
Back Office Requirement		Compliant with OCPP 1.6 or above

2. Data collection and processing

2.1. Assumptions and research questions

In conducting the evaluation of the Leicester City Hall pilot business model, as defined in the SEEV4-City project specification, the following key assumptions were made:

- EV charging at the pilot location, Leicester City Hall, is regarded here as the only charging method. Charging events that may have taken place elsewhere are not considered as part of the pilot.
- The battery degradation cost used in this report is based on the empirical model that is derived from laboratory tests performed by Northumbria University on commercial EV cells. Currently this model is solely dependent on the C-rate and temperature.
- The eV4ES considered in this analysis covers both smart charging and V2B/V2G. Note that only simulation work has been conducted to verify V2B/V2G, as these services are not yet implemented at Leicester City Hall in view of the delays encountered in commissioning the requisite bi-directional EV charging equipment.
- A lifetime of 10 years is assumed for the V2B charger, and 20 years for the PV system (section 4.8).
- As per industry standards, a 2% discount rate has been used for the Net Present Value (NPV) calculation (see section 4.8).

Research Questions

In cooperation with Cenex UK, LCC proposed a demonstration project to evaluate the technical requirements and commercial benefits of Smart Charging and V2B/V2G technologies. The project is aimed at developing the cost benefit analysis of these technologies with the City local authority in Leicester, the grid and energy companies, large building owners, EV fleet operators and EV owners. A large council building in Leicester has on-site renewable energy (PV) generation and this feeds into the building power distribution system where EV chargers are connected. The possibility that a large public (or in principle this could also be a commercial) building in Leicester might utilise electric vehicles for short term energy storage from local renewable energy generation using smart charging and V2B/V2G is considered via simulation only, as real data was not available due to delay in procurement of new equipment.

2.2. Data Processing

The available data from the Leicester City Hall pilot was provided by the Planning, Development & Transportation as well as the Energy departments of Leicester City Council from their own measurements. This data set is used to derive the four parameters that will be used in the cost-benefit analyses for smart charging and V2B (described in Section 3). The four parameters are PV generation, the building's electricity base load, the EVs' driving energy consumption and EVs' availability for charging and provision of non-driving services (eV4ES). The data processing with associated assumptions is presented as follows.

2.2.1. EV usage data

Four Nissan Leaf EVs are involved in the Leicester City Hall study, namely:

- '7241', 30 kWh battery, registration number BT16 APO RFID 840ABFDA 100% charging at City Hall
- '7242', 24 kWh battery, registration number BD16 ABX RFID 040ABFDA/13BA876A 100% charging at City Hall
- '7243', 24 kWh battery, registration number BD16 AEB RFID B4E7BADA 100% charging at City Hall
- '5132', 24 kWh battery, registration number BL16 TOJ RFID 9490BCDA 100% charging at City Hall.

The first three EVs are 100% charged at Leicester City Hall, the fourth one '5132' initially had a comparatively lesser % in this regard, being mostly charged at Duke Street, away from the City Hall, but this EV is now, like the other 3, entirely charged at City Hall. Leicester City Council has confirmed that '5132' has the same charging arrangements as the other EVs; namely mostly at City Hall and occasionally at the depot, when it returns for maintenance or repairs. The council expects that the 2018/19 telemetry & charging data to show that there is not a marked difference in the way '5132' is used compared to the other 3 EVs, even though the mileage of '5132' was not directly recorded .

From the EV usage data, three parameters, namely the drive mode, the GPS position and the charging EV energy were used to determine the EV driving energy consumption and their EV availability for eV4ES within the OP boundaries set. The EVs in this pilot are used by Leicester City Hall staff for their duties, and City Hall based EV charging was considered to be the only charging method. Charging events that took place when the EV was away from this base (such as public charging, or during long trips) were not considered in this report. Therefore, an EV is assumed to be available when it is parked at the City Hall base and unavailable otherwise. When the EVs return to City Hall during their working day they can benefit from smart charging. Between 16:00 & 23:00 (DUoS Red & Amber periods) they will be available for V2B bi-directional charging. EV availability is determined by checking the telemetry data (vehicle GPS). Base location is GPS bounded in the vicinity of the City Hall. As such, EV availability is shown in Figure 3 for a typical period in 2017. In subsequent years, EV use was better established amongst staff than in 2017; so idle times should be somewhat lower.

It can be seen from Figure 3, which is based on telemetry data for March to May 2017, that the 4 EVs are idle at base for 34.5%, 41.4%, 46% and 48.2% of the time. An EV's driving energy consumption is found from the charging energy requirement for each base arrival, which depends on EV usage. The charging energy input is recorded, and this may be compared with miles driven to enable calculation of CO_2 savings when compared to driving a normal ICE - powered comparative vehicle.

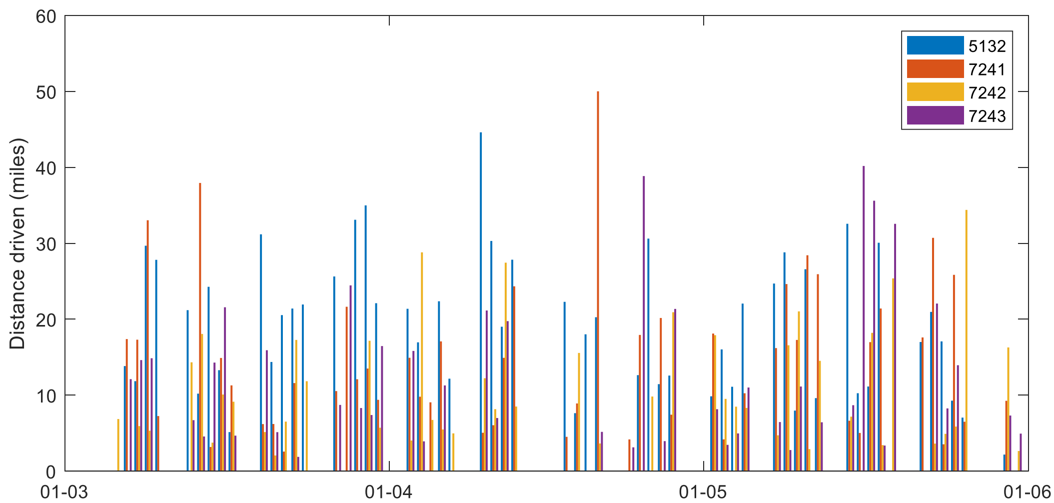

Figure 3: EV usage data March to May 2017

In Figure 4, the charging profile for the four EVs is shown, superimposed onto the PV output for the period from the 6th to the 12th of March 2017. It can be seen that, generally speaking, the EVs are arranged to charge in a 'smart' way when PV output is available. The EVs do not charge during the hours of darkness so it may be anticipated that some PV energy will be available for charging. EVs may or may not charge at the same time; even the power taken by a single 7 kW charger will often exceed the available PV output. In this situation grid power must be used to make up the shortfall in charging power. If variable power chargers were available, more of the PV energy could be used for charging if a lower power setting for a longer period was used. A discussion of the possibilities offered by Smart Charging is provided in section 4.9 below.

2.2.2. Leicester City Hall energy data

Figure 2 depicts the power flow within the pilot. Power consumption for the City Hall is monitored, as is PV generation and EV charging data is measured separately. The City Hall baseload profile (including the EVs' charging) and PV generation profile are shown in Figure 4.

In Figure 5, the electrical load of the office building is shown, together with the recorded PV output, for the period March to June 2018. Prior to March 2018 the PV data was only recorded monthly, and so cannot be used in this analysis for comparison purposes. The PV output figures are probably subject to inaccurate measurement according to LCC. The Baseload includes the EV charging. As may be seen, the PV output never approaches the minimum building demand, so there will be no possibility of PV energy export, and all of the PV production is consumed within the building, thus reducing the import of power flow from the Grid. It was thought worthwhile to consider the PV generation as comprising a 'virtual carport' in which it is assumed that PV output is preferentially used to charge the available four EVs. In fact no such physical carport exists but the electrical measurements can reveal the performance of an actual carport with the EV charging fed directly from the PV output, rather than flowing through the City Hall distribution system. In this way one may obtain information which can inform a possible further development of the upcoming V2B installation at City Hall, (which does not include prioritising PV for EVs) or EV4ES schemes elsewhere in Leicester.

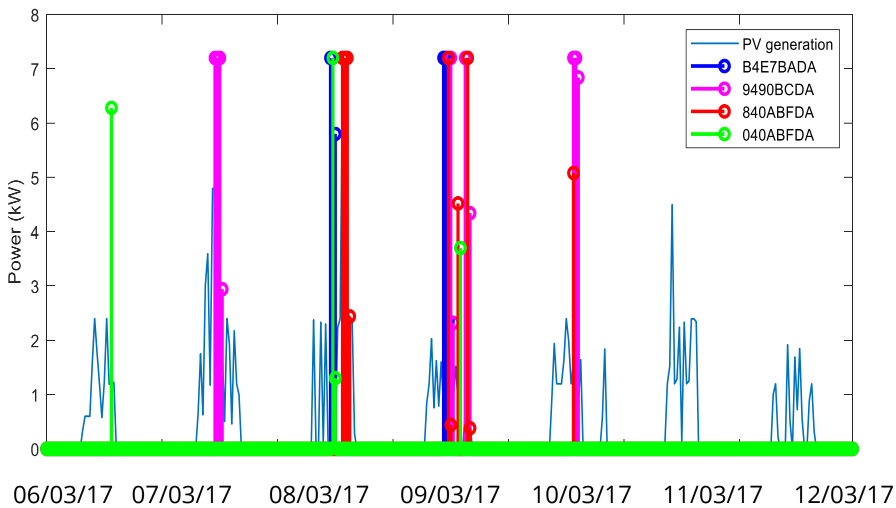

Figure 4: EV charging profile and PV output 06/03/2017 to 12/03/2017

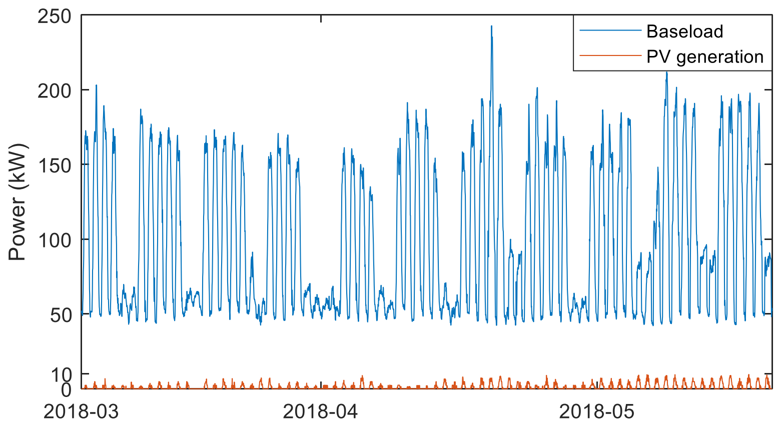

Figure 5: Electricity demand & PV data for the period March to May 2018

Table 2 gives a description of the available energy flow data to be used in this report.

In addition, driving telemetry data is recorded, as shown in Table 3. Unfortunately changes in battery SoC were not recorded, but the overall energy consumption may be gleaned from the charging data. The proposed new V2B control interface will be specified to gauge the battery SoC.

Table 2: Energy flow variable list

	Name in the database	Interpretation	Data source
1	Grid to Building kWh	Half hourly figures	Recorded
2	PV Output kWh	Half hourly figures	Recorded
3	Charging connector	Socket type used	Recorded
4	Charging start time and date	Time and date	Recorded
5	Charging end time and date	Time and date	Recorded
6	Charging duration	Time in hours	Recorded
7	RFID number	Number of card used for charge	Recorded
8	Energy	Amount of charge in kWh	Recorded

Table 3: Traffilog telemetry data recorded

	Name in the database	Interpretation	Data source
1	Vehicle number	Vehicle ID code	Recorded
2	Vehicle group	Driver ID	Recorded
3	Start drive	Time and date	Recorded
4	Start location	Address	Recorded
5	End drive	Time and date	Recorded
6	End location	Address	Recorded
7	Distance	Miles	Recorded
8	Drive time	Journey time	Recorded

As an example, Figure 6 shows the charging profile in kWh per charge for RFID 13BA876A which represents EV '7242' 24 kWh Leaf EV registration number BD16 ABX for the period 13th March 2019 to 29th March 2019. Figure 7 shows the duration of connection time for the same EV over the same period. It is evident that some connections are for a very long period, well in excess of that required to charge the EV. 15th and 29th March 2019 were both Fridays, so it would appear that the very long connection times represent leaving the EV connected over the weekend. There would be scope for increasing energy autonomy and green EV charging by enabling the charging function over the weekends when the EVs are not being utilised. At present all EVs are fully charged by mid/late evening, but they are not required until 7 a.m. at the very earliest the following day. With the proposed V2B scheme as designed, after discharging to the City Hall onwards from 11 p.m. the EVs will be able to recharge from the mains on the Council's cheaper overnight rate. There may be scope here to use the smart functionality of the chargers to achieve some battery management good practice. Thus the EVs could be brought up to 50% SoC by the early hours and held here until 4 a.m. or 5 a.m. when the remainder of the charging could be completed. Normally the EVs are only used in weekday office hours and not at weekends. Thus at weekends at Bank Holidays charging would either be split between the night of the last working day and the night of the next working day, or fully take place during the latter. Normally the EVs are only used in weekday office hours and not at weekends. Thus at weekends at Bank Holidays charging would either be split between the night of the last working day and the night of the next working day, or fully take place during the latter. However, if the battery management approach is taken there will be little or no opportunity for EV charging to benefit from weekend solar generation. To date, no batteries on any of the Leicester City Councils' EVs (mostly purchased in 2016) have needed replacing.

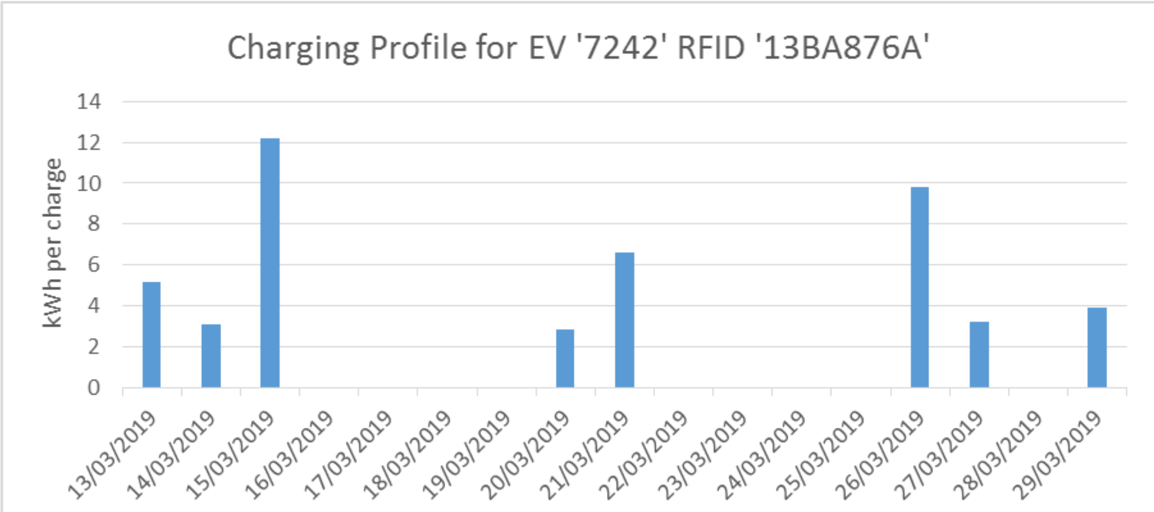

Figure 6: Charging profile in kWh for EV '7242'

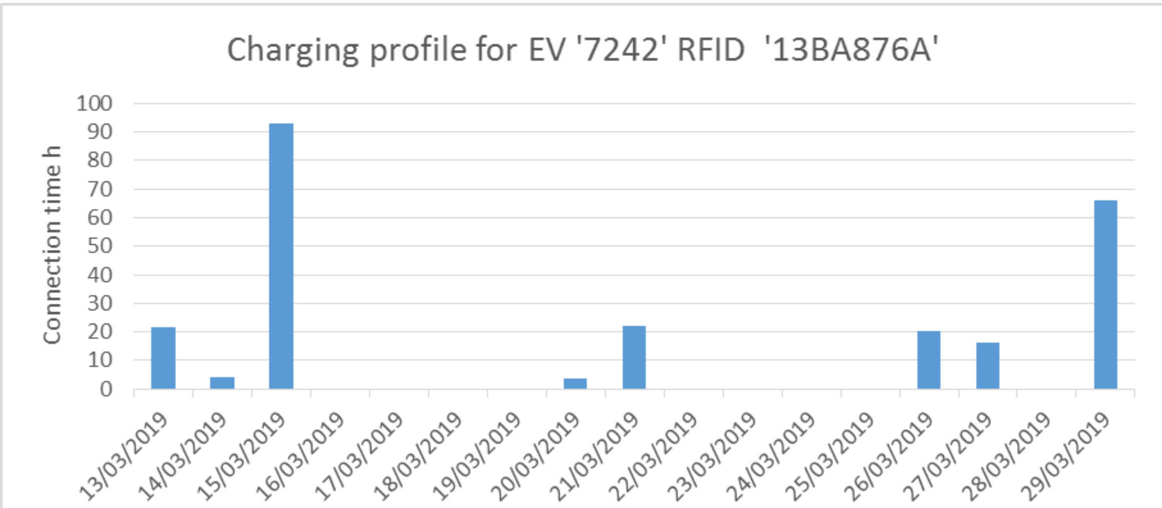

Figure 7: Charging profile connection time in hours for EV '7242'

2.2.3. Yearly data selection

The aforementioned parameters, PV generation, base load, EV driving consumption and EV availability, have all been prepared in the format of a 30-minute resolution and were used in the cost-benefit analysis of (smart charging) presented in Section 4.

Calendar Year 2017 was initially selected to carry out the yearly analysis. However, the period between the 5th March 2018 to 31st March 2019 was subsequently chosen since before the 5th March 2018, when the PV was connected to the Automatic Meter Reading system (AMR), data was recorded manually on a monthly basis from a panel on the front of the inverter, and thus is not available for processing on a 30-minute resolution basis.

3. SEEV4-City Results – KPIs

3.1. Methodology

Each of the SEEV4-City pilots adopt different system components and have their own approach within its system boundaries. They do not all use the same combination of components but are applied in different combinations and variations. The SEEV4-City project recognised the potential value in identifying the benefits of individual energy system components (such as PV, BESS and EV battery as storage) for design decisions for a specific location in relation to the project's main KPIs, for CO_2 and Energy Autonomy in particular.

CO_2 emissions savings consist of ICE substitution (by EV), where the different lifecycle emissions of ICE and EV have been considered, as well as those achieved via energy autonomy (section 3.3.1).

Energy autonomy for this pilot is defined as 'self-sufficiency' (see section 0).

These are then translated into percentage values of improvement for the associated component savings. The project has therefore chosen to define several sub-indicators for KPIs for the purpose of capturing potential additional insights in relation to CO_2 (KPI A) and Energy Autonomy (KPI B) objectives and the role these different components may play. The methodology for calculating their contributions is described in more detail in the project's KPI Baseline and Methodology Report. The identified sub-indicators within the methodology are:

KPI A – CO_2 reduction

- CO_2 related to baseline demand
- CO_2 related to use of battery: EV
- CO_2 related to use of battery: BSS
- CO_2 savings by PV production
- Zero Emission kilometres increase

KPI B – Energy Autonomy

- Self-consumption
- PV to Baseline Demand
- PV to EV
- PV to BSS
- PV to Grid

For **KPI C – Grid Investment Deferral**, the methodology does not narrow itself to the specific pilot site only, but instead looks at the impact potential of the chosen eV4ES solution of the location's system design within the regional grid context (where the pilot is based).

Relevant results for the combinations used at Leicester City Hall are highlighted in section 3.3 of this report.

3.2. Baseline and Final measurements

3.2.1. Component data requirements

Data requirements are specified in Table 4.

Table 4: Data Requirements

Leicester City Hall - Data	
KPI A	
Relevant components	***Data (sets) required***
Grid to Building kWh	Half hourly figures
PV Output kWh	Half hourly figures
Charging start time and date	Time and date
Charging end time and date	Time and date
Charging duration	Time in hours
RFID number	Number of card used for charge
Energy	Amount of charge in kWh
Vehicle number	Vehicle ID code
Vehicle group	Driver ID
Start drive	Time and date
Start location	Address
End drive	Time and date
End location	Address
Distance	Miles
Drive time	Journey time
KPI B	
Relevant components	***Data (sets) required***
Grid to Building kWh	Half hourly figures
PV Output kWh	Half hourly figures
Charging connector	Socket type used
Charging start time and date	Time and date
Charging end time and date	Time and date
Charging duration	Time in hours
RFID number	Number of card used for charge
Energy	Amount of charge in kWh
KPI C	
Relevant components	***Data (sets) required***
System Electrical Diagram	

3.2.2. Baseline and Final measurements

Baseline and Final measurements are summarised in Table 5, Table 6 and Table 7.

Table 5: Baseline and Final measurements relating to annual CO_2 reduction

	Initial stage (a)	End of Project (b)	
	Value	**Value**	**Improvement Compared to (a)**
Pilot CO_2 footprint	252.1 tonnes	249 tonnes	3.1 tonnes
CO_2 related to baseline demand	257 tonnes	257 tonnes	0 tonnes
CO_2 related to use of battery: EV	0	-4.09 tonnes	4.09 tonnes
CO_2 related to use of battery: BESS	N/A	N/A	N/A
CO_2 savings by PV production	4.9 tonnes	4.9 tonnes	0 tonnes
ZE km increase	0 km	26793.66 km	26793.66 km
Battery as back-up services (replacement of diesel generators)	N/A	N/A	N/A

Table 6: Baseline and Final measurements relating to Energy Autonomy

		Initial stage (a)	End of Project (b)	
		Value	**Value**	**Improvement Compared to (a)**
	B. Energy Autonomy Increase			
B.1	Self Sufficiency	2%	2%	0%
B.2	PV to Baseline Demand	2%	2%	0%
B.3	PV to EV	0	1310.5 kWh	1310.5 kWh
B.6	'Virtual Carport'	0	41% EA	41% EA

Table 7: Baseline and Final measurements relating to Grid Investment Deferral

		Initial stage (a)	End of Project (b)	
		Value	**Value**	**Compared to (a)**
	C. Grid Investment Deferral			
C.1	Peak Demand Value	250 kW	254 kW	4 kW

From Table 7 it is clear to see that there is no Grid investment deferral. The only factors changed under the OP were the addition of EV charging and EV use. The amount of charging was small in comparison with the total City Hall load, and even if bi-directional chargers were used to enable V2B, the effect would be small. In 2017 the City Hall maximum peak demand (250 kW) was experienced on 19th of June 2017 between 10 a.m. and noon. In 2018 the peak demand (254 kW) was experienced at 2 p.m. on the 27th of June 2017. An additional point to note is that even when V2B operation is established, the times of peak City Hall load occurred when the EVs are in use, so in the absence of a BESS system there is no available improvement in this KPI.

3.3. *KPI results*

3.3.1. CO_2 Reduction or Savings

The CO_2 emission savings for the Leicester City Hall operational pilot were calculated from the following two parts:

- Savings due to ICE substitution;
- Savings due to smart energy management.

The first part considers the difference between the CO_2 emissions in the lifecycles of ICEs and EVs, covering all stages of manufacturing, operation, maintenance and decommissioning. During each of these stages, a certain amount of CO_2 is emitted. To allow a fair comparison, the whole lifecycle for both types of vehicles must be taken into account. It is worth noting that within the scope of SEEV4-City project, the operation of the vehicle is the only controllable part; the other three parts are driven by technology advancement and penetration level of the technology. Consequently, in this project, the savings in CO_2 emission due to the operation of the electric vehicle must at least compensate for the inherent CO_2 emission penalty due to manufacturing, maintenance and decommissioning, the sum of which for ICE vehicles are significantly less than those for EVs, as shown in Figure 8 [2].

Based on 2010 data shown in Figure 8 [2], CO_2 emissions due to the manufacturing, maintenance and decommissioning phases for EVs (totalling 65.28 g/km) are almost double those for ICE vehicles (34.45 g/km). This is due to the considerable CO_2 emission in the manufacturing of the EV battery. It is worth pointing out that with the continuous advancement in both manufacturing processes, where some Original Equipment Manufacturers and Electric Vehicle producers are focusing on reducing the CO_2 footprint (including with some using renewable energy during the manufacturing process), as well as battery technology and the utilization of automotive batteries in second life applications, these figures have already and will significantly further improve in the future in favour of EVs [2]. In fact, predictions suggest a CO_2 emission value of 15.53 g/km for EVs in 2050, excluding the operation of the vehicles [2]. In the case of second life battery usage, the overall CO_2 emitted from the aforementioned three phases is distributed over a longer period and therefore the emission per km (or kWh) can be reduced further.

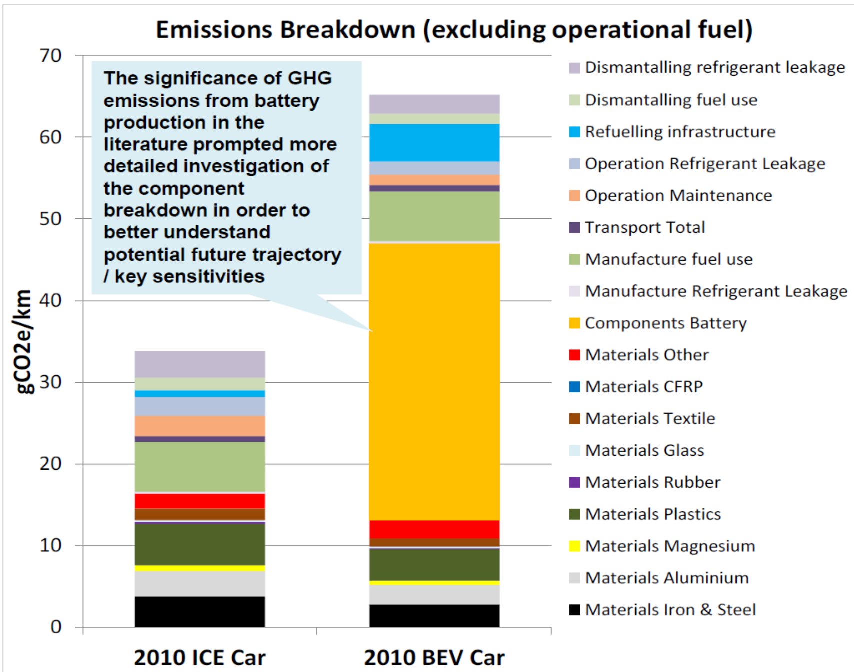

Figure 8: 2010 CO_2 emission for ICE and EV for manufacturing, maintenance and decommissioning [2]

A 2019 study [3] found that a diesel car will have 217 gCO_2/km direct emissions (combustion of diesel) and 27 gCO2/km indirect emissions (manufacturing). By contrast, a battery electric vehicle (BEV) has a total of 95 gCO_2/km emissions, of which 55 gCO_2/km relate to the emissions typically associated with generating the electricity used to propel the EV, 40 gCO_2/km are associated with the manufacture of the BEV and 16 gCO_2/km are recovered when the battery is recycled. For the purposes of the SEEV4-City project these more recent Hoekstra figures are used. Figure 9 shows a comparison taken from [3]. In practice the actual BEV CO_2 emissions will depend upon the relevant generation mix and the efficiency of the actual BEV being considered. In this study we are provided with the BEV distance travelled and the energy consumed, so the BEV efficiency may be directly calculated.

	Buchal et al.[5]	Hoekstra et al.[9]	Renewable Future
Diesel Car Total	170	244	153
Driving	143	217	150
Manufacturing	27	27	3
BEV Total	189–214	95	10
Driving	73	55	6
Manufacturing	100–125	40	4
(Battery)	(73–98)	(16)	(2)

Figure 9: 2019 CO_2 emission due to the operation of ICE and BEV [3]

The energy mix used for EV charging changes during the day, week and the season, and hence the CO_2 emissions will accordingly change. Therefore, there are periods of low marginal gCO_2/kWh, which usually occur during off-peak periods (when low-carbon power plants are operated), as opposed to periods with high marginal gCO_2/kWh, which usually happen during peak times (when CO_2 intensive power plants are deployed). An example of this is given in Figure 10 which shows the daily CO_2 emissions per kWh based on the UK's national energy mix for 09/11/2017 (winter day) [4].

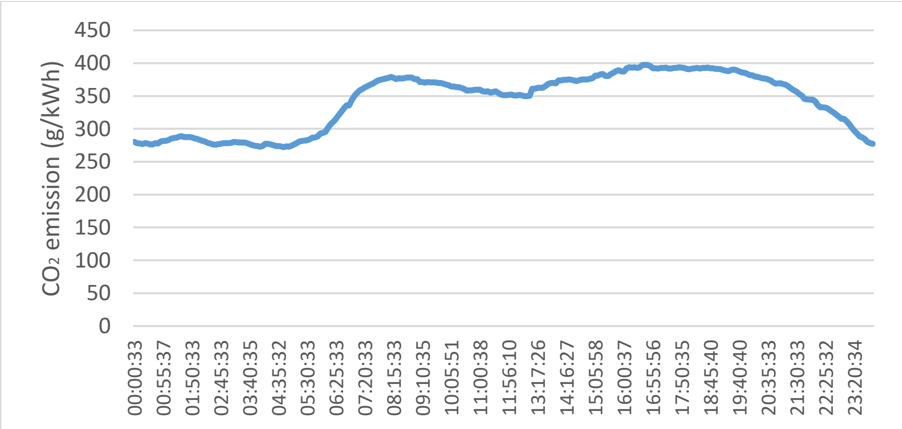

Figure 10: Energy mix based CO_2 emission for the UK on 09/11/2017 [4]

The energy mix based on the CO_2 emission figures are obtained considering the lifetime CO_2 emissions values for the various generation types which are listed in Table 8. This demonstrate that the equivalent CO_2 emission per kWh imported from the grid varies significantly, depending on the generation mix at any specific time. Therefore, CO_2 emissions caused by EV operation can in principle be reduced by implementing smart energy management and smart charging of EVs. Scheduling EV charging to occur during off-peak periods with low-carbon generation and local PV generation will reduce overall CO_2 emissions, maximize the energy autonomy and at the same time smooth the overall grid demand profile. However, since all of the locally generated PV energy was consumed within the City Hall at all relevant times, overall the EVs must be considered as being charged solely from Grid energy. Over a year it is found that ICE substitution by the 4 Leaf EVs yields a net saving of 4.09 tonnes, as demonstrated in Table 9.

At the commencement of the OP, annual EV charging at City Hall totalled 2,995.89 kWh corresponding to annual ZE km of 25,111.5 at the calculated efficiency of 8.382 km/kWh. Therefore, ZE km improvement factor over the project is an increase by 1.07x.

Table 8: Lifetime CO_2 emission for different generation types [4]

Generation type	Lifetime CO_2 emission [g/kWh]
Wind	11
Nuclear	16
Hydro	20
PV	40
CCGT	487
OCGT	487
Oil	650
Coal	870

Table 9: Calculation of CO_2 savings per year from ICE substitution

ICE to BEV replacement	Value	Unit
Diesel Car Fuel emissions	217	g CO2/km
Diesel Manufacturing emissions	27	g CO2/km
Total Diesel emissions	244	g CO2/km
2019 measured kWh charged	3196.24	kWh
Km driven with charged kWh (est)	26793.66	km
Measured EV energy use (Nissan Leaf**)**	8.38	km/kWh
UK average generation emissions	0.281715	kgCO2/kWh
EV driving emissions	33.6	g CO2/km
EV manufacturing emissions	40	g CO2/km
Saving if EV batteries fully recycled	16	g CO2/km
Net EV manufacturing emissions	24	g CO2/km
Saving if EV **batteries fully recycled**	16	g CO2/km
Net EV manufacturing emissions	24	g CO2/km
Total EV emissions	57.6	g CO2/km
ICE to BEV **savings**	186.39396	g CO2/km
Annual CO2 savings from ICE substitution	5	tons/year
CO2 from generation	0.9	tons/year

Before the commencement of the OP, all of the generated PV energy was consumed within the City Hall. This remained the case during the OP so the additional energy used to charge the EVs was effectively all imported from the Grid.

3.3.2. Energy Autonomy increase

Within the scope of SEEV4-City project, the energy autonomy is defined (in line with established literature [5]) as energy self-sufficiency as expressed by equation (1) [6] and is illustrated in Figure 11. In the case where PV is the only local production source, the energy storage (stationary or electric vehicle) is used to store excess generation from the PV and supply this during the peak demand later in the day (see **ES+** and **ES-** in Figure 11). The difference between an EV and a stationary battery (apart from the potential size difference) lies mainly with the fact that an EV (essentially used as a transportation vehicle) presents constraints of availability and the associated SoC requirement before journeys.

$$Energy\ Autonomy = \frac{Amount\ of\ local\ PV\ production\ consumed}{Total\ energy\ consumed} = \frac{C + ES^{+}}{A + C} \quad (1)$$

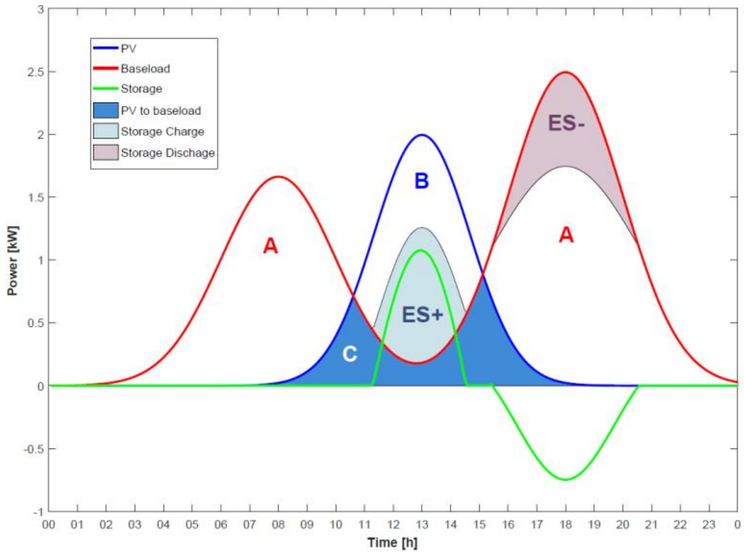

Figure 11: Illustration of energy autonomy

3.3.3. Grid Investment Deferral

Due to the small scale of the Leicester City Hall pilot in terms of PV generation, 23 kWp, its output is insignificant when compared with the measured Grid loading of the entire City Hall, which tends to peak at some 200 kW. Similarly, there are four EVs which may be charged at 7 kW, again small in comparison with the City Hall's baseload. Accordingly, the degree to which these affect Grid investment deferral is not significant. The City Hall has insufficient roof area to install a significant additional amount of PV generation, and thus the renewables output will remain small, preventing significant reductions in peak Grid demand and hence the need for Grid reinforcement.

3.3.4. EV transportation and charging patters

Due to the inherent variability of the use patterns of EV for transportation and their EV charging, modelling of EV utilization patterns has been investigated. Although this issue has been widely discussed in the literature, but there is still a lack of studies on the impact of different transportation usage patterns on the optimal operation of EVs for Vehicle for Energy Services. The transportation and EV charging patterns recorded here have been modelled using advanced hierarchical clustering and K-means clustering methods to provide insight into the hidden issues in EV operation. Extensive scenario analysis is performed with a variety of penetration rates and varied EVs to provide advice on the present and future optimal operation of EVs for both transportation functions (the primary use function that has to be satisfied first here for council staff) and the remaining potential for Vehicle for Energy Services (such as Vehicle-to-Building and Vehicle-to-Grid).

4. Cost-Benefit Analysis

4.1. Generic Business Model

A cost-benefit analysis is the core of any business model and, in the context of the SEEV4-City project, this must be conducted for each eV4ES service to evaluate the profitability of the required investment. The structure of a generic business model for eV4ES is presented in Figure 13. According to the business model actually adopted (baseline or the proposed one), there will be different stakeholders involved as well as different costs or benefits for each stakeholder.

The user (City Hall) entities consist of the base load, PV, EV charger and the EVs under consideration here. All of these are linked to the power grid (distribution and transmission) and the direction of energy flow is as indicated in Figure 13 (black coloured arrows). Currently, the contract is signed between the user and electricity retailer, which then links with the energy market (marked in green colour). In the future, when V2B or V2G is carried out, and possibly energy storage in a stationary battery also takes place, more stakeholders will be involved in eV4ES and these are coloured in red in Figure 13, where the blocks indicate a commercial entity and the red dashed arrows show the associated ICT connections.

The aggregator shown in Figure 13 is the contractor/coordinator of EV energy; this role is currently not present in the actual Leicester City Hall operational pilot, as the V2G function is technically unavailable until the necessary hardware is installed and commissioned. The energy retailer in this case is responsible for settling the transactions for base load with the user. The mobility retailer (for leased vehicles, for instance) and the infrastructure provider are included in the structure and the OEM of EV is also included in the value chain. Finally, policies of energy, transportation and environment can have direct or indirect impact on the EV energy scheduling scenarios; however, since V2G still lies in the future these were not considered in the business model.

It should be noted that the services provided by different stakeholders could be fully or partially combined to achieve certain objectives for the stakeholders. In the Leicester City context it would be advantageous for a number of participants in the city to amalgamate their resources such as energy storage and PV to produce a sufficient level of output to enable participation in services such as Firm Frequency Response (FFR), which require a minimum power output as a pre-condition.

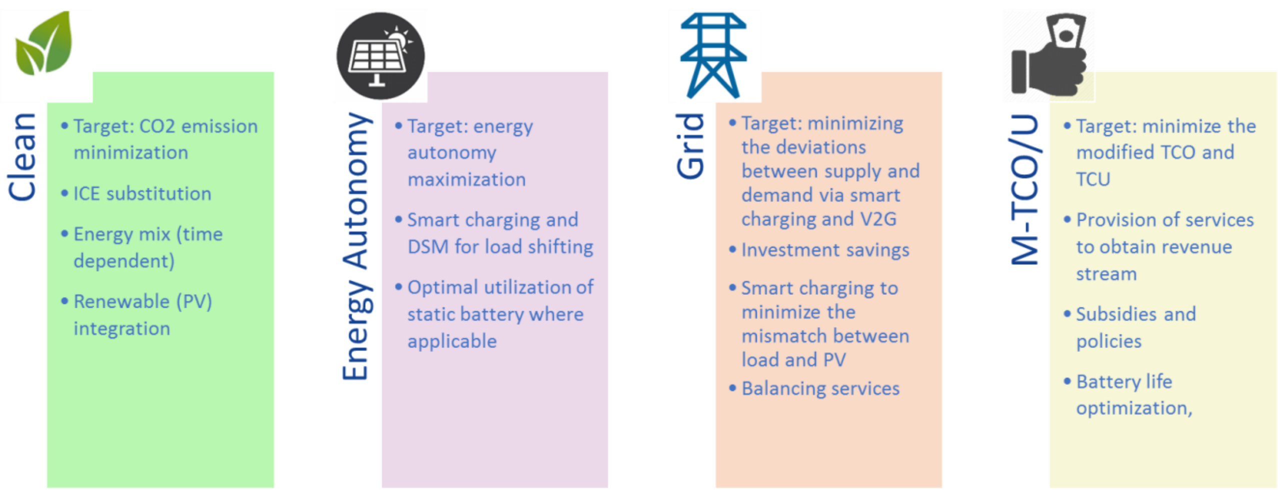

Figure 12: Business model pillars

eV4ES and the associated business model can be tailored to favour different targets, following the reasoning illustrated in the 4 pillars shown in Figure 12. Currently, the priority objective of the Leicester City Hall pilot is the maximization of energy autonomy (Pillar 2) as well as the promotion of Green Miles (Pillar 1). As such, the stakeholders involved in the baseline case include the EV, the EV charger and the retailer that is responsible for the billing of the energy consumption. V2G operation is not currently implemented in this specific pilot. Leicester City Council pays for certified renewable energy as its mains supply.

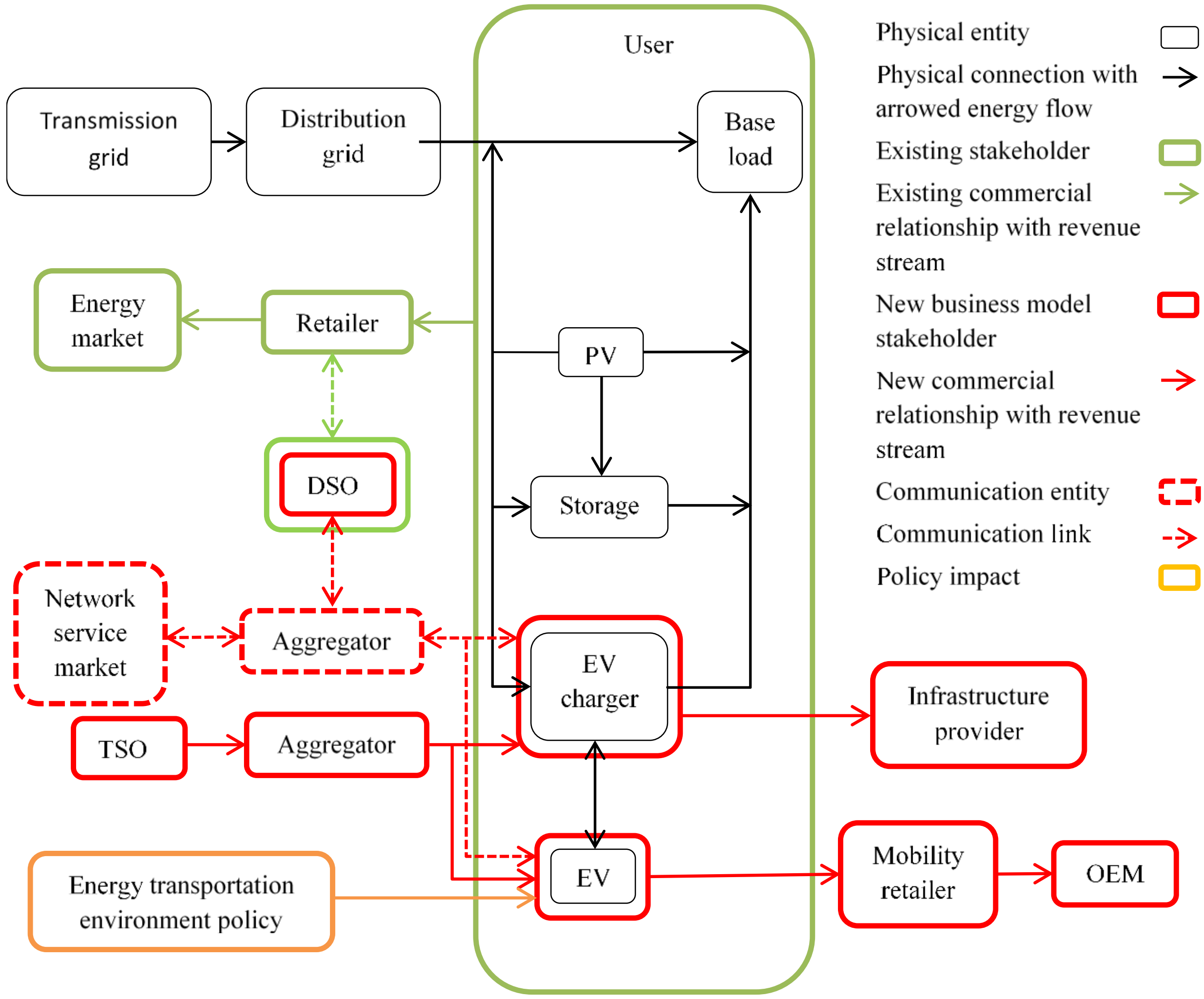

Figure 13: Generic business model structure for eV4ES

4.2. Specific Business Model

The Leicester operational pilot consists of a five-storey office (council headquarters) building with a roof-top PV installation, four EVs and in the future associated V2G chargers, aiming to demonstrate controlled and bi-directional charging at an office location, i.e. V2B/V2G, to increase energy autonomy and also the share of clean km driven.

Table 10 lists the stakeholders that are involved in the pilot operation. The main stakeholder, Leicester City Council, owns all the non-grid side assets - although some are still under procurement. The pilot intends to maximise the use of PV energy to power the EVs, and so seeks to maximise the amount of ultra-low km powered by local renewable generation, i.e. a virtual solar carport. To this end, the energy management system (EMS, still under procurement) will need to be programmed to permit PV generation to be prioritised in the following order:

1) EVs charging – when solar generation and EV demand coincide;
2) Charging of the stationary battery storage – to be confirmed if this will be procured;
3) Supply Leicester City Hall building demand;

4) Support the Grid – to gain revenue from Feed-in Tariff or firm frequency regulation (although this is unlikely to happen due to the small scale of PV installation compared to the building consumption).

In addition, Western Power Distribution (WPD), the local distribution network operator, is another key project stakeholder; they need to assess the grid impact due to EV charging requirement before tendering for the associated equipment and integrating the energy generation/consumption.

Table 10: Stakeholders involved in the Leicester City Hall operational pilot

Roles	Stakeholders
Building owner, EV owner, PV owner, smart/V2G owner, stationary battery (TBC) owner	Leicester City Council
Smart/V2G charger provider	Under procurement
Energy management system provider/operator	Under procurement
Distribution network operator	Western Power Distribution (WPD)

Current (derived) business model

The business model structure that depicts the direction of flows of energy and communication signals, as well as the associated commercial relationships between the abovementioned stakeholders, are derived for the Leicester pilot and are illustrated in Figure 14.

It can be seen that the EMS is at the core for communication and control with different components in the Leicester pilot, such as the power flow from the PV to the EVs and the building as part of the solar carport as descripted above. Additionally, the EMS also controls the EV-charging profile by responding to the dynamic price from the utility, in order to minimise the charging cost. There is a balance to be struck between minimising charging costs and maximising the amount of charge, when an EV returns to City Hall during a working day.

Proposed business model

As mentioned earlier, the V2G chargers have not yet been procured or installed, so no data is yet available. When the V2G chargers will be in place with their function activated, the EVs could start to potentially bring in extra revenue by network services provision (especially during nights and weekends when the EV are mostly available), where the EMS plays the role of the aggregator to enter the balancing market. This is the extra value proposition in the proposed business model, which is presented accordingly in Figure 14 by dashed lines. The Leicester City Hall V2B specification Includes the estimated annual generation from the four project EVs discharging which is estimated to amount to some 15,000 kWh. Cenex UK think that this estimate is valid. As per the current V2B design this amount represents a potential cost saving for City Hall as it can replace peak period energy drawn from the mains. With a V2G system it might even prove profitable to sell this amount for network services.

In addition, it is noted that a BESS is not considered in the derived business model since it has been decided by Leicester that a BESS will not be part of the pilot installation. Another value proposition, in case the additional BESS is installed later on – i.e. the proposed business model – would be the further savings in electricity bill via energy arbitrage, which would in turn recover over time the return on the associated investment. Stationary battery storage of c. 30 kWh size was originally considered for the Leicester OP; fed from the PV to assist day time top-up charging & the principal overnight recharge. It was considered that the installation would not provide value for money given the small size and the electrical losses with the PV located on the 5th floor and the potential stationary battery storage location adjacent to the EVs, although no calculations have been carried out to demonstrate this. Leicester City Council made their decision entirely in the context of developing a V2B system, with no intended export to grid.

If ever the Council moved to V2G at City Hall or went for V2G at other locations, an added value proposition could arise based on selling on BESS stored solar energy to the grid at peak energy times. Such a BESS would need to be of a large enough size to make money despite the energy losses and battery degradation involved. Calculations would need to be done to identify the size of BESS that would be economical to work with the current V2B design.

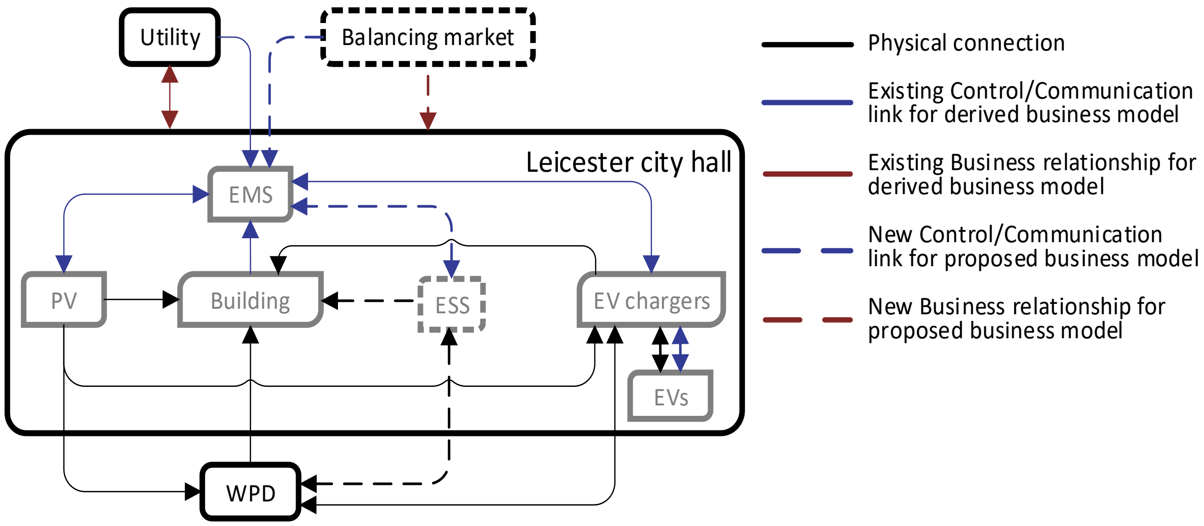

Figure 14: Business model structure for the Leicester City Hall operational pilot

The derived and proposed business models for the Leicester operational pilot are shown in Table 11, focusing on the aim of a solar carport and the recovery of investment.

Table 11: Business model for the Leicester City Hall operational pilot

Key potential activities	**1) Solar carport** **2) Smart charging** **3) Network service provision (nights and weekends)**
Value proposition	1) Electricity bill saving due to PV self-consumption 2) Reduced charging cost due to PV self-consumption and smart charging 3) Revenue from network service provision 4) Clean km driven
Cost structure	1) Leicester City Council: smart/V2G EV chargers
Revenue stream	1) Leicester City Council: network service provision, electricity bill savings, charging cost savings

The economic feasibility of the proposed business model (with associated eV4ES) was compared with a baseline case which reflects the current status of the operational pilot. The baseline case was derived from the records in the databases, as explained in section 2, where smart charging has been implemented. The analysis demonstrates the improvements the proposed business model for eV4ES might bring in to the baseline case in terms of the KPIs, i.e. improved energy autonomy, CO_2 emissions reduction, grid investment deferral, and overall improved economics. The setting of the baseline case is defined in Table 12.

Table 12: Baseline setting for the Leicester City Hall pilot

Variable	Value	Unit
PV system	23	kWp
Vehicle battery capacity	24/30	kWh
Original charging unit converter size	7.4	kW (fixed)
Proposed V2B charger size	7 (charge) 10 (discharge)	kW (variable)
Electricity standing charge	173.064	p/day
Electricity tariff price (day)	14.5042	p/kWh
Electricity tariff price (night)	12.0202	p/kWh
Capacity Charge	1.05	£/kVA
Battery Degradation Cost 0.29C	5.9	p/kWh throughput

In terms of the renewable supporting scheme, the Leicester City Hall pilot does not benefit from the UK's Feed in Tariff (FiT) since it is not registered with it.

4.3. EV battery degradation cost

Both EV and stationary batteries are expensive assets (albeit decreasing in price over time over the past decade at least and likely to do so further), and therefore need to be utilized in the most efficient way to preserve their State of Health. Previous work suggested that extra degradation can be caused by providing V2B/V2G [7]. As such, battery degradation is investigated in this section, and this is included in the eV4ES business model.

Battery capacity reduction (fading) always occurs regardless whether the battery is exercised (cycle loss) or not (calendar loss) [7]. Calendar degradation occurs even when a battery is not used, and it is a function of the time of storage, the average SoC and the temperature during storage. Storage at a low temperature in the absence of energy exchange is favourable, as is storage at a low SoC, since both these factors represent stress factors (electrical and thermal), which promote degradation [8]. When the battery is used to provide energy services, energy is stored (charging) in the battery or supplied (discharging) and the battery is cycled at a certain charge/discharge rate. Performing a cycle at a high charge/discharge rate has a more adverse impact than performing a cycle at a low charge rate [8]. Both calendar and cycle degradation affect the available capacity of the battery.

The charge rate is usually normalised with respect to the battery's full capacity, which is known as the C-rate. For example, a nC rate means that the battery can be fully charged or discharged in 1/n hours at this current level. Thus, 1C represents the current to charge the battery from zero to full in 1 hour. This normalisation helps to present the charging speed directly without considering the specific battery capacity. The current V2B specification is for variable charging output of 7 kW maximum and variable discharging output of 10 kW maximum. These rates represent less than C/2 for a 24 kWh Nissan Leaf battery, and will count as relatively low C rates.

In the automotive industry standard practice, an EV battery reaches the end of its useful automotive life when its maximum capacity falls below 80% of its nominal capacity when the battery was new. In this case, the battery needs to be replaced, and may perhaps be used to provide stationary storage (as a second-life application).

The research work carried out at Northumbria University has evaluated the effects of different factors that contribute to battery degradation. Commercial battery cells are stored and cycled under different conditions and their lifetime is measured in terms of number of cycles before reaching end of life (20% of capacity degradation).

In the context of the SEEV4-City project, the C-rate, one of the factors which determines the energy throughput, has been selected as the main stress factor along with temperature for the following analysis of V2G. If the temperature and average SoC are kept reasonably constant, then the main determinant of battery wear is the charge rate. The current V2B specification is for discharging down to minimum of 20% SoC. This represents a realistic minimum to avoid excessive battery degradation.

The battery degradation model is:

$$C(Wh) = C_0 - a^c Wh \qquad (2)$$

Where $a^c = -2.54 \times 10^{-8} \times (4.98 T^b - 94.33) \times (42.02 \times (mean\ SoC) + 39.26) \times (1.29 \times C^r + 0.61)$

C^r is the charge rate, and

T^b is the ambient temperature.

For SEEV4-City analysis, cells are tested using the experimental setting given in Table 13, where 2016 Nissan Leaf 32.5 Ah LiNiMnCoO2 EV pouch cells are cycled at 0.3C and 1C. It is known that, for Li-ion cells of a given type, the degree of battery degradation per cycle is proportional to the C rate [9] [10]. The experimental results enabled the production of a graph of cycling degradation vs charging rate. For these tests, a full cycle means a discharge at a certain depth of discharge (DoD), followed by a charge at the same DoD, so the average SoC remains constant.

Table 13: Experimental setting for battery testing

C-rate	Temperature (°C)	DoD(%)	Battery type
0.3 C	25	80	EV pouch 33 Ah chemistry LiNiMnCoO2
1 C			

The test results are illustrated in Figure 15, where the capacity degradation is plotted against the number of cycles under different C-rates.

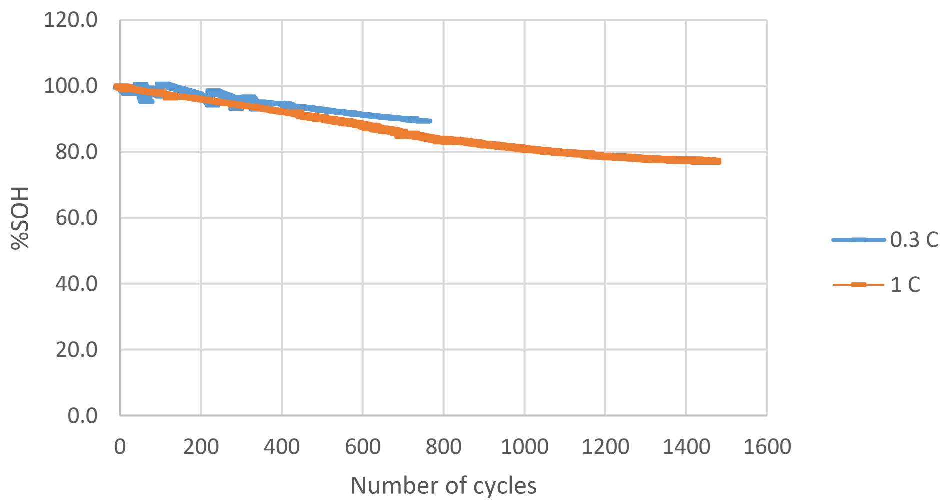

Figure 15: Capacity degradation of Leaf cell due to cycling at 0.3C and 1C charging rates

The different slopes of the curves in Figure 15 indicate different degradation rates at the corresponding C-rate, i.e. 0.3C and 1C. These two degradation rates are illustrated in Figure 15 against the C-rate they were tested under, and a linear fitting, as expressed in Equation (3), is assumed [11] [9].

$$Degradation\ per\ cycle\ (\%) = 0.0067 \times C + 0.0122 \qquad (3)$$

The EV battery degradation per cycle can be determined from Figure 16 given the C-rate, which could then be used to calculate the number of cycles (as well as the lifetime energy throughput) before the end of life.

As such, the cost of degradation can be achieved by dividing the cost of battery by the lifetime energy throughput , $E_{life@C\text{-}rate}$, as expressed in Equation (4)

$$c_{\deg\_C} = \frac{c_b}{E_{life@C-rate}} \; [£/kWh] \qquad (4)$$

Where $c_{\deg\_C}$ is the degradation cost due to a specific charging rate and c_b is the cost of the battery. The specification for the V2B bidirectional chargers to be installed at Leicester City Hall is not yet available, but the proposed rating of the EV charger will be 10 kW discharge and 7 kW charge. For the purposes of the provision of grid services, only 7 kW is guaranteed to be available which translates to approximately 0.29 C for the Nissan Leaf battery (24 kWh capacity). This gives a degradation of 0.014% per cycle according to Equation (3), which leads to a capability of 1429 cycles and an energy throughput of 49392 kWh before the end of automotive life. The cost of commercial Lithium ion cells is currently (February 2020) in the range of £121/kWh - $156/kWh and is expected to fall to $100/kWh (£78) by 2023 [12]. As such the current battery degradation cost per kWh at 0.29 C for a Nissan Leaf battery can be estimated using Equation (3) as 5.9 pence/kWh.

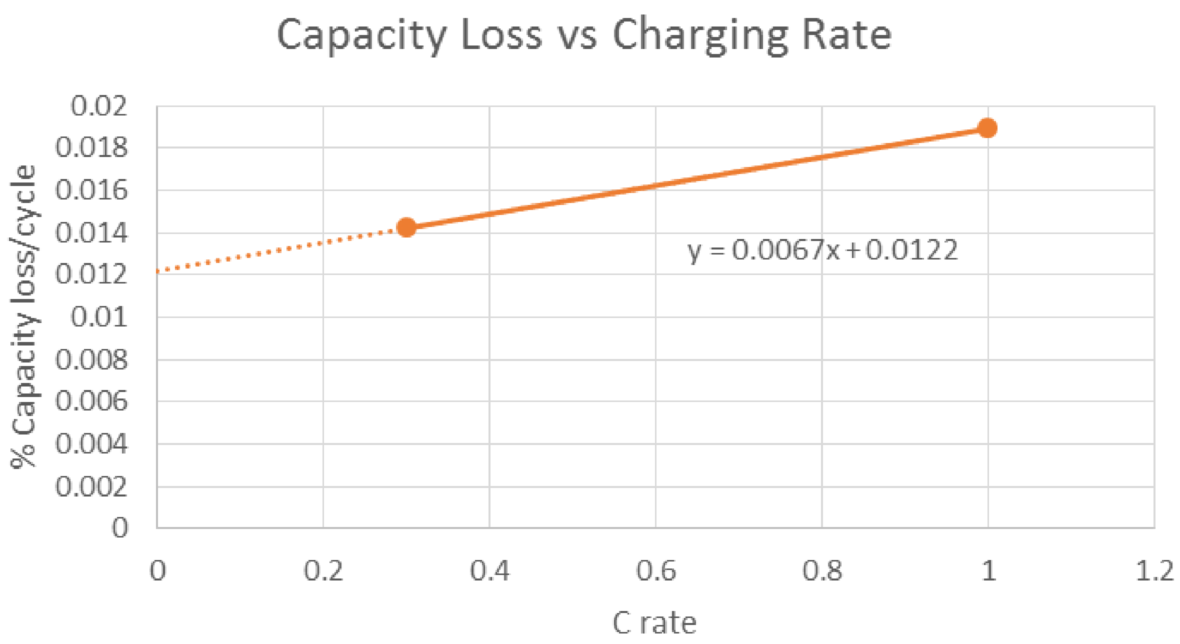

Figure 16: Extrapolation of the capacity loss against the charging rate from actual results

4.4. *Smart charging methodology*

eV4ES considered in this report cover smart charging and V2G. V2B is not provided in the proposed business model due to the flat daytime/night-time tariffs (14.5042/12.0202 p/kWh) for the City Hall, which prevents price arbitrage since the battery degradation cost, 5.9 p/kWh, exceeds the possible profit. In contrast, V2G in the form of frequency regulation receives an extra payment for the service provision and it is therefore provisionally evaluated in section 4.7.

The smart charging methodology presented in this section is designed to maximize energy autonomy, which also reduces the CO_2 emission by utilizing local renewable generation, and at the same time smooth the demand profiles exchanged with the grid to a small degree. To this end, a smart charging methodology was adopted, where the energy consumed due to driving is supposed to be recharged from PV upon arrival at the City Hall.

4.5. *Annual evaluation results*

Following the discussion of the yearly data selection in Section 0 and the smart charging methodology explained in the previous section, the improvement by smart charging compared to the baseline case is presented here in terms of the SEEV4-City project KPIs and the operational cost of the pilot. As mentioned in section 2.1, given the available data, City Hall charging was assumed to be the only charging method for both weekdays and weekends.

Over the period 3/4/2018 to 29/03/2019 the energy used to charge EVs at City Hall totalled 3,196.24 kWh; 658.7 kWh for EV '7242', 605.27 kWh for EV '7243', 1,074.49 kWh for EV '7241' and 857.78 kWh for EV '5132'. In the similar period (1/4/2018 to 31/3/2019), PV generation was recorded as 8,406.91 kWh, but this figure is possibly unreliable, given the annual PV generation figures for 2016 (18,123.00 kWh) and 2017 (16,622.00 kWh). The discrepancy is being investigated by Leicester City Council, and may well be due to a faulty measuring device.

An example to illustrate the scheduling results from the smart charging methodology for EV '7242', eight consecutive days from the midnight of 18th February 2019 (Monday) to the midnight of 26th February 2019 (Tuesday) are considered, as shown in Figure 17. The EV's availability, as illustrated by the green line in this figure, presents 5 full arrival–departure cycles during the period of illustration, and the profiles for EV smart charging is represented by the red curve. The PV generation is represented by the blue line. It is evident that the charging for this period is not optimum in respect of using PV generation to power the EV; the available PV from 21st to 24th February 2019 is not used, and due to the fixed charging rate of 7.4 kW, the power used to charge only one EV exceeds the solar output. A longer charge time at a lower charge rate would allow greater absorption of the available solar energy. Variably rated (controlled) V2G chargers are to be installed, which would allow charging at a lower rate for longer, and the use of the stored energy for FFR via V2G thus improving the economics of the pilot, as well as improving the green miles and reducing CO_2 emissions.

In the context of the continuing roll out of EVs into their fleet, Leicester City Council are considering having a 'bi-directional fleet' of Nissan Leaf EVs all with a battery size of 30 kWh or above. To meet operational needs, longer charge times may not be available during the working day. However, starting the day with a minimum of a 30 kWh battery should allow greater absorption of available solar energy by slower top-up charging without range anxiety; particularly if average daily mileage does not increase much.

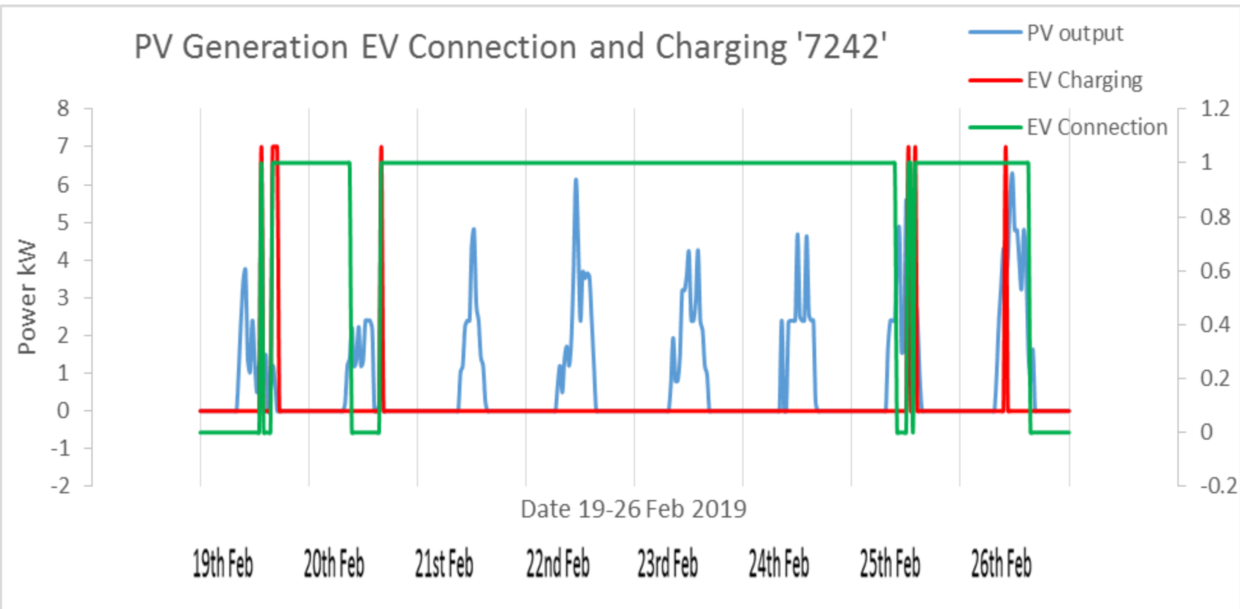

Figure 17: Charging scheduling of EV for energy autonomy maximization

4.6. Initial KPI evaluation results

1. City Hall

Leicester City Council provided figures for PV generation for the years 2016, 2017 and April 2018 to March 2019. The PV figures for 2018/19 were around half of those reported for the two calendar years, whilst the annual mains consumption is nearly constant, as detailed in Table 14.

It has emerged that there is a problem with the new half hourly PV monitoring system at City Hall, whereby the PV output is under recorded for 2018/9 onwards to address this problem, data for March, April and May 2017 were used (1,396, 2,064 and 2,465 kWh respectively, totalling 5,955 kWh). The corresponding PV output for a similar period in 2018/9 (5/3/2018 to 5/6/2018) was recorded as totalling only 2,684.5 kWh. The ratio between these two amounts (2.22) was then used as a correction factor to adjust the actual measured half hourly PV output figures.

For the City Hall, EA is taken to be self-sufficiency, defined as:

$$Self - sufficiency = \frac{Amount\ of\ local\ PV\ production\ \ consumed\ on\ site}{Total\ energy\ used\ on\ site}$$

Based on the corrected figures, EA can be established for the City Hall as shown in Table 14. A figure of 2% is obtained for 2016 and 2018/9; 1.9% being obtained for 2017.

Table 14: City Hall mains consumption, recorded PV output and EA, 2016, 2017 and 2018/9

	Mains kWh	Solar kWh	Total Site Demand kWh	EA %
2018/19	894,910.00	8,406.91(measured)	903,316.91	0.9
2018/19	894,910.00	18663.34 (corrected)	913573.34	2
2017	864,364.00	16,622.00	880,986.00	1.9
2016	871,730.20	18,123.00	889,853.20	2

The corrected values for 6/3/2018 to 21/5/2018 can then be taken to represent the unmeasured half hourly 2017 values for PV output for the period from 6/3/2017 to 21/5/2017.

These corrected figures could then be compared to the known half hourly EV charging figures for the four EVs over this particular period. This procedure permits identification of times when PV output coincides with the charging of one or more EVs, see Figure 18, and hence determination of the amount of PV which could actually be used to charge EVs in the virtual solar carport. During this period, 4,922.6 kWh of PV energy was generated, of which 441.91 kWh was used to charge EVs in the solar carport. Total EV charging in the period absorbed 1,527.44 kWh. The consumption of Leicester City Hall in this period was estimated as 180,844 kWh excluding PV. Thus, self-consumption for Leicester City Hall for the period 6/3/2017 to 21/5/2017 was 2.65%; for the whole of 2017 the figure was 1.89%. A further example is given by the values for the period 1st-29th March 2019, when total PV output after applying the above correction factor of 2.22 was 1245.5 kWh. In the same period only 521.6 kWh was used to charge the 4 EVs. Once again, PV output was amply sufficient to provide for the charging of the EV fleet if the problem on non-synchronisation of PV output with EV charging requirements could be overcome. A BESS could allow for a much greater provision of EV charging energy than occurs at present.

2. Virtual Carport

For the virtual solar carport, self-sufficiency would be defined as:

$$Self - sufficiency = \frac{Amount\ of\ local\ PV\ production\ used\ for\ EV\ charging}{Total\ energy\ used\ for\ EV\ charging}$$

Resulting in a self-consumption value in the period 6/3/2017 to 21/5/2017 for the virtual carport of 28.9%, increasing to 41% for the period of the 1st -29th March 2019 as EV use became established. KPI evaluation results are given Table 15.

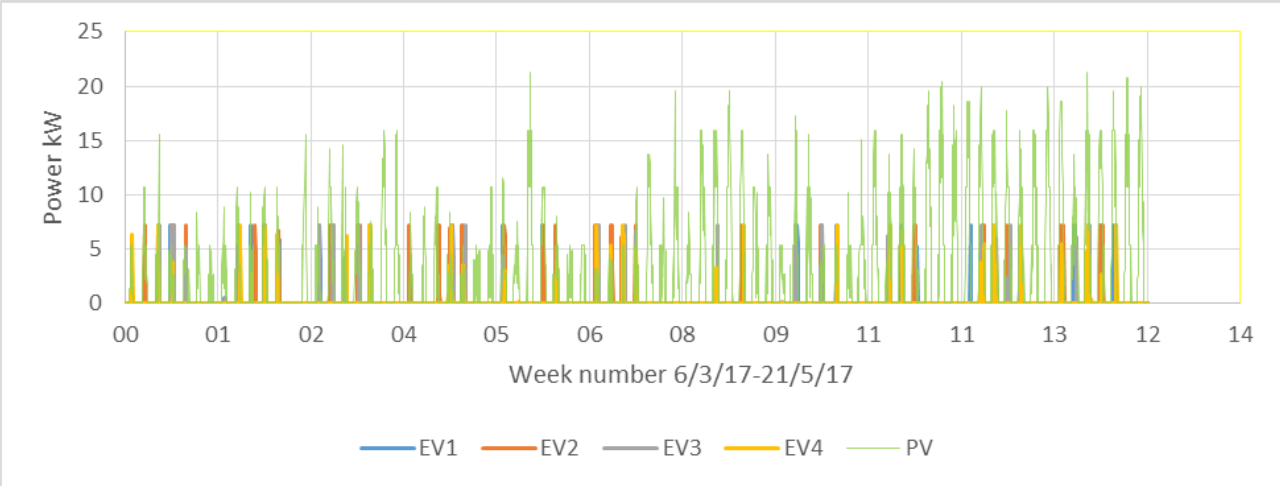

Figure 18: EV charging and PV output showing overlap

Table 15: Results for Leicester City Hall 'Virtual Carport' pilot

Variable	Value	Unit
Self - sufficiency of virtual carport	41	%
CO_2 saved from ICE substitution	4.09	tonnes
CO_2 emitted by grid charging	0.53	tonnes
CO_2 emitted if fully charging from grid	0.9	tonnes
CO_2 saved with the PV system	0.37	tonnes

The above figures relate to the current (derived) business model. With regards to grid impact analysis, the PV generation and EV charging represent such a small proportion of the total Leceister City Hall baseload that their effect on the grid is minimal even when optimised. However, a study was carried out on the internal electrical system of Leceister City Hall to ascertain whether there are any bottlenecks which would prevent more widespread adoption of EV charging and PV generation. For details please see Appendix (A).

The City Hall's electrical distribution system experiences only a small degree of voltage variation, as the system load varies from minimum to maximum. Given the statutory voltage limits of +10% to -6%, there is scope for an increase in renewable generation and EV charging before a need for system reinforcement would arise.

The current electricity system is strong enough to allocate PV generation, which is very small compared to the building demand and also EV charging. An upscaling of PV (where possible with the roof-top spare size capacity restrictions), EVs and installation of stationary storage would provide additional energy cost savings. It will not be possible to increase the amount of PV generation at the Leicester City Hall due to space constraints. Three more EVs are coming to Leceister City Hall although they will not be V2X capable. However, Leceister City Council is considering phasing out the 24 kWh Leafs in the OP fleet and replacing them with 30 kWh or larger battery vehicles. Adding BESS is a future possibility.

EV charging can be controlled with smart charging and/or V2B together with BESS, if this facility were to be installed, to have a fully autonomous solar carport (100% self-sufficiency). As will be seen in section 4.9, even without the provision of a BESS a considerable increase in the autonomy of the 'Virtual Carport' may be achieved via Smart Charging, without adversely impacting the existing EV usage pattern. The (virtual) solar carport at the baseline status (without smart charging or V2B), can achieve CO_2 emissions savings from ICE substitution and solar-charging.

4.7. V2G – Frequency Regulation provision

The SEEV4-City State-of-the-Art review identified frequency regulation as the currently most profitable ancillary service in the UK, though the value and share of this market may shrink in the future; reasons for this may be found in the State of the Art Report produced as part of this project. In addition, frequency regulation requires shallower battery cycling compared to other V2G services such as peak shaving and therefore is less harmful for the battery's State of Health [9].

In addition to smart charging, as presented in the previous section, frequency regulation service provision is investigated in this section as a V2G service, in terms of its associated technical requirements and economic feasibility. 4 x 10 kW V2G chargers are planned to be installed at Leicester City Hall, so this section deals with the economics of such operation once up and running. To carry out V2G it will be necessary to have separate metering for the V2G chargers, because the City Hall baseload always exceeds planned V2G output so without separate metering the V2G output would be 'swamped'. Although the Council is working on ways to reduce the baseload demand it will still exceed what can be discharged from four EVs at City Hall - or even the discharge amount if all 12 spaces in this small car park had a bi-directional charger. In future, as the cost of V2G bidirectional chargers falls, it may well become economic to attempt to reduce the level of the City Hall peak demand via V2G; the peak demand level sets the Capacity Cost which could be curtailed. In addition electrical power could be bought off peak at lower rates for use during the peak period.

FFR was selected out of the three frequency response options in the UK, due to its tender based procurement process and low entry capacity requirement, though again the value and share of this market may change in the future. FFR in the UK exists in 2 main variants, Dynamic Firm Frequency Response (DFFR) and Static Firm Frequency Response (SFFR) [13] SFFR is the simplest and most widely used form of frequency balancing service in the UK. Participants agree to respond to a change in the frequency from 50 Hz to 49.7 Hz or 50.3 Hz by exporting or importing energy for a period of up to 30 minutes [14] These events can be caused by power outages and tend to be irregular at between 7 and 12 times a year [13]. DFFR concentrates on managing the system frequency under normal operating conditions and tracks precise grid frequency through high and low frequency periods.

Participants in DFFR are paid to both ramp up their load on the grid, i.e. increase their energy import as well as ramping down, exporting energy, during times of frequency imbalance, to restore the grid to 50 Hz optimum operating frequency. They begin to deliver a response within 2 seconds and usually complete their response within 10 seconds, although this can last for a few minutes.

Both types of FFR are procured via monthly tenders and the successful providers are rewarded with an availability fee (a payment being made based on power committed and the period for which the commitment is offered) and for DFFR a regulation energy fee (a payment based on the actual energy consumed/provided). For SFFR the costs of energy interchange may be neglected, being infrequent. Table 16 summarises the tender details for the 2 types of FFR provision considered in this report, where the primary dynamic frequency response with a response range of 0.2 Hz was selected, and compared to the results of SFFR.

Firstly, for DFFR, the regulation asset for primary dynamic frequency response must respond within 2s from the provision request and provide all of the power requested within 10s followed by continuous provision for a further 30s. References [15] [16] have shown the technical feasibility of frequency regulation provided by EV fleets. The FFR commitment period from 11 p.m. – 7 a.m. was an appropriate time for the service to be contracted due to the compatibility with the user requirement for transportation in the Leicester City Hall pilot. This was judged based on the historical data on EV GPS and driving data, which showed that EV driving took place during office hours.

In addition, overnight primary FFR provision between 11 p.m. – 7 a.m. is currently deemed the most valuable by the UK National Grid [17]. Under the current arrangements, the EVs are available for V2B operations between 14 p.m. and 11 p.m. (The booking system shows no EVs booked out after 4 p.m. although all four may not have returned & been connected until closer to 6.30 p.m.) Any V4ES duties must allow all four to be fully charged by 7 a.m. the following morning. There would appear to be no reason why the EVs could not be used after 11 p.m. provided that they were available with a full state of charge at 7 a.m.

Table 16: FFR provision tender details

		Value
Contracted period		11 p.m. – 7 a.m.
Annual contracted available hours @ 8h/day		2920
Annual available contracted amount (4 EVs)		4 x 7 x 2920 kWh = 81.76 0MWh
Contracted type		**Primary dynamic frequency response**
Availability payment		23.03 £MW/h
Energy payment (£/MWh)	**Regulation up**	$p_e = E_r * 1.25 * PXP$ [18] [19]
	Regulation down	$p_e = E_r * 0.75 * PXP$
Contracted type		**Static Firm Frequency Response**
Contracted period		11 p.m. – 7 a.m.
Availability payment		£15.00 per MW/h
PV Cost and expected lifespan		£42,000/25 years
Estimated unit cost of proposed V2B Unit		£12,000
Estimated installation costs of V2B units		£10,000

The contracted amount of power was set at the minimum of the EV discharging/charging rate of the V2G units proposed to be installed in the City Hall (4 x 7/10 kW), and it was assumed that these EVs are part of an aggregated balancing unit in order to meet the entry capacity requirement of 1.0 MW (but aggregation costs were not considered here). The availability payment was obtained from a post-tender report in November 2017 [18]. Energy payment symbolised by p_e is calculated differently for regulation up and regulation down as can be seen from Table 16, and E_r is the energy absorbed from or injected into the grid during FFR provision. PXP is the wholesale market index price.

The droop frequency control characteristic is illustrated in Figure 19, where the power requirement responds linearly to the frequency deviation within 50±0.2 Hz, with a dead band of ±0.015 Hz. This would require a variable rate EV charger, or variable numbers of EVs committed. The technical feasibility of the former operation is supported by the current standard IEC 61851 in the form of 1 A-discrete modulation [20].

As such, the annual economic evaluation for the period from March 2018 to March 2019 is shown in Table 17 with detailed cost and profit terms. FFR in this case is demonstrated to be profitable, ignoring capital costs (as EV is already paid for the main use, which is transport), even when battery degradation cost is considered as presented in section 4.3.

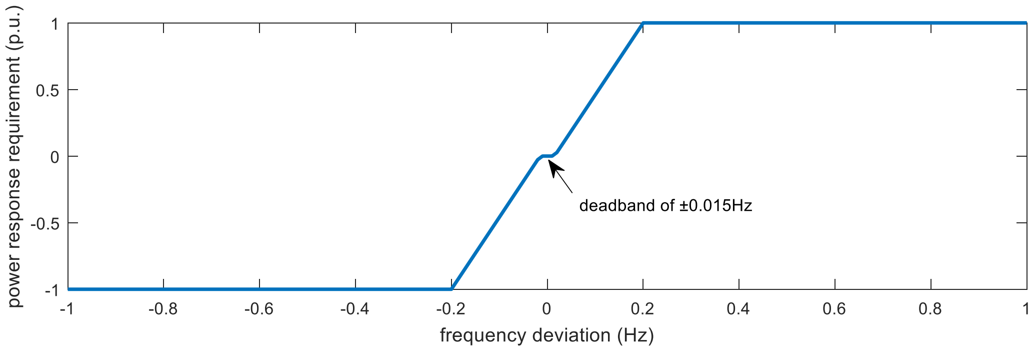

Figure 19: Droop frequency control characteristic

Table 17: Cost and benefit of DFFR provision

		Annual Value
Availability annual payment (£) per EV		470.70
Energy annual payment (£)	**Regulation up per EV**	95.70
	Regulation down per EV	60.67
Battery annual degradation cost (£) per EV at 7 kW		-219.00
Total annual cost benefit (£) per EV		286.06
Total annual cost benefit (£)		1144.24

Secondly for SFFR, as before, the FFR commitment period from 11 p.m. – 7 a.m. was an appropriate time for the service to be contracted due to the compatibility with the user requirement for transportation in the Leicester City Hall pilot. FFR providers can expect to be called upon some 7-12 times per year with an estimated 6 hours of operation per year, with a maximum of 30 minutes per period of operation [13] [21] . As each use involves only a small exchange of energy with the Grid (a maximum of 5 kWh with a 10-kW charger over a period of 30 minutes), provision of FFR is only slightly harmful to the battery's State of Health. Accordingly, the aspect of battery degradation will be neglected. It appears that the UK current average value of SFFR is £15/MW/h as of March 2020 [22]. Table 18 shows the cost benefit situation for SFFR provision.

Table 18: Cost and benefit of SFFR provision

	Annual Value
Availability annual payment (£) per EV	306.60
Battery degradation cost (£) per EV	NIL
Total annual cost benefit (£) per EV	306.60
Total annual cost benefit (£) 4EVs	1226.40

It is found that the net financial benefits of SFFR and DFRR are virtually the same, SFFR having a very slight advantage. However, in order to operate DFFR the hardware requirements are more stringent [14] and thus more expensive, so for the purposes of this report SFRR is to be preferred.

4.8. Investment/ return analysis

The cost and benefit analysis is presented in this section in terms of the NPV, for the proposed business model, which includes proposed V2G via FFR provision. The assumed lifetime of the V2G bi-directional chargers is as per industry standards. In the Leicester City Hall operational pilot the cost of the PV installation is not relevant, since it was present prior to the commencement of the SEEV-4 project.

The costs of the V2G chargers are not definitely known at present, but In September 2019 Cenex UK estimated that the V2B units would cost approximately £12,000 each, including hardware and software. Thus the intended four chargers would cost some £50,000, plus some £10,000 for associated civils, etc; i.e. approximately £60,000/ (€67,000) in total. Precise numerical calculations cannot yet be carried out as the costs are only estimates from several months ago, prior to actual tendering and procurement. However, on the understanding that four 7/10 kW bi-directional chargers will be used, it is possible to discuss the likely financial implications of this part of the project in terms of the NPV. If at the commencement of a project the NPV is positive, the project is deemed financially viable.

FFR is thought to be the most profitable ancillary service in the UK for EVs, though the value and share of this market may shrink in the future. FFR requires shallower battery cycling compared to other V2G services such as peak shaving. The financial implications of FFR service provision are investigated here, in terms of economic feasibility. To carry out V2G it will be necessary to have separate metering for the V2G chargers, because the City Hall baseload always exceeds the proposed V2G output so without separate metering the V2G output would be 'swamped'.

On the basis that each FFR intervention will last for at most 30 minutes, the maximum energy to be supplied per intervention is merely 5 kWh, with a 10 kW charger. It is felt that perhaps 10 such interventions per year will have a negligible effect on EV battery life even with the smaller 24 kWh Leaf EV. The limiting factor in attempting to obtain revenue from FFR is the V2G charger capacity, and not the size of the EV battery. Newer models of the Nissan Leaf are now available with batteries of 40 and 62 kWh, whose guarantee is not affected by carrying out V2G operations.

Replacement of the existing EVs with newer equivalents with a larger battery pack will not in itself increase the revenue available from FFR. However, it is felt that FFR revenues are falling over time due to competition [22] and it is impossible to guarantee that future income streams will be maintained. Alternative V2G propositions may become economic, involving a larger amount of energy exchange, and in these circumstances EVs with a larger capacity battery may be at an advantage.

NPV was used in this report to analyse the profitability of the Leicester City Hall pilot, being an international industry standard method for conducting such an assessment. NPV provides the current monetary value of a potential investment project by converting the yearly cash flow throughout its lifetime to the present value using a discount rate. An investment with a positive NPV will be profitable, prior to the non-accounted aggregation costs, whereas an investment with a negative NPV will result in a net loss [23] PV is defined by Equation (5):

$$NPV = \sum_{i=1}^{N} \frac{Yearly\ cash\ flow}{(1+r)^i} - Investment \quad (5)$$

where the *yearly cash flow* during the investment lifetime of *N* (*N*=10 in this case) years is converted to the present value using a discount rate, *r*, of 2% [24]. The investment and return terms are detailed in Table 10 for three cases, namely the baseline, smart charging and eV4ES which includes additional FFR provision in addition to smart charging.

The precise cost of the 4 V2G chargers is not known at present, since tendering is continuing. What can be done is to start from the annual revenue accruing from SFFR (see Figure 19) and calculate from this figure the maximum present investment cost for the project to be economic.

Certain assumptions must be made:

- For the purposes of the following calculation, based on observed usage patterns, it is assumed that the 4 Nissan Leaf EVs based at Leicester City Hall can without inconvenience be each be parked there connected to a bidirectional 7/10 kW EV charger between the hours of 11 p.m. and 7 a.m. daily;

- The services of an aggregator are available. The costs of the provision of the aggregation service are not included in this calculation;
- The rate of interest applicable is 2% [24]. Given the present unstable economic position this is felt to be reasonable;
- The lifetime of the proposed bi-directional charging equipment is 10 years;
- The most profitable form of V2G is FFR;
- V2G induced battery degradation in the 4 Nissan Leaf EVs will be small, accordingly its financial effects have been ignored.

Calculation
4 EVs connected via 7/10 Kw bi-directional chargers for 8 hours daily = 81760 kW/h yearly, given that the charging rate and the discharging rates differ, the lower rate is used here.

At £15 per MW/h [22] annual revenue/cash flow = £ 1226.40

NPV of an investment is given by the formula (5):

$$NPV = \sum_{i=1}^{N} \frac{Yearly\ cash\ flow}{(1+r)^i} - Investment$$

For an investment to be *just* profitable, one can rearrange this with NPV=0:

$$Investment = \sum_{i=1}^{N} \frac{Yearly\ cash\ flow}{(1+r)^i}$$

We have assumed that N=10 annual revenue = £1226.40 and r=2%.

Therefore, required investment should not exceed £11015.90. Anything larger than this will result in negative NPV.

4.9. Application of Smart Charging

As may be seen from Figure 5, the output of the PV system never approaches the minimum demand from the City Hall. This has two results, firstly that no export of PV energy is realistic under present conditions since any such export will serve to increase grid energy importation to compensate, and secondly that is difficult to increase EA by means of energy storage, since there is never a time when grid importation may be dispensed with.

It would be of interest to examine the possibility of using the PV energy to directly charge the EVs based at City Hall. A 'Virtual Carport' is proposed, which could notionally exist even though the City Hall system is not in fact connected to allow such a thing.

Given that figures for PV output and EV charging are available, one can determine the performance of the system which would exist if the EV chargers were given first call on the output of the PV system, and the degree of EA arising within the 'Virtual Carport' examined. It would also be interesting to examine the degree to which the performance of the 'Virtual Carport' could be augmented by arranging the EV charging pattern to best match the available PV output. For the purpose of this study the PV output figures were corrected by a factor of 2.22 as discussed in section 4.6 to take into account of the error occurring in the measurement system.

Improvement in the performance of the 'Virtual Carport' can be achieved by considering that when the EVs are charging; they tend not to do so when PV output is at a maximum. The EVs are connected, typically, for a much longer period than is required to achieve the amount of charging required. Advantage may be taken of this fact to calculate the amount of PV energy which could be absorbed by the EVs if their charging were re scheduled to take place to achieve maximum energy sourced from the PV installation. The requirement is merely that charging is re scheduled to take place during the same period of connection, but after the actual charging time if this leads to greater absorption of the PV output by the EVs.

This scheme was simulated for the period of 1st-29th of March 2019. Figure 20 shows the initial charging pattern for this period as it actually took place, and also the optimised charging pattern which could have been achieved with best use of the available PV output. Whilst these results are theoretically achievable, they do show the very significant improvement in EA which the 'Virtual Carport' could achieve. The results are summarised in Table 19.

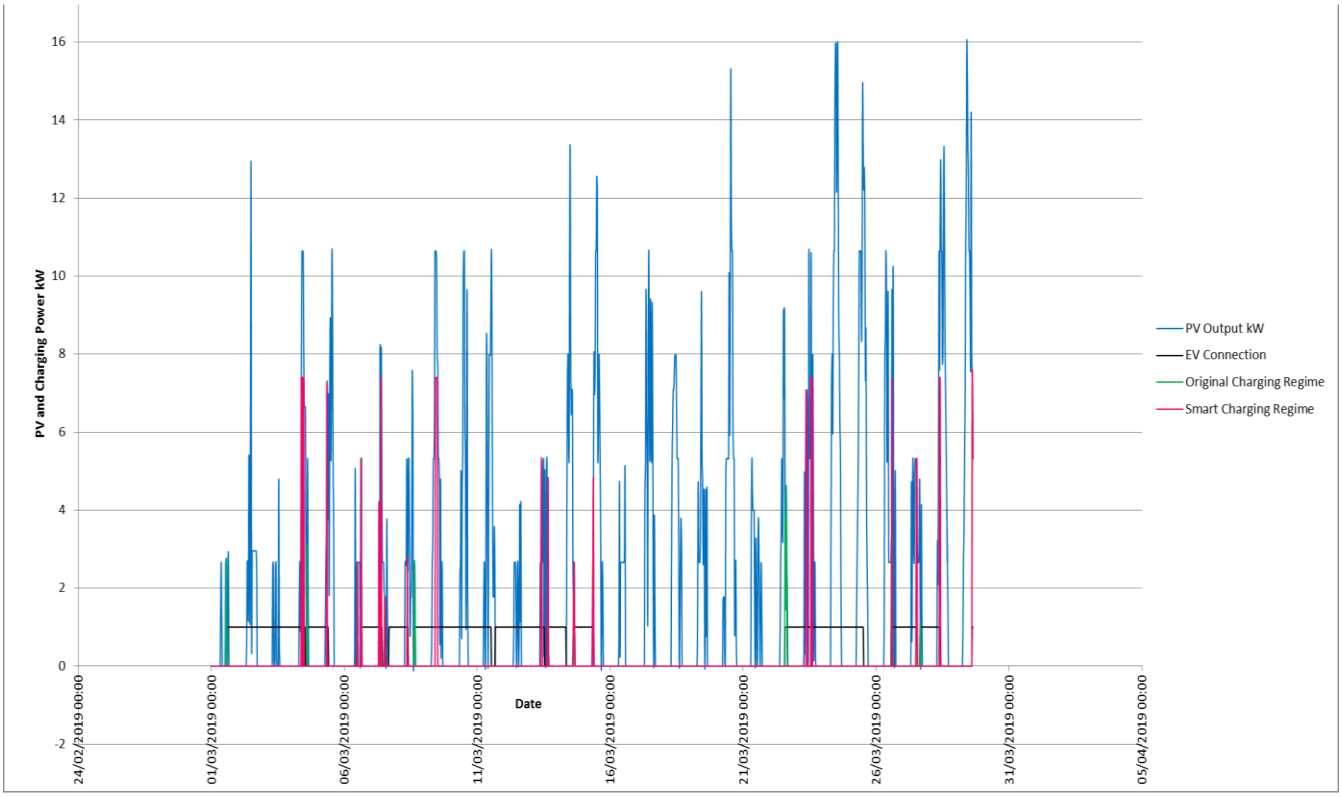

Figure 20: actual and optimum charging schedules for the period of 1st-29th March 2019.

Table 19: effects of Smart Charging on performance of 'Virtual Carport'

	13BA kWh	13BA kWh	9490 kWh	9490 kWh	840A kWh	840A kWh	B4E7 kWh	B4E7 kWh
	Total Charge	Charge from PV	Total Charge	Charge from PV	Total Charge	Charge from PV	Total charge	Charge from PV
Smart Charging Regime	140.6	117.8	136.75	93.2	140.6	86.5	103.6	69.4
Original Non Smart Regime	140.6	75.405229	136.75	34.455752	140.6	55.833076	103.6	48.942076
% Improvement from Smart Charging		56.22258769		170.4918471		54.92608718		41.80027835
EA under original Non Smart Regime	41.00%							
EA under Smart Regime	70.30%							

As may be seen from Table 19, the results of Smart Charging are that Energy Autonomy for the 'Virtual Carport' rises from 41% to over 70%, so if the priority is to maximise EA within the 'Virtual Carport' this outcome is achieved by Smart Charging. Given the vagaries of the weather and the coming & goings of 4 EVs it is unlikely that EVs would be entirely recharged by PV on return to base. A stationary battery storage system, fed by the rooftop PV, could still further increase the amount of PV energy reaching the EVs, but the extra cost incurred needs to be considered.

5. Data mining to identify types of EV use behaviour

Data collected from the charging points for 2018/9 was analysed to determine the charging behaviour of EVs users, the utilization of the chargers and level of charging energy. Five features for each charging behaviour were defined, as listed in the first column in Table 20. Because the units of each feature are of a different nature and in order to represent them together as a data series that reflects the charging behaviour, all values are normalized. The maximum value that any normalized data can take is 1, and the minimum value is 0, and this has a different meaning for each feature. For example, the third feature in the database is the charging duration, which is displayed in the clustering profiles (Table 20) as "C". A high value of C means a longer connection time of the EV to the charging point. Processing of data representing the charging behaviour of the EVs is illustrated in Figure 20.

As shown in Figure 21, analysis of the charging behaviour is performed in five steps. In the first step, the data related to the charging events of EVs is normalized to form a coherent series of data sets. In the second step, the series of data sets are clustered by the k-means method, then the self-distribution table of EVs is determined in the third step. In sub-step 3, the percentage of EVs impact factor obtained by performing a new clustering on the table of the main found in step 3. In step 4, the cross-distribution table of EVs is calculated, using the results of the second step. In a sub-step of step 4, the percentage of vehicle penetration is obtained by performing a new clustering on the table of the main found in step 4. In step 5, the decision tree is constructed based on the results found in step 2. Based on the balance coefficients and error coefficients obtained from the decision tree, practical features in clustering the events of EVs are determined.

Table 20: Charging information database

Name in the Database	Symbol in Clustering profiles	Interpretation of High Value	Interpretation of Low Value
Charging start time	A	End of the day	Beginning of the day
Charging stop time	B	End of the day	Beginning of the day
Charging duration	C	Connect to charging point for longer	Connect to charging point in a shorter time
Energy	D	High amount of charging	Low amount of charging
Useful time ratio	E	Low idle time	High idle time

With the reference to Figure 19, the following equation is used to normalize EV charging data:

$$FN = \frac{F - \min F}{\max F - \min F} \qquad \textbf{(6)}$$

Where F is the charging data of electric vehicles, which can be the charging start time, charging stop time, charging duration, the transferred energy, and the useful time ratio.

FN is the normalized value of F,

Max*F* is maximum value of F and

Min*F* is minimum value of F.

After calculating the normalized values of all data available, a data series for the charging behaviour is created by putting all 5 features together. The existing 1,178 data series are separated into four groups (clusters) by the K-mean method [25] as shown in Figure 22.

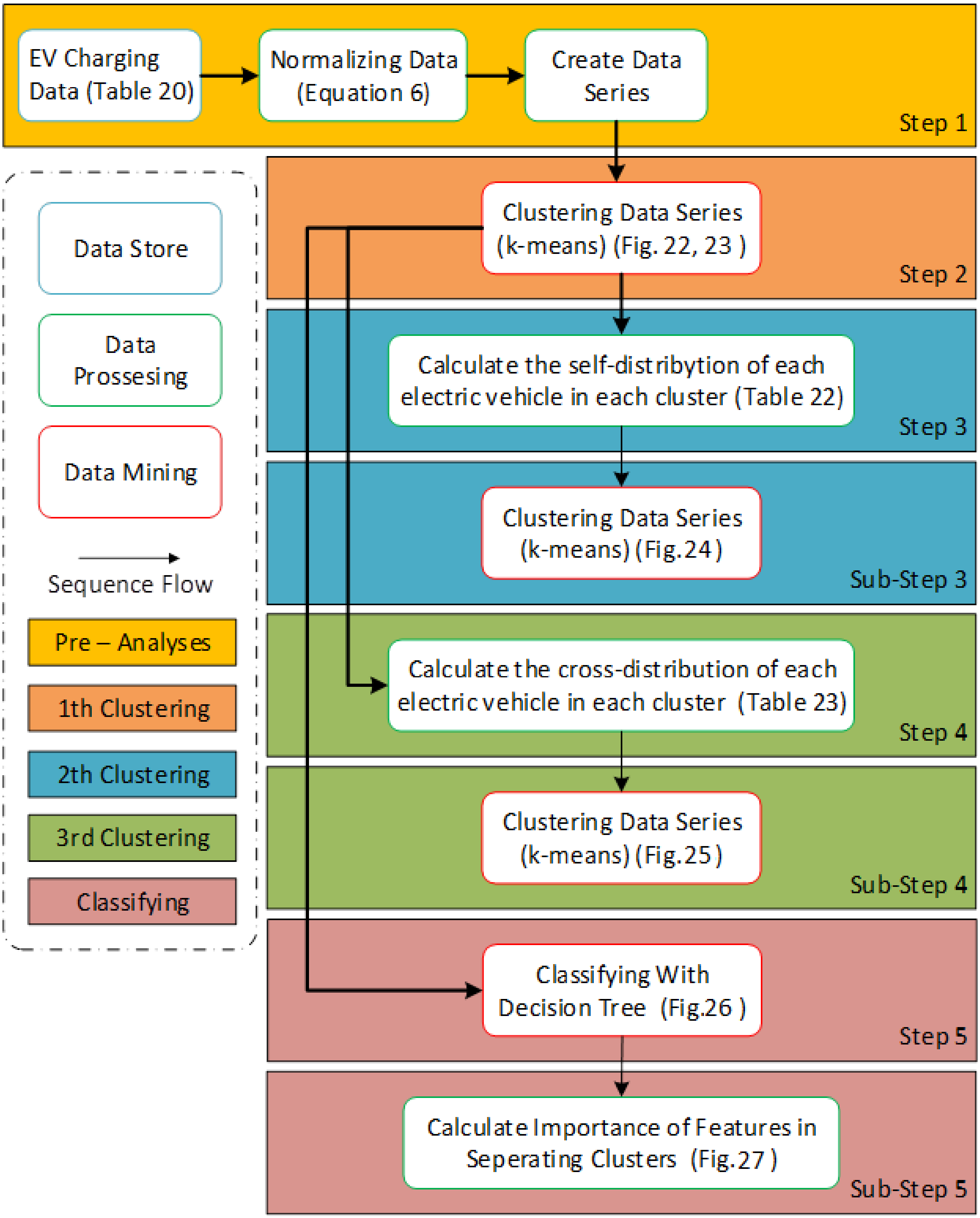

Figure 21: Charging behaviour detection structure

Each group represent a unique charging behaviour of a cluster of EV charging events. By calculating the average of each cluster, the characteristics curve of that cluster is obtained which is shown in Figure 23. Please note that there are 266, 490, 179 and 243 events in cluster 1, cluster 2, cluster 3 and cluster 4, respectively.

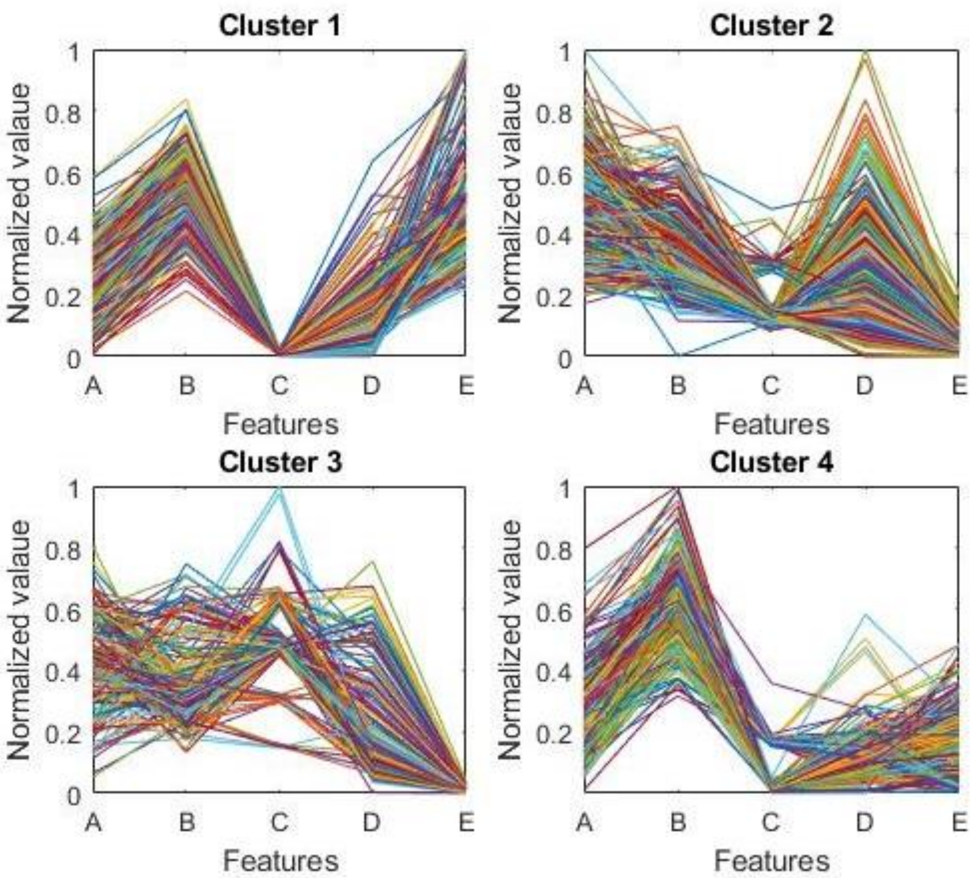

Figure 22: K-Means Clustering of Profiles

The characteristics curve of cluster 1 (see Figure 23) show that feature A is less than 0.5, which means that EVs are likely to be connected to the charger early in the day. Feature B is more than 0.5 (one in this case), which indicates that EVs are disconnected from the charger at the end of the day. Feature C has the lowest possible value, indicating a relatively short connection time of EV to the charging point. Feature D indicates the amount of energy exchanged with the electrical network (upstream grid) and is below 0.5, which means a relatively low energy exchange for charging. This feature (D) in the characteristics curves is about the same for all clusters (within a narrow range). Feature E shows the ratio of useful time during the connection of the EVs to the charging point. This has a high value in cluster 1, which indicates a low idle time (i.e. the EV was charging most of the time when it was connected to the charger).

As a reality check, Leicester City Council advise that the EVs start a working day still connected to the charging points, from the previous evening's recharge. EVs are not physically disconnected from the chargers until first use in the day. Their recharging from the previous day will be complete by mid-late evening latest on the previous day. Day time top-up charges between trips maybe relatively short, exchange less energy than the principal recharge in the evening, and have the EV charging for most of the time it is connected to the charger. This is by comparison with the evening recharge, where an EV could be fully charged by 9 p.m. but not used until onwards from c. 8 a.m. the following morning,

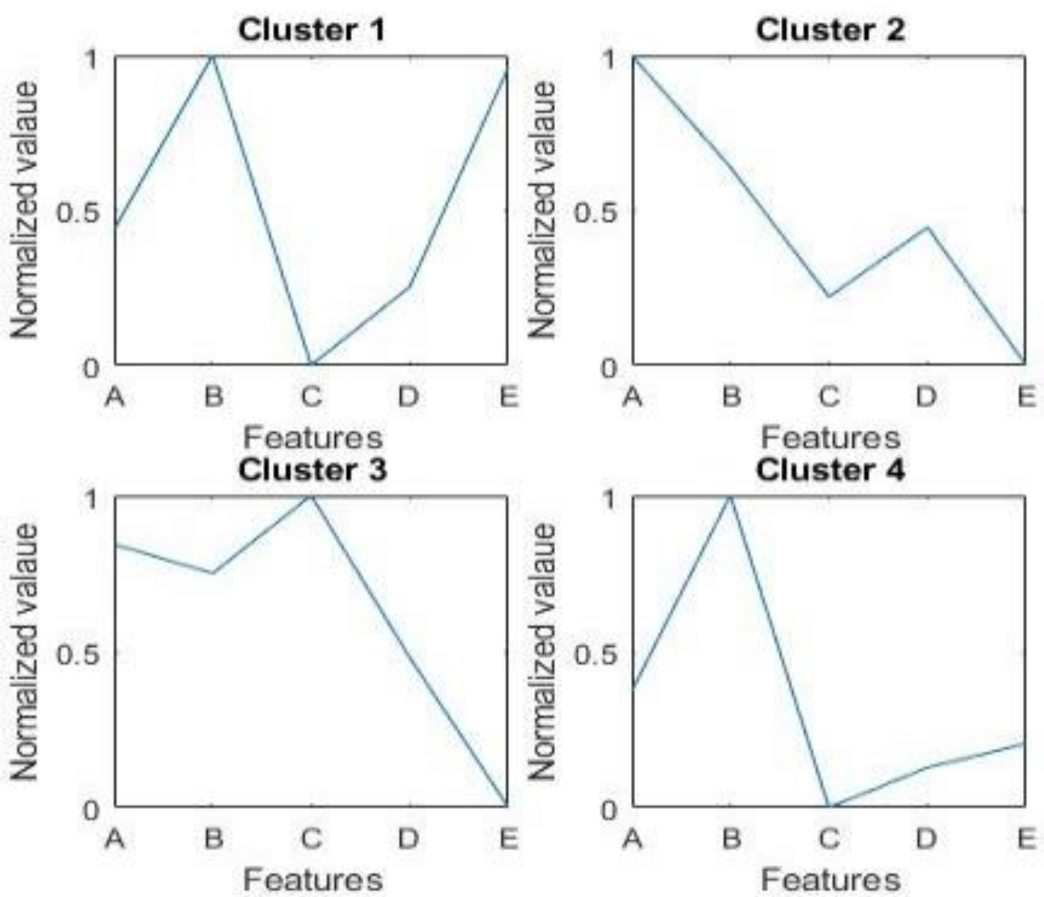

Figure 23: Characteristics curve for K-Means Clustering of Profiles

The distribution weight of each EV charging event in each cluster is calculated, and results obtained are given in Table 21 and shown in Figure 23. The profile of each EV may be considered as a new feature for the relevance of each EV in the four clusters performed. These show that EV 5132 is most effective in forming the characteristic curve behaviour for cluster 3 whilst EV 7241, EV 7242 and EV 7243 were more effective than EV 5132 in forming the characteristic curve for clusters 4. That is, the former has a different charging behaviour and the last three have more common charging behaviour.

It is clear that EV 5132 charging behaviour is different from the others, which is due to a small number of charging events for EV 5132 at the City Hall (i.e., this EV is likely charging in other places too).

Table 21: Penetration rate of EVs in each cluster

RFID	EV	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Sum
840ABFDA	7241	19.10	37.01	16.11	27.76	100
13BA876A	7242	22.04	38.65	15.01	24.28	100
B4E7BADA	7243	29.06	38.93	12.53	19.46	100
9490BCDA	5132	15.49	63.87	20	0.64	100

Figure 24 shows that a small number of EV 5132 charging events have been involved in cluster formation. The difference between the two new clustering groups is related to cluster 4, where EV 5132 has less penetration than the other 3 EVs.

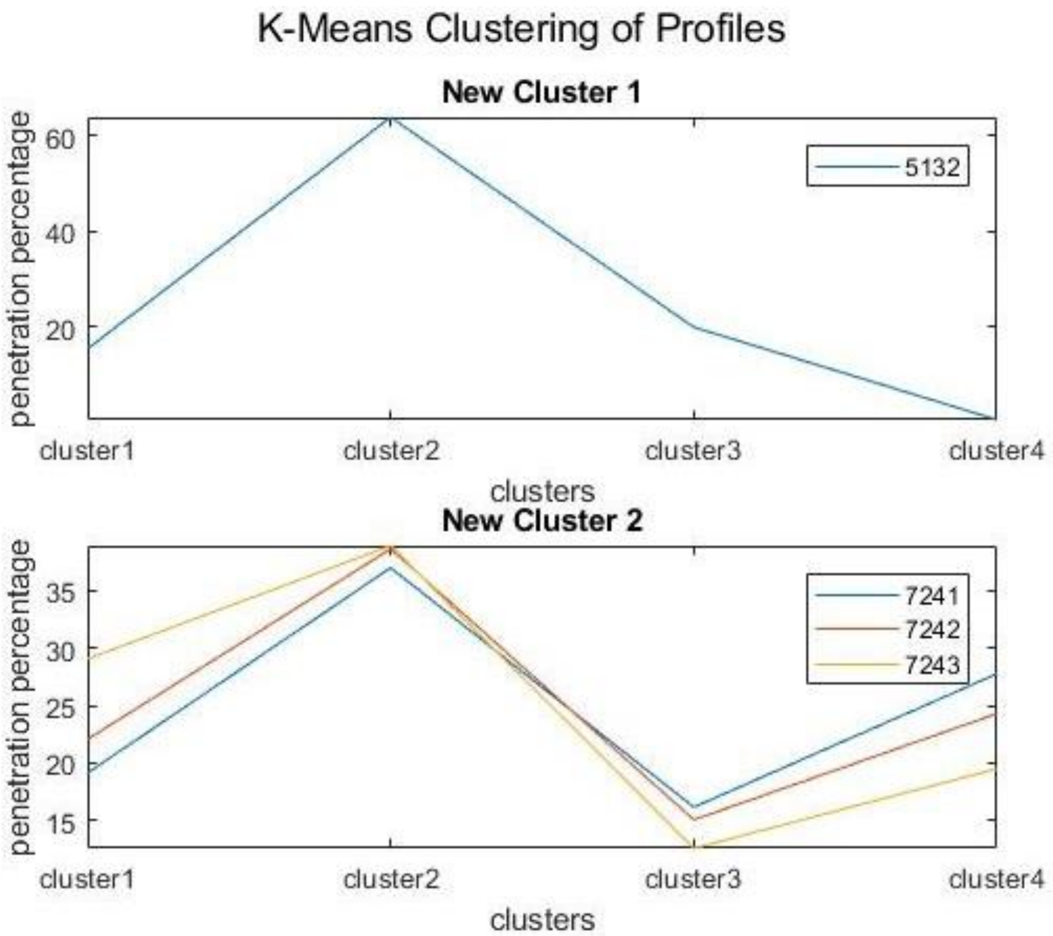

Figure 24: K-Means clustering of self-distribution data

Then the new clustering is performed after calculating the cross-distribution shown in Figure 21. This clustering is also a k-means method, and the results are shown in Table 22.

Table 22: Impact rate of EVs in each cluster

RFID	EV	Cluster 1	Cluster 2	Cluster 3	Cluster 4
840ABFDA	7241	24.06	25.31	30.16	38.27
13BA876A	7242	25.94	24.70	26.25	31.27
B4E7BADA	7243	40.97	29.80	26.25	30.04
9490BCDA	5132	15.49	63.87	20	0.64
Sum		100	100	100	100

Figure 25 shows that EV 7241 was most effective in forming the characteristic curve behaviour for cluster 1 and 2. Also, EV 7242 and EV 7243 were more effective than EV 5132 in forming the characteristic curve for cluster 4. EV 7241 and 7242 are less effective in forming characteristic curve for cluster 1. In other words, EV 7241 and EV 7242 treats like each other due to cluster 1 and cluster 4. Also EV 7243 and EV 5132 treats like each other due to cluster 2 and cluster 3.

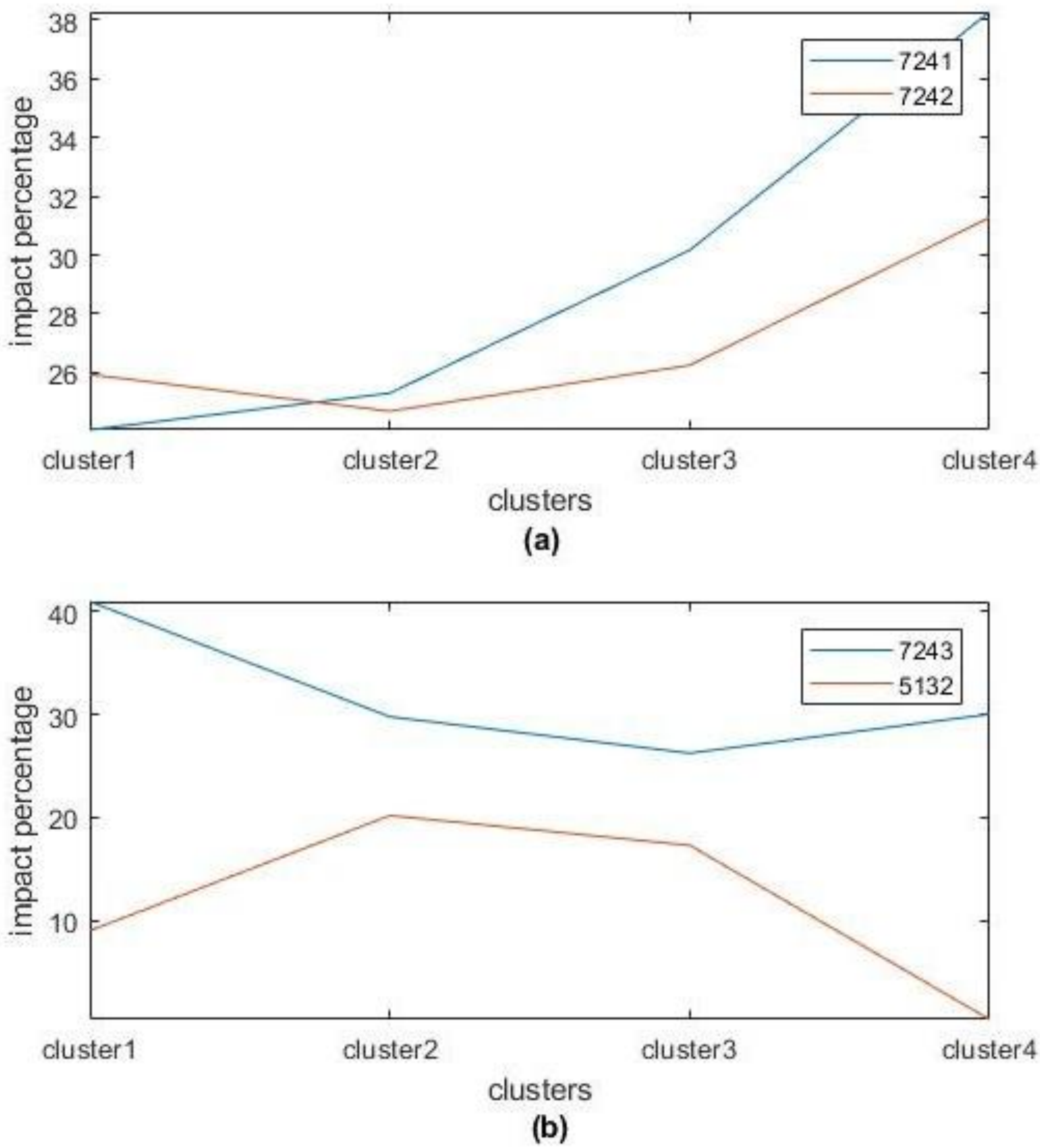

Figure 25: K-Means clustering of cross-distribution data

EV use and charging behaviour prediction for V2G and G2V operation can be achieved using a decision tree, such as shown in Figure 26. The relative importance of the various features is shown in Figure 27. The weighted coefficients calculated from Figure 26 obtained from the decision tree method show which feature has the most impact on the separation of clusters from others. The results are displayed in Figure 27.

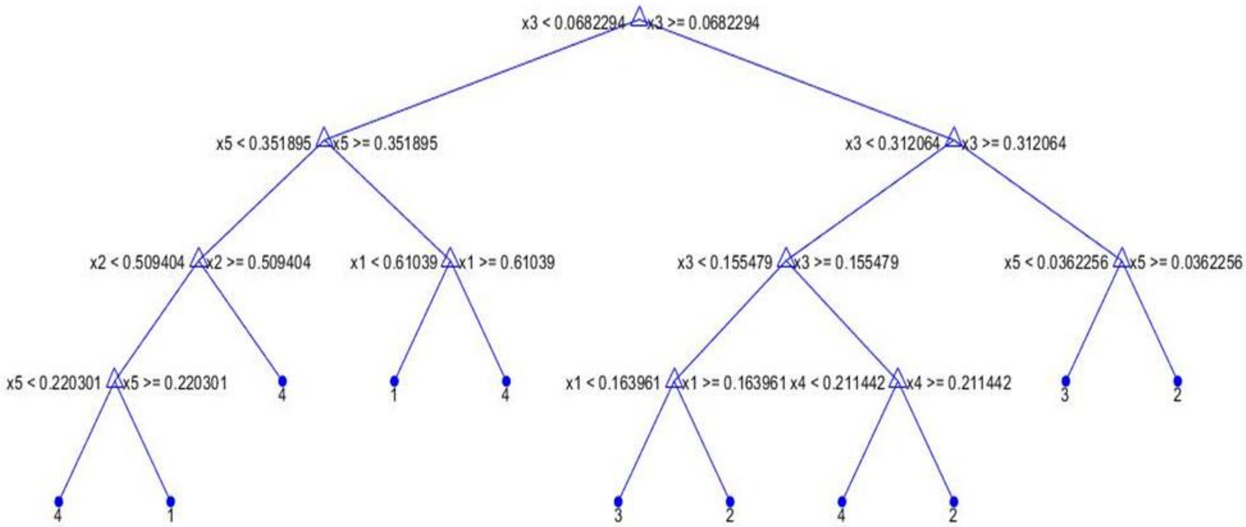

Figure 26: binary decision tree for classifying

As shown in Figure 27, the C and E features have the most significant impact on the difference in EV charging behaviour recorded in the Leicester City Hall pilot (baseline). Based on Figure 24 and Figure 25, these characteristics (C and E) give rise to a charge behaviour difference for the EV5132 compared to the other three. In other words, how to deal with EV 5132 for charging is different from the other three EVs.

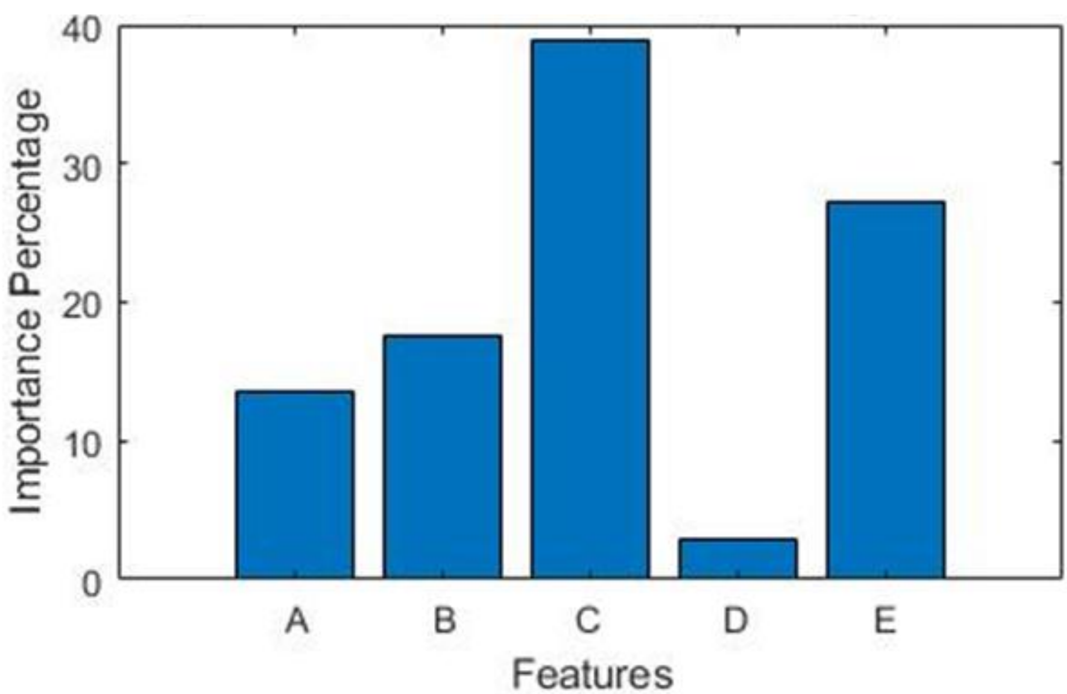

Figure 27: feature importance of separating clusters

Practical Application

Data mining allows:

- The critical identification of driver or 'EV use' behaviour (where there are multiple users in a pool as in this case) in terms of transportation use and re-charging provides key features in cluster formation such as the ideal time and duration required to connect the EV to electricity supply from the electricity/energy dimension perspective, which is important for defining smart charging, V2B or V2G operation.

- The assessment of EV use during cluster formation gives information about the availability of the EV for V4ES. Further, EV use together with the driver behaviour provides information that may be used to demonstrate how many drivers or 'EV use' events share similar characteristics, in order to categorize them appropriately and gain better understanding on profiling of EV drivers and use. Such profiling may be used to the development of optimization criteria for the use of EVs, from the driver's perspective and their charging from an electricity/energy perspective. In this case, no information is reasonably available about the EV drivers (there is a log-book, but it was not accessible to the researchers).

The primary purpose of the four EVs in this operational pilot is to provide mobility for the staff members using the pooled EVs for carrying out their work. The provision of eV4ES is a subsidiary factor, and it is not considered feasible to limit the use of an EV for transportation merely to facilitate eV4ES. Accordingly, it will be most useful to establish which EV(s) and which usage pattern (staff work routines) is (are) most applicable for eV4ES. Considering Figure 22, the algorithm enables one to establish that there are four differing patterns of use/ charging behaviour amongst the EVs. For eV4ES it is desirable to have as long a connection period as possible, to enable smart charging using as much PV as possible, and to maximize the potential to carry out V2G services. A favourable duration of connection during the day is demonstrated by Cluster three; this is the only one which is associated with a long period of connection between the EV and the charger. Clusters one and four display a low (i.e. poor) period of connection, and cluster two only a short period of connection. Thus, from the point of view of eV4ES only, the behaviour displayed by cluster three is really useful from the point of view of maximising PV energy use for charging in the 'Virtual Carport'.

The EVs remain somewhat underutilised, but as they are used for transport by daytime workers their daytime connections will always be much shorter than the overnight connection time, which could last from 4 p.m. to 8 a.m.+ the following day. During their working day it may be counter-productive to use the EV discharging function, but using variable charging rates to maximise the amount of PV energy reaching the EVs would be a useful option. Earlier in section 4.8, a V2G (FFR) commitment period from 11 p.m. to 7 a.m. was seen as an appropriate time for V4ES services to be contracted, as it was correctly identified that the EVs are only away from base during office hours. It may be that EV '5132' has longer day time layovers than the others, but it has been confirmed that its principal charging location is City Hall, like the rest. For the future, Leicester City Council are considering having a 'bi-directional fleet' comprised entirely of Nissan Leaf EVs with batteries of 30 kWh or more.

The technique allows further analysis. Given that cluster three is the desirable form of connection behaviour for eV4ES, Table 21 shows that only EV 5132 significantly conforms to the desirable behaviour. Therefore, this EV (5132) is the one most likely to prove useful for smart charging, V2G and other forms of eV4ES. Table 21 also demonstrates that the other three EVs (7241, 7242 and 7243) fail to conform to the desirable charger connection behaviour during the day. Given that EV usage patterns are not to be interfered with (as this is their primary use for work routines), these three EVs will prove of limited use to provide eV4ES. Thus, attention should be concentrated on the behaviour displayed by EV 5132.

Given that EV 7241 is a 30 kWh vehicle, and the others are all of 24 kWh battery capacity, one finds from use of the algorithm that the maximum benefit would be obtained by exchanging EV 5132 for EV 7241 with regard to charger connection (and thus likely routinised use), to allow the EV with the largest capacity battery to be in the position to carry out the most eV4ES service. This will result in the best use of the EV battery, the maximum storage available for PV energy and the least amount of battery degradation (if V2G is done properly, by avoiding discharging the EV batteries to a low SoC, or by letting them remain for protracted periods with a fully charged battery).

6. Lessons learnt from the different pilot phases

6.1. Preparation and initiation

Finding the right location

In comparison to initial expectations, significant delays were experienced in the preparation and initiation, mainly due to two site relocations and resource constraints. For the first prospective building owned by the municipality, conflicting plans had emerged for it to be potentially sold. Consequently, it was no longer a good candidate site to install new equipment there. The pilot lost approximately a year of preparation time allocating the eventual site location. The second site option was a multi-storey car park in the city centre. Efforts were made in the building assessment including a baseline document. The carpark would need a PV system that could have been added by installing solar portals on the roof of the carpark. However, because of the novelty of this approach it was determined that the time needed to get planning consent would cause significant further delays. Considering the loss of time on the first location, the pilot manager did not want to take any risk and searched for another location. Which led them to the Leicester City Hall as the definitive location of this operational pilot. The site already has 90 solar panels (23.4 kWp) on its roof and provides 2,5% of the City Hall's electricity consumption. Leicester City Council are now developing a scheme for this car park to add a 85 kWp PV array. This will supply energy to conventional charge points at the car park - but also has the potential for future development along the lines of the derived or proposed business models of this report.

In preparation to the tender, the pilot manager attended workshops and visited other operational pilots to gain knowledge concerning the V2X technology and the required components. This learning process was deemed very valuable in the preparation phase.

Battery considerations

A 24 kWh battery storage system was considered to boost the pilot's energy autonomy. However, the evening discharge from EV batteries is expected to have a bigger impact on energy autonomy. It is estimated that the average daily discharge available from the four EVs is some 60 kWh. When considering the extra costs and complexity of adding storage as well as the energy losses from PV to storage to EV, this element was not considered to be value for money.

Anticipating on a growing EV fleet

Due to the expected growth of EVs in the fleet, Leicester City Council decided not to replace its five unidirectional charge point but to add four bi-directional units. Additionally, Leicester City Council are considering a fleet of Leafs all having a battery capacity of 30 kWh or more, to work with the V2B chargers.

6.2. Procurement

Organisational engagement

Alignment with and engagement of relevant stakeholders within the internal organisation, such as with the Facility Management team/department of Leicester City Council, was one of the biggest challenges in the Leicester pilot, once choosing the City Hall as the OP location. There is a high dependency for the project on this council team/department, because of the existing technical knowledge of the building, and because of this, also need to provide the necessary permissions for changes. An additional factor, was that during the timeframe of the SEEV4-City project, the Facilities Management team/department underwent a major review and included the loss of some staff who were key to the project. The fact that those responsible for managing the pilot were not positioned within the parts of the organisation that have key information and decision-making power, added to the complexity to achieving the comprehensive alignment for this relatively small, yet innovative project. For example, for a long time it was expected that the V2X system could incorporate the building management system to provide mains supply and solar generation data. Some steps were already taken towards this end before it became clear that this would not be contractually possible with the building management system. With no time to consider re-opening this contract, an alternative solution had to be found. Leicester City Council was well supported by technical advice from Cenex UK to identify a way to operate V2X system independent of the building management system. In the summer of 2019, an electrical engineer from Arcadis was procured to help the pilot get started.

CE certification

In earlier days, only a limited number of manufacturers were producing or developing V2X units. At this stage, not all the units were carrying a CE mark. Leicester City Council's ICT procurement department needed assurance from manufacturers that the units proposed will get a CE certification and would have resulted in delays (had it not been for already existing delays). One possible advantage of the project's delays is the improved availability of V2X units that are carrying a CE mark.

6.3. Implementation and installation

The bi-directional charging installation is due to be installed. Tendering is under way but the authors understand that no concrete information will be available within the timescale of the present SEEV4-City project. Leicester City Council advise that they are currently expecting to go to market in the second half of September 2020. This would mean a contract could be in the books around the end of October, but an operational date looks to be taking as long as at the back end of 2020/21.

6.4. Operation

The bi-directional charging installation is set to be installed. It will be necessary to form a business relationship with an aggregator in order to actually carry out V2G, and the type of V2G service to be adopted is not yet decided upon. FFR is a likely candidate for adoption. In the meantime Vehicle to Building (V2B) operations will be undertaken to increase the amount of PV energy utilised in EV charging and to increase Energy Autonomy. The economics of V2B are not favourable. The installation cost must not exceed £11,015.90 to avoid a negative NPV; we understand that the actual installation costs of the V2B system will be in of the order of £60,000 so in financial terms a foreseeable (financial) Return on Investment is considered as a loss.

7. Conclusions and Recommendations

7.1. Key messages

Based on the results achieved from the Leicester pilot, the following ***key messages*** can be drawn:

- Smart charging demonstrates an improvement in the KPIs set in the SEEV4-City project, namely, energy autonomy, CO_2 emission reduction, and lower operational cost compared to the baseline.
- The achievable energy autonomy and the associated CO_2 emission savings depend on the season and weather conditions, and therefore show variations accordingly.
- DFFR is profitable even when the battery degradation was taken into account. However, the technically simpler SFFR offers a virtually identical profit. The commitment for this service provision, i.e. the EV being available for the contracted period of 11 p.m. – 7 a.m., is unlikely to conflict with user's requirements, there being no overnight journeys.
- FFR provision, if applicable and enabled, would produce an estimated revenue of £286.06 per year per EV. A combination of profitable services would make the most economically rewarding solution to the eV4ES business model. Using NPV techniques it may be shown that for the proposed V2G installation to be profitable, the investment cost should not exceed £11015.90.
- Given that EV 7241 is a 30 kWh vehicle, and the others are all of 24 kWh battery capacity, one finds from use of the algorithm that the maximum benefit would be obtained by exchanging EV 5132 for EV 7241 with regard to charger connection (and thus likely routinised use), to allow the EV with the largest capacity battery to be in the position to carry out the most eV4ES service. This will result in the best use of the EV battery, the maximum storage available for PV energy and the least amount of battery degradation (if V2G is done properly).

7.2. Policy suggestions

The following policy suggestions are provided to enable a smoother transition into smart and clean electrification of transportation.

Subsidies/incentives:

Given the high battery investment cost for BESS, additional subsidies on BESS could be beneficial to encourage the utilization of BESS and to achieve higher energy autonomy, lower CO_2 emission and better grid stress alleviation.

Alternatively, a specific V2G Feed-in Tariff could be established, and progressively reduced as EV battery costs decline as projected.

Data availability and transparency for better integration of electric transportation at all levels:

To enable and stimulate an uptake of electric vehicles beyond the early adopters (which are also often the participants of experimental and organisational set-ups of pre-commercial trials), there will need to be a greater need for making data recordings and readings more transparent. This will also lead to fewer assumptions needing to be made for a cost-benefit analyses.

In this way, automatic recording and accurate processing (with clear data definition) of historic data on EV transport energy are required, to calculate the charging energy requirement. This record data will then be coupled with energy price data to construct a smart energy management model. This could be further optimised by automated intelligent route planning for EVs.

Rewards for carbon savings to encourage EV uptake and usage:

There are increasingly advanced tools that allow the analysis of CO_2 (carbon) intensity of electricity at regional levels within the UK. The National Grid, for instance, have led the development of a Regional Carbon Intensity forecast for the GB electricity system which can be accessed from http://carbonintensity.org.uk/. This should be given greater prominence in framing the messages to encourage motorists to use EVs for their transportation needs.

Dissemination of the benefits of smart charging and V2G to relevant stakeholders:

It is important to organise communication efforts to frame and explain the relative merits of smart charging and V2G to a broad spectrum of stakeholders. This could be combined with the carbon savings mentioned above and presented in a Dashboard similar to that of a smart meter or like the MyGridGB smart home's Dashboard (http://www.mygridgb.co.uk/dashboard/) which provides a quick overview of the live electricity mix, carbon emissions and the amount of low carbon electricity generated in the UK. The MyGridGB dashboard and site both display live electricity data for the UK (including with a Twitter feed) by generation source of low-carbon electricity, as well as carbon intensity by generation type, trends in electricity supply and demand over time (both annual and monthly: http://www.mygridgb.co.uk/last-12-months/).

Standardization and communication protocols to allow interoperable smart charging and V2G:

International level agreements should be reached to allow more standards such as CCS to be compatible with V2G in addition to the current standard CHAdeMO [26]. Open standards should be further encouraged through the adoption of the Open Charge Point Protocol (OCPP) [27], and the Open Smart Charging Protocol (OSCP) [28] in their updated versions.

Successful business model development to benefit relevant stakeholders:

As part of any stimulation of V2G uptake in the UK, it is essential to develop business models with built in distributional dimensions, i.e. shared (including monetarised) benefits for stakeholders built in which encourage and incentivise the respective stakeholders – including the EV owners – at domestic scale to contribute to an aggregated eV4ES future.

Users' acceptability towards V2G services:

Consumer behaviour and receptiveness should be measured to provide insights into EV owners' attitudes and their response to V2G products and services.

Development of an energy market or a platform for V2G services:

Some of these dimensions are to be explored in the latest funded V2G projects by Innovate UK, with the support of the Office of Low Emission Vehicles (OLEV) [29] Policy makers are advised to closely follow the outcomes of these projects over the next 2 years. To understand the current UK V2G context, it is recommended to refer to the findings from two Innovate UK funded V2G studies conducted by Cenex UK [30] [31].

7.3. Relevant dimensions for Upscaling and Transnational transfer potential

In this paragraph, we provide a brief indication of which dimensions SEEV4-City identified for the eV4ES used in this OP that play an instrumental role for both its Upscaling and Transnational transfer potential. A more in-depth analysis of the potential of each individual eV4ES applied across the SEEV4-City Operational Pilots can be found in a separate report.

7.3.1. Within the country of the OP (UK)

Upscaling potential in the United Kingdom:

- The most common purpose of V2B is to reduce electricity bills by balancing differential tariffs or costs within the building. Leicester City Hall daytime and night-time electricity costs are 14.5042 p/kWh and 12.0202 p/kWh respectively. These are also the energy costs of charging the EVs from the Grid. There is also a capacity charge of 1.05 £/kVA. Accordingly, if PV or Grid energy were stored in the EVs the overall electricity bill could be reduce, both directly and by reducing the measured peak consumption level. In terms of the market size, there are some 1.8 million office/commercial/industrial buildings in the UK, many of which have car parking spaces and can accommodate rooftop PV.
- Further possibilities are to utilise the energy stored in the EV batteries to increase EA, reduce CO_2 emissions and reduce the need for grid reinforcement particularly as the number of EVs to be charged rises over time.
- For V2B, a CHAdeMO-compliant vehicle is needed, Leicester City Hall utilises four Nissan Leaf EVs. Around 27,000 Leafs have been sold in the UK, meaning that with the right charging equipment, many of these EVs could participate in V2B, which in the case of the recent types of Leaf does not invalidate the EV battery warranty.

Possible barriers for upscaling are as follows:

- V2B is governed under the UK's Distribution Network Code, part G99, which requires a pre-installation application and potential post-installation checks. As a minimum, the requisite bi-directional charger must be G-99 type-tested, which restricts the range from which a customer may choose.
- The V2B technology must be compatible with an office building environment, it is likely to involve a relatively small 7/10 kW charger. The local distribution network may place restrictions on the power rating of the charger to ensure stability of the local grid. For V2B, there is no expectation of export, although the exporting power will be evaluated in case some aspects of V2G such as FFR or Frequency Containment Reserve (FCR) may become economic.
- The customer will need to find a commercial offering which will allow this eV4ES service. V2B services do not generate significant financial savings owing to the substantial capital cost of the hardware, and without coupling to on-site generation, will not bring carbon savings either. In the case of Leicester City Hall there is a certain amount of PV generation.
- In the span of 5-10 years, the costs of the necessary bidirectional chargers may well fall to such a degree as to render the proposition more economic. Coupled with an increase of localised PV / renewable energy generation this would result in further reduction of electricity costs as well as an increase in self-sufficiency and Energy Autonomy, reducing the dependence on external energy supply.

7.3.2. Transfer to other countries

The Netherlands

An organisation in the Netherlands can make savings since there is a cheaper 'night rate' for electricity supply:

One major supplier, MainEnergie, currently charges a supply tariff as follows:

Normal	Off-peak	Single
€ 0,0947	€ 0,0796	€ 0,0917

There is no peak capacity charge element in the Dutch electrical energy pricing system.

Barriers/ opportunities

The most common purpose of V2B is to reduce electricity bills by balancing differential tariffs or costs within the building. If Leicester City Hall's daytime and night-time electricity costs were located in the Netherlands they would be €0,0947/kWh and €0,0796 /kWh, respectively. These would also be the energy costs of charging the EVs from the Grid. Accordingly, if PV or Grid energy were stored in the EVs the overall electricity bill could be directly reduced.

Further possibilities are to utilise the energy stored in the EV batteries to increase EA, reduce CO_2 emissions and reduce the need for grid reinforcement particularly as the number of EVs to be charged rises over time.

To conduct V2B services, a CHAdeMO-compliant vehicle is needed. There were 142,686 EVs in the Netherlands in 2018, and many would be suitable for this service.

Possible barriers for transnational operation are as follows:

- The V2B technology will need to be suited to use in an office building environment. This means that it is likely to use e a 7/10 kW charger.
- The local distribution network may place restrictions on the power rating of the charger(s) to ensure stability of the local grid. If the grid is constrained, the customer may be requested to pay for a connection upgrade to support the expected increase in incoming supply. For V2B, there is no expectation of export, although the exporting power will be evaluated in case some aspects of V2G such as FCR may be economic.
- As in the UK, the customer will need to find a commercial offering which will allow this eV4ES service. V2B services do not generate significant financial savings owing to the substantial capital cost of the V2G/V2H hardware, and without coupling to on-site generation, will not bring carbon savings either. In the case of Leicester City Hall there is of course a certain amount of PV generation.
- In the span of 5-10 years, the costs of the necessary bi directional chargers may well fall to such a degree as to render the proposition much more economically attractive. Coupled with an increase of localised PV renewable energy generation, this would result in further reduction of electricity costs as well as having the benefit of an increased level self-sufficiency and increasing energy autonomy by reducing the dependence on external energy supply.

Belgium

In Belgium, there are a number of different elements which go together to comprise a customer's electricity bill. Only the distribution costs provide a night time economy rate. Network Transmission and distribution charges both have a capacity-based element.

In 2019 the relevant costs were, for businesses consuming 500-1999MWh/year such as Leicester City Hall: Energy and supply cost €0.0464/kWh; Network costs €0.0340/kWh; VAT €0.0235/kWh; Renewable taxes €0.0311/kWh; Environmental tax €0.0007/kWh; Nuclear tax €0.0005/kWh; Capacity tax; €0.0013/kW; Other taxes €0.0011/kWh

Network costs may be split into distribution costs and transmission costs.

The distribution costs include an element reflecting peak power consumption. In 2020 a typical Belgian tariff for an operation with a peak load such as that of Leicester City Hall (some 250 kW) was €28.6967257/kW. In addition, the distribution costs include elements for daytime and night time consumption in kWh. In 2020 typical figures were €0.0013729/kWh daytime and €0.0007787/kWh night time. Transmission costs for an enterprise the size of Leicester City Hall would attract a capacity based tariff of €34.4963097. There is no transmission based day/night tariff.

Barriers/ opportunities

In Belgium, the main opportunity for extending the V2B concept is that there is short-term variation (day/night charges) in power distribution costs, which could in principle allow some form of cost reduction by importing energy at tight when the distribution tariff is lower. Also, there is a 'capacity charge' related to charges for both transmission and distribution, whose effect could be reduced by the V2B process, which could reduce the peak level of demand via energy storage.

Possible barriers for transnational transfer are as follows:

- Belgium had only 5,742 BEVs in 2018, suggesting that the scope for EV based projects may be somewhat limited for now.
- A V2B application will need to be suited to use in an office building environment. This means that it is likely to be limited to a 7/10 kW charger.
- The local distribution network may place restrictions on the power rating of the charger to ensure stability of the local grid. For V2B, there is no expectation of export, although the exporting power will be evaluated in case some aspects of V2G such as FCR may be economic.
- The customer will need to find a commercial offer which will allow this eV4ES service. V2B services do not generate significant financial savings owing to the substantial hardware costs, and without coupling to on-site generation, will not bring carbon savings either. In the case of Leicester City Hall there is of course a certain amount of PV generation.
- Bi-directional chargers are often expensive and funded through suppliers' revenues from grid services, so a pure V2B offering is rare. In the span of 5-10 years, the costs of the necessary chargers may well fall to make the proposition economic. Coupled with an increase of localised PV / renewable energy generation, this would result in a further reduction of electricity costs as well as having the benefit of an increased level of self-sufficiency and increasing energy autonomy by reducing the dependence on external energy supply.

Norway

In Norway, electricity prices now consist of 3 parts: the basic power cost, a contribution towards maintenance and development of the transmission and distribution systems known as the Grid rent, and an element of taxation. VAT is charged on the sum of the above. There is no day/night variation in power costs. The Grid Rent charge includes a 'power link' charge calculated according to the highest energy consumption during one hour per month, based on the hour of highest power consumption during the invoice month.

Barriers/ opportunities

The only evident opportunity to carry the Leicester City Hall model to Norway would be to use the energy stored in EVs to shave the amount of the peak demand, recharging when demand is lower, thus reducing the amount paid for the power link charge as discussed above. This procedure is the rationale behind the use of stationary battery storage within the Oslo OP. Another way of achieving a reduction in power link charge would be to adjust the charging of EVs, so that the peak power demand was minimised – effectively 'Smart Charging'.

Further possibilities are to utilise the energy stored in the EV batteries to increase EA, reduce CO_2 emissions and decrease the need for grid reinforcement, particularly as the number of EVs to be charged rises over time.

To conduct V2B, a CHAdeMO-compliant vehicle is needed. In 2018 Norway had 249,043 EVs, meaning that, with the right charging equipment, many of these cars could participate in V2B.

Possible barriers for Trans-national transfer are as follows:

- The V2B technology will need to be suited to use in the office building environment. This means that it is likely to be a 7/10 kW charger.
- The local distribution network may place restrictions on the power rating of the charger to ensure stability of the local grid. If the grid is constrained, the customer may be requested to pay for a connection upgrade to support the expected increase in incoming supply. For V2B, there is no expectation of export, although the exporting power will be evaluated in case some aspects of V2G such as FCR may be economic.
- The customer will need to find a commercial offering which will allow this eV4ES service. V2B services do not generate significant financial savings owing to the substantial cost of the hardware, and without coupling to on-site generation, will not bring carbon savings either. In the case of Leicester City Hall there is of course a certain amount of PV generation.
- Bi-directional chargers are often expensive and funded through suppliers' revenues from grid services, so a pure Vehicle2Building offering is rare. In the span of 5-10 years, the costs of the necessary chargers may well fall to such a degree as to render the proposition much more economically attractive. Coupled with an increase of localised PV/ renewable generation, this would result in further reduction of electricity costs as well as the benefit of an increased level self-sufficiency and increased energy autonomy, reducing the dependence on external energy supply.

7.3.3. Policy suggestions

The following UK-based policy suggestions may well be appropriate in a Transnational contest.

Subsidies/incentives:

Given the high battery and hardware investment cost for BESS, additional subsidies could be beneficial to encourage the utilization of BESS and to achieve higher energy autonomy, lower CO_2 emission and better grid stress alleviation. Alternatively, a specific V2B/V2G Feed-in Tariff could be established and progressively reduced as EV battery and bidirectional charger costs decline as projected.

Data availability and transparency for better integration of electric transportation at all levels:

To enable and stimulate an uptake of electric vehicles beyond the early adopters (which are often also the participants of experimental and organisational set-ups of pre-commercial trials), there will be a greater need for more transparent data recordings and readings. This will also lead to fewer assumptions to be made for a cost-benefit analysis. In this way, automatic recording and accurate processing (with clear data definition) of historic data on EV transport energy will be needed to calculate the charging energy requirement. Such record data will then be coupled with energy price data to construct a smart energy management model. This could be further optimised by automated intelligent route planning for EVs.

Rewards for carbon savings to encourage EV uptake and usage:

There are increasingly advanced tools that allow the analysis of CO_2 (carbon) intensity of electricity at regional levels within the EU. These should be given greater prominence in framing the messages to encourage motorists to use EVs for their transportation needs.

Dissemination of the benefits of smart charging andV2B/ V2G to relevant stakeholders:

It is important to organise communication efforts to frame and explain the relative merits of smart charging and V2B/V2G to a broad spectrum of stakeholders. This could be combined with the carbon savings mentioned above and presented in a Dashboard similar to that of a smart meter.

Standardization and communication protocols to allow interoperable smart charging and V2B/ V2G:

International level agreements should be reached to allow more standards such as CCS to be compatible with V2G in addition to the current standard CHAdeMO. Open standards should be further encouraged through the adoption of the OCPP, and the OSCP, in their updated versions.

Successful business model development to benefit relevant stakeholders:

As part of any stimulation of V2G uptake in the North Sea Region of Europe, policy should be to incentivise the development of business models with built-in distributional dimensions – that is shared (including monetarised) benefits for stakeholders built in which encourage and incentivise the respective stakeholders – including the EV owners – at domestic scale to contribute to an aggregated eV4ES future.

Users' acceptability towards V2G services:

Consumer behaviour and receptiveness should be measured to provide insights into EV owners' attitudes and their response to V2G products and services.

Development of an energy market or a platform for V2B/ V2G services:

These dimensions should be explored. Policy makers are advised to provide encouragement for research and market development.

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Appendix (A)

A1. Study to ascertain limitations of the City Hall Power Distribution System

A diagram of the wiring installation was made available, as shown in Figure 28.

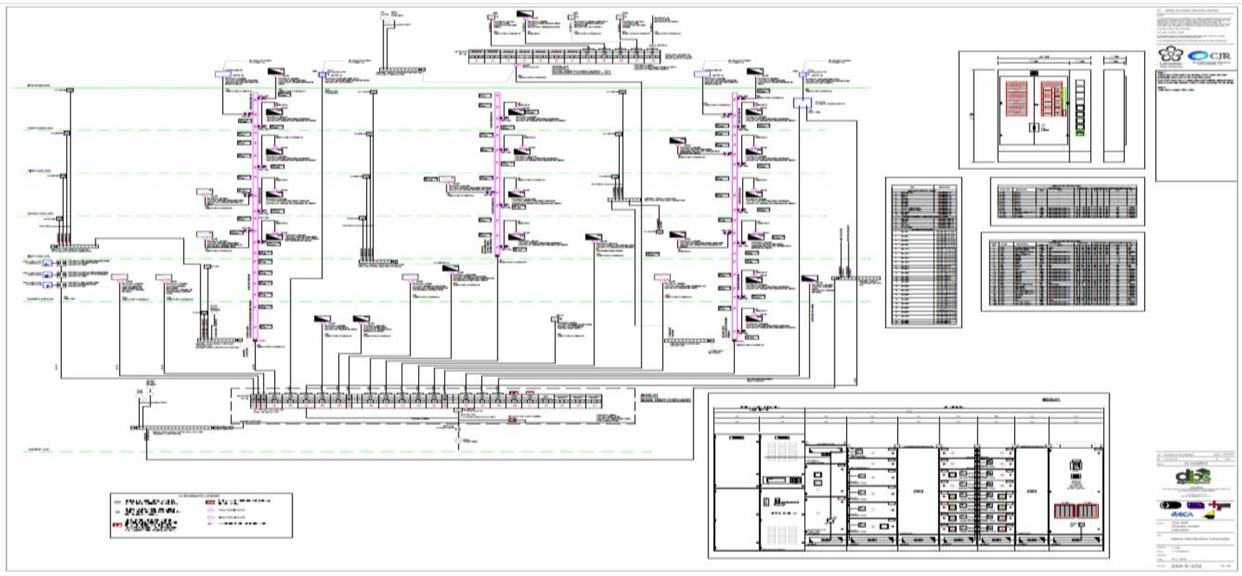

Figure 28 Leicester City Hall mains distribution schematic

A Simulink model was created based on the schematic, shown in Figure 29.

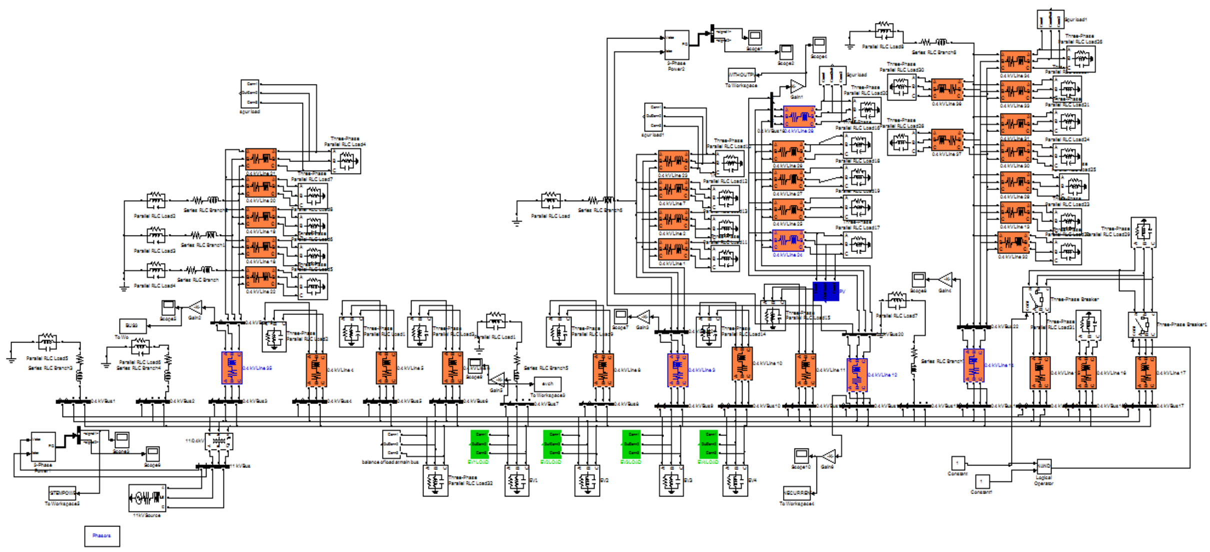

Figure 29 Leicester City Hall mains distribution Simulink model

The total system input power was known. No information was however available on the amount of power flow in each line. Accordingly, each line was rated in terms of its fuse capacity, and the assumed percentage of total input power allocated to each line, see Table 23.

The 800 kVA main transformer was found to be well specified, for instance on 22 June 2018 the transformer loading never exceeded 25%. Given the considerable spare transformer capacity an additional 80 times 7 kW EV chargers at main switchboard could be installed without transformer overload, see Figure 30 Main Transformer Loading 22 June 2018.

Table 23 Derived percentage of total load power in each line

Power in Lines limited by fuse capacity				
Line no.	**Fuse rating**	**Line Type**	**Fuse limited line power W**	**Line % power**
1	63A	1.phase	14490	0.817399496
2	63A	1.phase	14490	0.817399496
3	400A	3 phase	277130	15.63325896
4	63A	3 phase	43648	2.462239697
5	100A	3 phase	69280	3.908173713
6	100A	3 phase	69280	3.908173713
7	63A	1.phase	14490	0.817399496
8	63A	3 phase	43648	2.462239697
9	400A	3 phase	277130	15.63325896
10	160A	3 phase	110851	6.253247174
11	200A	3 phase	138564	7.816573071
12	400A	3 phase	277130	15.63325896
13	63A	1.phase	14490	0.817399496
14	400A	3 phase	277130	15.63325896
15	63A	3 phase	43648	2.462239697
16	63A	3 phase	43648	2.462239697
17	63A	3 phase	43648	2.462239697
		TOTAL	1772695	100

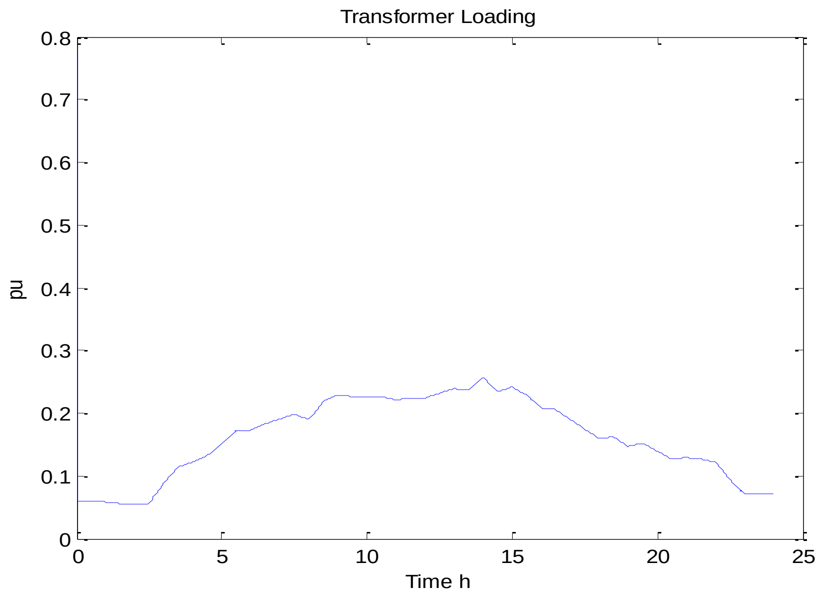

Figure 30 Main Transformer Loading 22 June 2018

The ability of the City Hall's electrical installation to accept additional PV generation was examined; the supply cable was found to be able to support 20 times the existing output without current overload, seeFigure 31.

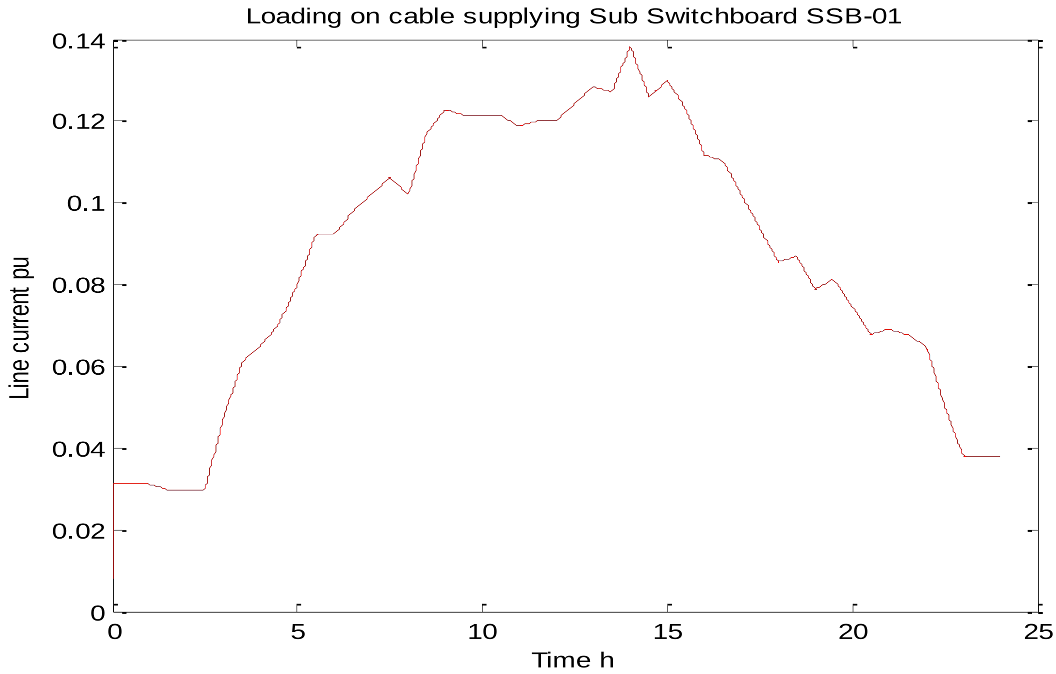

Figure 31 Loading on cable supplying Sub Switchboard SSB-01 22 June 2018 (PV Connection)

The PV installation represented a small fraction of the City Hall baseload, the PV generation curve generally follows pattern of the City Hall load profile. 20 times the existing PV output could be consumed within the City Hall without energy storage becoming necessary. Peak PV occurred on 22 June 2018, see Figure 32.

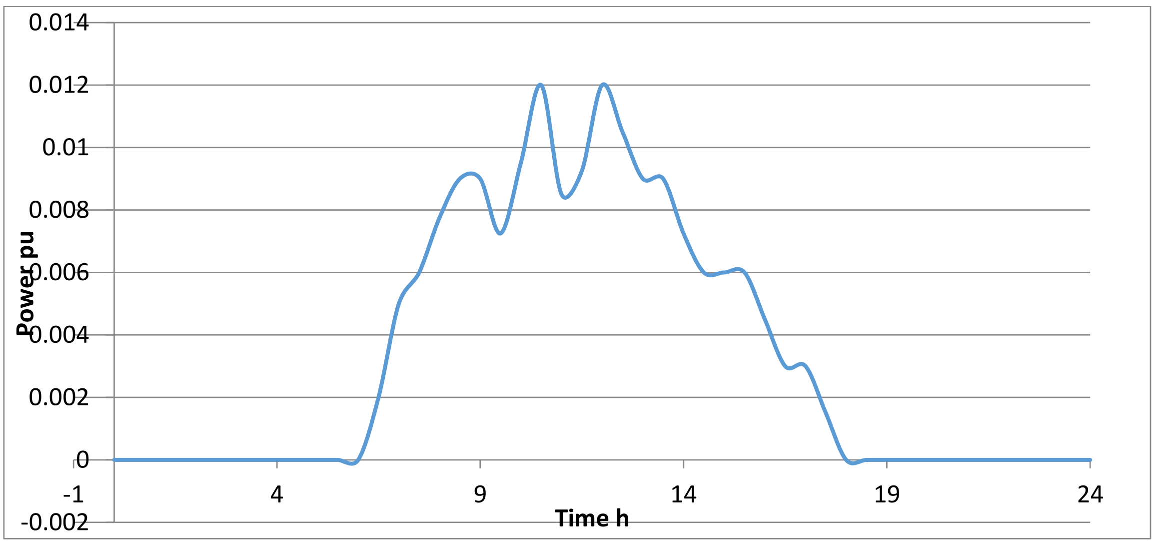

Figure 32 PV generation on 22 June 2018 (800 kVA Base)

Only a very small voltage drop occurred at the main switchboard arising from EV charging.

60 times 7 kW chargers could be operated concurrently before the voltage drop caused the line voltage to reach the statutory minimum of -6%, see Figure 33.

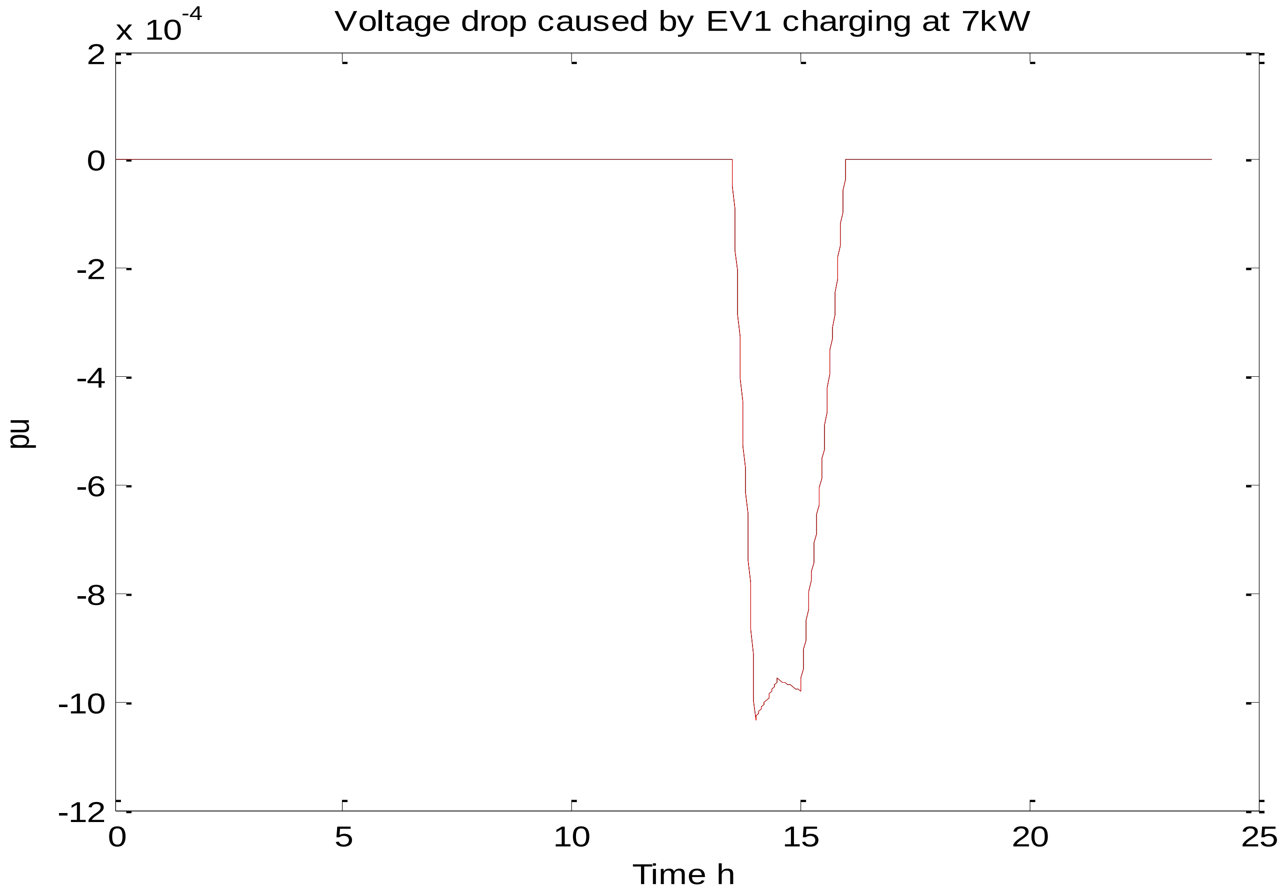

Figure 33 Voltage drop caused by EV1 Charging at Main Switchboard 30 March 2017