SEEV4-City approach to KPI Methodology

SEEV4-city methodology approach to the three Key Performance Indicators

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With additional contributions from all SEEV4-City pilot partners.

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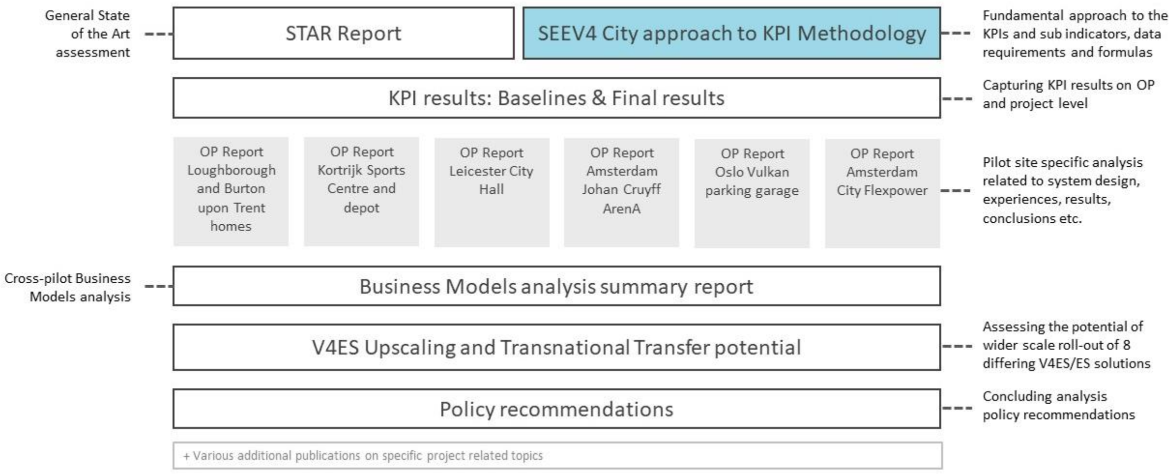
Executive Summary

SEEV4-City is an innovation project funded by the EU Interreg North Sea Region Programme. Its main objective is to demonstrate smart electric mobility and renewable energy solutions integration and share its learnings. The project must report on the results of 6 Operational Pilots (OPs) of the following three Key Performance Indicators (KPIs):

A. Estimated CO_2 reduction
B. Estimated increase in energy autonomy
C. Estimated Saving from Grid Investment Deferral

The project aimed to establish a common methodology to calculate the contributions to the three main KPIs with significant level of detail and accuracy (where feasible). This was a collaborative exercise between Work package (WP) partners leading WP3-Intelligence (Data analysis, monitoring and simulation), WP4-Operational Pilots Implementation and Coordination and WP5-Policy and Business Case work packages and was done in consultation with the OP partners. The result of this effort is collated in this defined approach the KPI Methodology report. It is part of a collection of reports published by the project covering a variation of specific and cross-cutting analysis as well as different evaluation perspectives spanning the 6 operational pilots. Below an overview is given of the set of reports that together form the collective analysis of SEEV4-City. The overview also provides an indication where this 'KPI Methodology' report fits in:



The methodology should be a uniform approach that also is flexible enough to accommodate all combinations that make up the different solutions in 6 OPs. For KPIs A and B this required the use of sub-KPIs to differentiate the effects of each (individual and combination of) implemented solutions and prevent double counting of results. This approach also helped to ensure that all 6 OPs use a common way and scope to calculate the various results. Consequently, this allowed the project to capture the results per OP *and* the total project in one 'measurement results' template. The template is used in both the individual OP reports and the 'KPI Results: Baseline & Final results' report where all results are accumulated; each instance providing a clear overview of what is achieved.

This report outlines the details of the methodology used and applied. It is not just meant to provide a clarification of the results of the project, but is also meant to allow others who are embarking on adopting similar solutions for the purpose of CO_2 reduction, becoming more energy autonomous or avoid grid stress or investments to learn about and possibly use the same methodology.

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Glossary

Term	Definition
BSS	Battery storage system
CO_2	Carbon di-oxide. When using the CO_2 reference in this report it refers to all Greenhouse Gases (GHG). It is common practice to express the extent of any GHG in its CO_2 equivalent (CO_2eq).
DNO	Distribution network operators (term traditionally used in UK) are the operating managers (and sometimes owners) of energy distribution networks.
DSO	Distribution system operators (term used across Europe) are the operating managers (and sometimes owners) of energy distribution networks. More capable of managing the increasingly complex interrelationships on the network than DNOs.
EV	Electric Vehicle – Plug-in Hybrid or Battery Electric Vehicle.
FCR	Frequency containment reserve – The aim of FCR is to stabilise frequency disturbances in the grid, regardless of the cause and location of disruptions.
ICE	Internal Combustion Engines (using fossil fuel)
KPI	Key Performance indicator – a means to measure and quantify the achievement of key desired results.
NSR	North Sea Region
OP	Operational Pilot
PV	Photovoltaic energy generation with solar panels. For The purpose of SEEV4-City where we use the term PV, in fact all forms of RE sources can be used in its place.
RE	Renewable Energy, sustainable and clean energy such as solar, wind, hydro.
SEEV4-City	Project abbreviation: Smart, clean Energy and Electric Vehicles for the City.
SC	Smart Charging - The application of smart technology solutions that enable flexible approaches to EV charging for the purpose of achieving desired objectives for key stakeholders.
V2B	Vehicle-to-Building, bi-directional charging technology where energy can flow in both directions between vehicle and buildings such as offices, sports facilities, factory etc.
V2G	Vehicle-to-Grid, bi-directional charging technology where energy can flow in both directions between vehicle and the energy grid.
V2H	Vehicle-to-Home, bi-directional charging technology where energy can flow in both directions between vehicle and a home.
V2X	Vehicle-to-X, collective term for all variations of bi-directional charging technology such as V2H, V2B and V2G.
V4ES	Vehicle for energy services - Collective or umbrella name for different kinds of (ancillary) Smart Energy Management services that involve EVs such as Smart Charging, V2G and the other services.
ZE km	Zero Emissions or 'green kilometres' for the operational use phase of a vehicle. The ZE km does not take into account emissions from the entire life cycle assessment (LCA) of energy source or vehicle and is intended as the EV equivalent of 'tailpipe' emissions for ICEs to indicate the number of km that are driven on renewable energy.

1. Introduction

SEEV4-City is an innovation project funded by the EU Interreg North Sea Region Programme. Its main objective is to demonstrate smart electric mobility and renewable energy solutions integration and use the experiences and learnings to encourage take-up in cities. Six Operational Pilots (OPs) across four European countries represent the adoption of different smart energy and EV charging solutions at varying scales, some looking only at single domestic properties; others considering whole city (neighbourhoods). The purpose of these smart EV charging solutions is to reduce the peak demand of uncontrolled charging, which refers to charging without any optimal scheduling (Figure 1, left). EV charging can be controlled to support the (local) grid by adopting Smart Charging (SC) or Vehicle-2-Grid (V2G) technologies. Controlled charging can reduce the peak demand and optimize the supply and demand by taking the production of renewable energy in consideration (Figure 1, right).

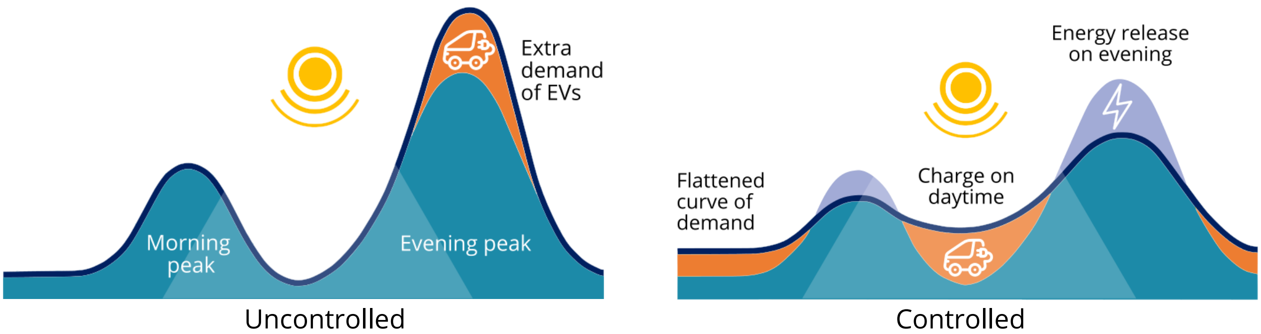

Figure 1 - Visualisation of effect of Controlled vs Uncontrolled

Smart Charging is a unidirectional form that influences the network by controlling the timing of charging. V2G is a bidirectional form of EV charging and discharging, which enables the EV to support the network to balance the energy supply and demand. These two and other ancillary grid services that EVs and stationary battery storage systems can provide are collectively known as Vehicle4EnergyServies (V4ES) [1]. In the six OPs of SEEV4-City, this concept is demonstrated to assess the feasibility, develop viable business models and policy recommendations.

The project indicated it would contribute to and must report on the results from six Operational Pilots (OPs) regarding the following three Key Performance Indicators (KPIs):

A. Estimated CO_2 Reduction
B. Estimated Increase in Energy Autonomy
C. Estimated Savings from Grid Investment Deferral

The methodology in this report is therefore geared towards these three KPIs. Each KPI will be elaborated upon in the corresponding paragraphs in section 2. Each paragraph provides insights to how that KPI is defined in relation to the context of this project.

Although the project consists of three KPIs, the partners realised that, given the significant variety in solutions, sizes and (local) context, the methodology essentially needed to be a uniform approach which is also flexible enough to accommodate all varieties across the different solutions. Therefore, a main requirement for the methodology was that it could be used to assess any combination of these building blocks (that represent the OPs adopted solutions) and the contribution these solutions make to each of the KPIs. First, an inventory was performed to identify the various elements used across all project OPs, from the different technology 'hardware' to the (part digital) smart solutions or 'services'. These represent the collection of 'building blocks' within the project, as visualised below in Figure 2:

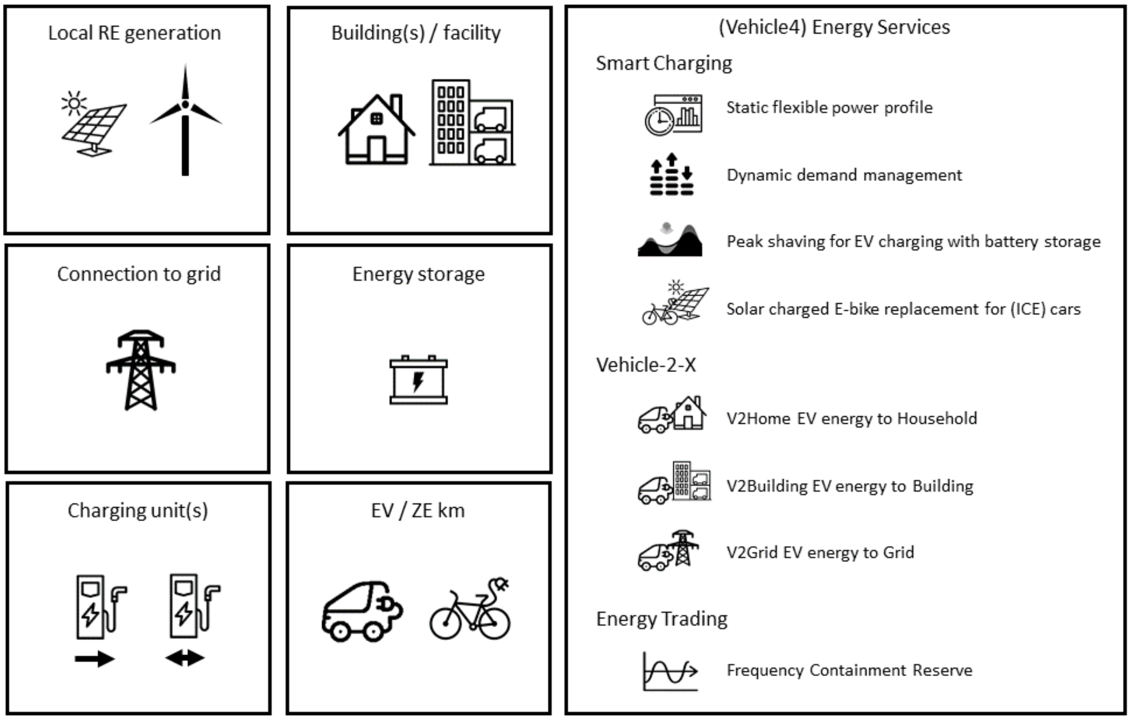

Figure 2 - Project building blocks schematic – system design components

This approach also meant it helped to define the system boundaries for the scope of calculations regarding the OPs ‘impact’ towards the KPIs. This was necessary to prevent an accumulation of (potentially) global variables that may or may not influence the results.

It became clear multiple sub-KPIs would have to be defined with detailed formulas for KPIs A and B. This allows for a uniform means of calculation for different combinations of building blocks and ultimately delivers the result outcomes of a main KPI for any particular OP. Details of the sub-KPIs can be found in the appendices I and II of this report.

The aim of this report is to provide a clear and detailed understanding of the KPI methodology as defined by the SEEV4-City project, supplemented with the detailed formula’s which underpin the calculations of the KPI results. These eventual results (baselines and final measurements, as well as the KPI results) will be analysed by the six Operational Pilots and documented in their Final OP Reports. They will also be collectively documented in the ‘KPI Results: Baselines and Final results’ report.

Section 2 introduces the context of the project and methodology. This is followed by more detailed explanation to methodology approach including key definitions regarding the KPIs in section 3. section 4 gives an indication of the template for capturing the data related to the KPIs and sub-KPIs. This report also includes a list of references used and an appendix providing details of each sub-KPI that collectively make up the calculation approach to KPIs A and B (KPI C has no sub-KPIs).

2. KPI Methodology

In this section the three main KPIs will be described and a methodology will be provided. An indication of the data requirements to calculate the results are also provided.

The concept of smart energy management and V2X to improve the KPIs is illustrated in Figure 3. The illustration does not represent the actual profile measurement of an investigated pilot. As can be seen from Figure 3, when PV is the only local production source, the energy storage (stationary or electric vehicle) is used to store excess generation from the PV (**ES+**) and supply this during the peak demand later in the day (**ES-**). The energy scheduling profile of the storage as such is illustrated by the green curve in Figure 3. The difference between an EV and a static battery (apart from the potential size difference) lies mainly with the fact that an EV (essentially used as a transportation vehicle) has constraints of both availability and the associated vehicle battery State of Charge (SoC) requirement before journeys. By this, also more PV is used locally saving grey energy form the grid, and the peak load is lowered, providing grind investment deferral.

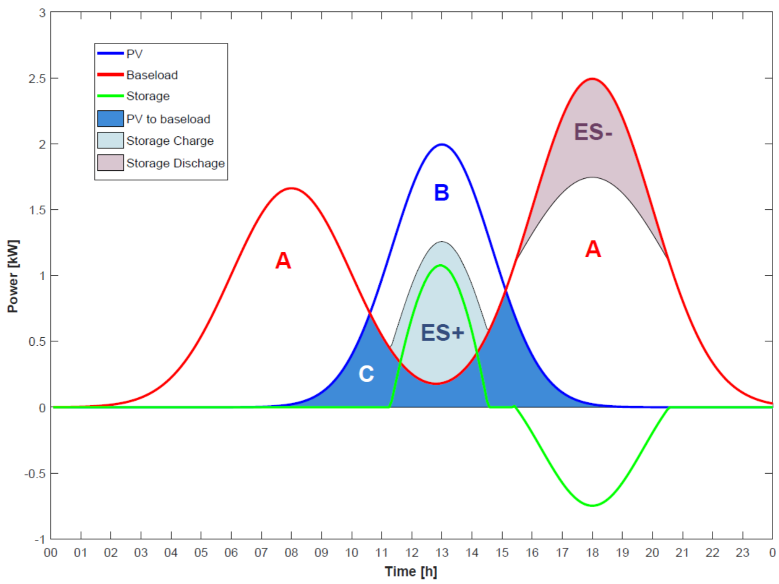

Figure 3 - Illustration of smart energy management

Energy efficiency improvement

Besides the adoptions of system design components such as PV, static storage, and smart charging solutions, it is also possible that measures to improve energy efficiency within the local energy system contribute to the three KPIs.

For example, in case of Amsterdam's Johan Cruyff Arena, where the lighting system (to light the stadium during football matches or concerts) was upgraded. As a result, the energy consumption of the lighting systems was significantly reduced. This potentially leaves more energy from the PV generation to be directed to other components such as to charge EVs, thus is expected to increase the self-sufficiency (therefore increasing energy autonomy) as well as contributing to grid investment deferral as peak demand is lowered, and CO_2 savings as total demand is lowered.

2.1. KPI A – CO_2 Reduction

Each individual Greenhouse Gas (GHG) has its own Global Warming Potential (GWP). The international standard to indicate the GWP impact of GHG emissions is to express them in their 'CO_2 equivalent' (CO_2eq), or CO_2 for short. This KPI reflects the reduction in CO_2 emissions realised by smart charging strategies with V4ES solutions and the replacement of ICE vehicles by EVs. With these, it is possible to shift electricity demand from hours where the energy mix of the grid has a high CO_2 footprint, to hours with a low CO_2 footprint or (stored) self-generated RE. With smart charging the demand profiles can be optimized, and V2X solutions and static batteries can be used as energy buffer.

Any initiative adopting a V4ES (be it any of the various SEEV4-City's solutions or other solutions) can dedicate their CO_2 saving efforts in two areas: improving local Energy (consumption and) Management or providing supporting Grid Services. The methodology for calculation KPI A is therefore defined and elaborated on in section A.1 Emission savings and section A2 Grid Services.

NB: Calculating CO_2 reduction improvements by comparing the footprint of the local energy system with the footprint of the grids energy mix at moment of consumption, is an often used and accepted approach in both literature and other projects. The question remains whether this results in actual CO_2 savings (which has been a lively subject of discussion amongst the partners of the SEEV4-City project). For the purpose of this project, where measuring the results of the operational pilots are central to the project, we maintain this chosen approach to quantifying CO_2 reduction. The project aims to address the pros and cons of this approach separately, for example through a position paper.

A.1 Emission savings

Within emissions savings we identified three categories; 1. CO_2 related to solution, 2. ICE replacement and 3. zero emission kilometres increase.

1. CO_2 related to solution

To understand the value and actual contribution of the CO_2 emission savings of the adopted solution, we compare the electric energy demand which would otherwise have been taken entirely from the grid with the actual grid consumption (also accounting for any energy that has been supplied back to the grid), which equals the CO_2 footprint of the pilot initiative. In an effort to identify what the added benefits of individual different energy system components are, such as static or EV batteries and PV (RE), the project has defined sub-KPIs in Appendix I, A1.1 to A1.5.

For calculating the CO_2 footprint of the pilot, we use the power exchange of the pilot with the national grid and the CO_2 emission factor of the mix of generation in the national grid. To do this we use the following formula:

$$CO_2^{pilot} = \sum_{t=1}^{T^s}(e_t^{CO2} * P_t^{grid} * \Delta t) \qquad (A.1)$$

Where,

- CO_2^{pilot} is the total amount of CO_2 emission related to the electric energy demand within the pilot boundaries;
- e_t^{CO2} is the emission factor of the national energy mix (average emission factor) at timestep t, in gram CO_2/kWh;

- P_t^{grid} is the power exchange with the grid at time t, in kW. A positive value is energy into the pilot, a negative value is feeding energy back into the grid (when there is a surplus of solar energy and/or delivery by a battery);
- T^s is the total number of timesteps. For calculating the yearly CO_2 footprint this is for one year;
- Δt is the duration of a timestep, preferably 15 minutes or 1 hour (and P * Δt = energy in the period Δt, in kWh);
- If energy is supplied back into the grid, P_t^{grid} will be negative

The power exchange with the national grid is measured in every pilot. Here, a positive CO_2 value indicates an CO_2 increase, and a negative value represents emission savings.

For the emission factor of the national grid we use the ENTSO-E data of every country [2]. This data gives for every hour of the year the generation mix for that hour. With data of the CO_2 emission for every kind of generation, we calculate the hourly emission factor of the energy mix of the relevant country's grid. See Table 1 for an example of the CO_2 emission per kWh for different generation sources. The data in this table includes LCA related CO_2 emissions for the energy infrastructure.

Table 1: g CO_2 emission per kWh for different generation sources [3]

Generation Source	g CO_2/kWh
CCGT	499
Nuclear	29
Biomass	45
Coal	888
Wind	26
Solar	85
Oil	733
OCGT	499
Hydro	26
Pumped Hydro	586

As the mix of generation sources varies during the day, for example with solar, the grid specific CO_2 emissions will also vary during the day. Figure 4 presents an example of the calculated grid specific CO_2 emissions for the Netherlands, made for 28/06/2018, with lower specific CO_2 emissions around midday because of the solar power production on this sunny day.
As the mix of generation sources varies per country, big differences can be seen in the grid specific CO_2 emissions. In 2019, for example, the calculated average annual value for Netherlands is 466 g CO_2/kWh, for UK 269, for Belgium 174 and for Norway 31.

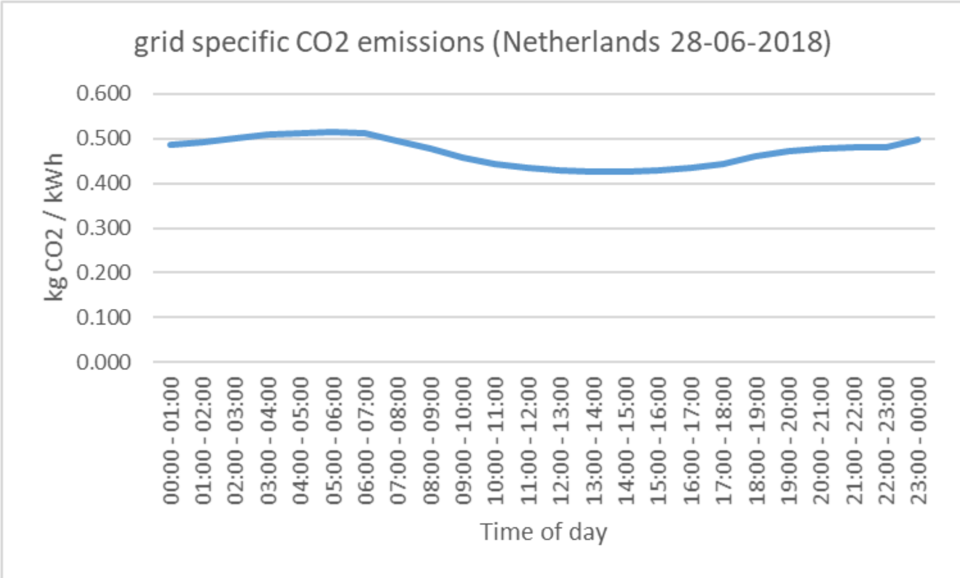

Figure 4 - NL Grid specific CO_2 emission 28/06/2018

For calculating the CO_2 reduction, we compare the periods before and after implementing energy technology solution.

Pilot data requirements:

Name	Unit	Notes
Energy exchange with the grid	kWh	Timestamp needed
Average national emission factor e_t^{CO2}	g CO_2/kWh	Timestamp needed

2. ICE replacement

EVs and Ebikes have a lower environmental impact and are therefore more sustainable solutions over ICE vehicles. CO_2 emissions are saved by replacing the existing ICE vehicles by an EV or Ebike. We have developed a calculation method for both types of transport and can be found in Appendix I, A1.5 and A1.5.1.

3. Zero emission kilometres increase

Lastly, charging EVs and Ebikes are prioritized to make use of renewable energy within the SEEV4-City project. By optimising this supply and demand, zero emission kilometres are increased. However, it is recognised that the EVs and Ebikes are partially charged by electric energy from the grid using a mix of different generation sources. Therefore, a methodology is developed to calculate the amount of RE that is used to charge the EVs or Ebikes and can be found in Appendix I, A1.6 and A1.6.1.

A.2 Grid Services

With renewable energy sources (RES), electric energy is generated intermittently, resulting in fluctuations on the energy grid. The grid needs to maintain a frequency of 50 hertz which means power generation and demand need to be balanced. With a growing installed capacity of RES on the national grid, keeping the frequency on the grid in balance becomes a greater challenge. Batteries can support the net balancing through different kind of grid services such as Frequency Containment Reserve (FCR) (A2.1) and back-up services (A2.2).

A.2.1 FCR - Frequency Containment Reserve

For FCR, a fossil power generator is running at a lower power than optimal, because some Mega Watt (MW) must remain available for gearing up when needed for FCR. See Figure 5.

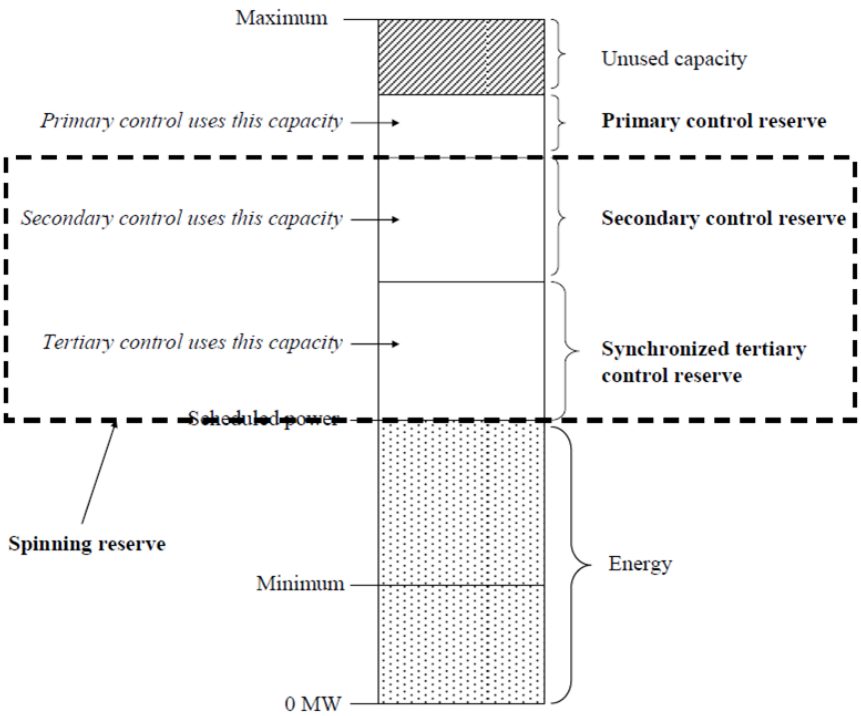

Figure 5 - Representation of the spinning reserve of a generating unit that participates in all three levels of frequency control [4].

This lower than optimal power means a lower efficiency. So, by use of a battery for FCR, less MW (usually from fossil generators) will need to be available for gearing up when needed for FCR.

Calculation method:

For calculating the avoided CO_2 emission, we need the battery power and the amount of MWh per year. For the fossil power plants we need a number for efficiency increase and related CO_2 savings. As the auctions for FCR are not public, it is not known which generators are replaced by the battery. It will also vary over the year with the variation in fuel prices. As a first order assumption we can take a mix of 50% coal fired power plants, and 50% gas fired. In Figure 6 and Figure 7 some efficiencies are given for fossil power plants in the Netherlands.

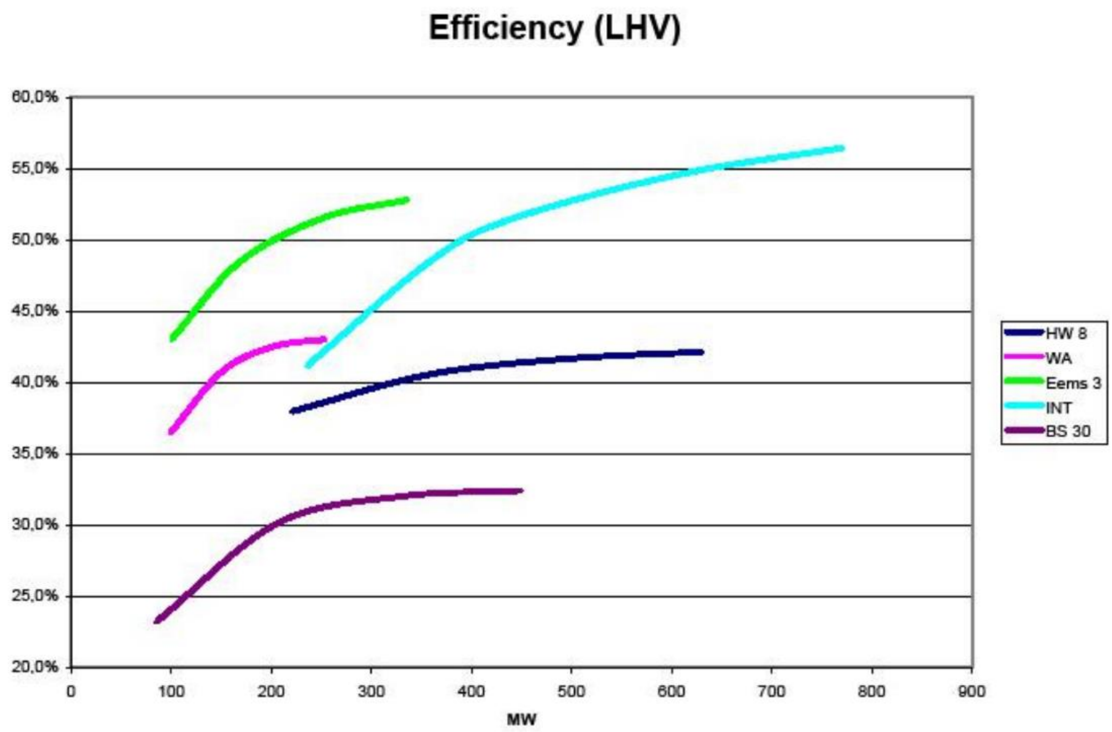

Figure 6 - The efficiency of several Dutch energy generators at full power and partial load [5]

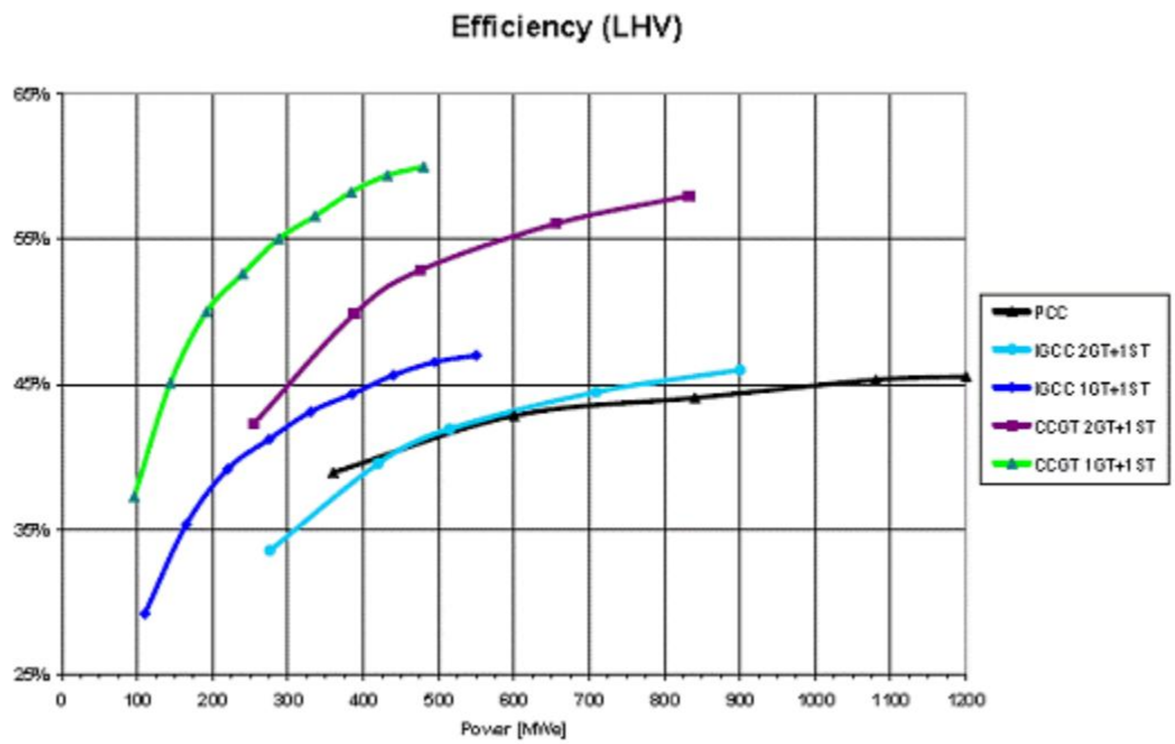

Figure 7 - Efficiency of newer generators [5]

Note: PCC = pulverised coal combustion, IGCC = integrated gasification combined cycle (Coal gasification), CCGT = combined cycle gas turbine.

For the Netherlands, the amount of FCR power is annually determined by ENTSO-e and is 111 MW in 2019 [6]. So, fossil generators must have at least this amount of power as reserve. The average size of the coal fired power plants is 932 MW, and from Figure 6 and Figure 7 we calculate an efficiency improvement of

0.005%/MW between 821 MW and 932 MW. The average size of an CCGT (STEG) is 446 MW, and for the gas fired power plants we see an efficiency improvement of 0.025%/MW between 335 MW and 446 MW. For coal, the emissions at full load are, according to Table 1Table 1: g CO_2 emission per kWh for different generation sources , 888 gr/kWh, and the efficiency (Figure 6 and Figure 7) around 42%.

For coal power plants, when running at 821 MW, the efficiency is 0.5% lower, so around 41.5%, and the emissions 42/41.5 * 888 = 899 gr/kWh. For gas, the emissions are 499 gr/ kWh at 100% load, with an efficiency of 60%, and when running at 335 MW, the efficiency is 57.5% and emissions are 521 gr/kWh. For calculating the CO_2 savings by the battery for FCR, we use the battery power to calculate the efficiency improvement, and by this the CO_2-savings in gr/kWh. Multiplied by the power of the generator, and by the number of hours per year gives the yearly CO_2 savings.

Pilot data requirements:

Name	Unit	Notes
Battery power	MW	
Hours used for FCR	Hours per year	

A.2.2 Battery as back-up services (replacement of diesel generators)

To calculate the CO_2 reduction for the replacement of diesel generators by use of a battery, we need to know how much energy was discharged from the battery that would otherwise be produced by the diesel generator(s). In general, an optimistic efficiency number for a diesel generator is η = approximately 35%[1], this should be checked with the specific diesel generator specifications. Diesel has an energy content of 38.6 MJ/l (10.72 kWh/l) [7]. Combusting 1 litre of diesel results in approximately 3.2 kg CO_2 [8] [9].

N.B: storing and discharging energy from a battery electric storage system results in losses. The losses should be considered when this data is available.

Calculation method:

Litres diesel saved = kWh saved / (10,72 kWh/l * η)
Kg CO_2/l = Litres diesel saved * 3.2 kg CO_2

[1] Efficiency of the ArenA diesel generators

Pilot data requirements:

Name	Unit	Notes
Efficiency of diesel generator (when available)	Percentage	η = approx. 0.35 when specifications are not available
Diesel use per year, or number of hours running per year	Liter, or Hours running	

2.2. KPI B – Energy Autonomy Increase

Energy autonomy is reflected by how self-sufficient a local energy system is by calculating how much of the self-generated RE is self-consumed compared to the total amount of energy consumed. Where the indicator of self-consumption reflects how much of the self-generated RE is self-consumed, it does not provide an indication of how this compares to the total energy demand.

For example, if all the energy generated within the local system boundaries (such as a household with PV) is consumed within that same local system, the self-consumption will be 100%. However, if the total energy demand of that local system boundary is ten times that amount, full energy autonomy is not achieved. Therefore, the self-sufficiency is a better indicator to reflect Energy Autonomy as it also incorporates the comparison to the total amount of energy consumed (including that what has been consumed from the grid).

This KPI reflects the increase in energy autonomy in percentage indicating the level of energy independence from the grid achieved through the interaction between electric vehicles and the renewable energy which is generated within the local system boundaries with different V2X solutions across the SEEV4-City project's OPs (at household, building, street or neighbourhood/city level). In an effort to identify what the added benefits of individual energy system components is, such as static or EV batteries and PV (RE), the project has defined several sub-KPIs in appendix II, in addition to B.1.

B.1 Self Sufficiency

With reference to Figure 9,

$$Self - sufficiency = \frac{Amount\ of\ local\ PV\ production\ consumed}{Total\ energy\ consumed} = \frac{C+ES^{+}}{A} \qquad \text{(B.1a)}$$

Where A is the baseload energy demand, C is the local demand supplied by local generation and ES^{+} is the energy stored(locally) from excess local generation

To calculate where the energy of the PV is going, we need to know if the battery (whether the EV battery and/or the BSS) is taking power or is delivering power within the duration of a timestep. When a battery is delivering power for some reason, this means that part of this energy will go to the baseload demand and less energy of the PV system can be used within the pilot.

This may also be derived algebraically from sampled data using the following expressions (the variables are explained below):
First, we calculate the net energy demand within the pilot for every timestep:

$$P_t^{demand} = P_t^{baseline} + \max(0, P_t^{EV}) + \max(0, P_t^{Ebike}) + \max(0, P_t^{BSS}) \quad \text{(B.1b)}$$

Then calculate the net energy delivery within the pilot:

$$P_t^{localsupply} = P_t^{PV} - \min(0, P_t^{EV}) - \min(0, P_t^{Ebike}) - \min(0, P_t^{BSS}) \quad \text{(B.1c)}$$

Then we can calculate how much of the PV energy is used within the pilot boundaries:

$$Self - Sufficiency = \frac{\sum_{t=1}^{T^S} min\left(P_t^{PV}, \frac{P_t^{PV}}{P_t^{supply}} * P_t^{demand}\right)}{\sum_{t=1}^{T^S} P_t^{baseline}} \quad \text{(B.1d)}$$

Where,

- P_t^{PV} is the PV generation at timestep t;
- $P_t^{baseline}$ is energy consumed, being archetype electricity demand;
- P_t^{EV} is the power exchange by the EV at timestep t, is positive when energy is going into the battery; and negative if energy is going out of the battery;
- P_t^{Ebike} is the power demand by the EV at timestep t, is positive when energy is going into the battery;
- P_t^{BSS} is the power exchange by the BSS at timestep t, is positive when energy is going into the battery; and negative if energy is going out of the battery;
- $P_t^{localsupply}$ is total energy supplied by PV and battery (EV and/or BSS);
- P_t^{demand} is total energy demand, by baseline and battery (EV, Ebike and/or BSS);
- $min\left(P_t^{PV}, \frac{P_t^{PV}}{P_t^{supply}} * P_t^{demand}\right)$ yields the amount of local PV production locally consumed;
- T^s is the total number of timesteps;
- Δt is the duration of a timestep, preferably 15 minutes or 1 hour.

The calculation of total energy consumed is straightforward when battery (EV in V2G and/or static battery) is taking power. But when a battery is giving power back, this interferes with the solar production that also gives power to the total demand.

Pilot data requirements:

Name	Unit	Notes
Archetype electricity demand ($P_t^{baseline} * \Delta t$)	kWh	Timestamp needed
EV energy exchange ($P_t^{EV} * \Delta t$)	kWh	Timestamp needed
Ebike energy exchange ($P_t^{Ebike} * \Delta t$)	kWh	Timestamp needed
Battery energy exchange ($P_t^{BSS} * \Delta t$)	kWh	Timestamp needed
PV generation ($P_t^{PV} * \Delta t$)	kWh	Timestamp needed

2.3. KPI C – Grid Investment Deferral

The third KPI of the SEEV4-city project is relating to the deferral of investment in the grid. As a rule of thumb, any grid is dimensioned to be able to meet the peak demand. If the electricity demand increases, the peak demand is expected to rise as well, but the grid capacity has its limits. Expanding the grid capacity would become a necessity to be able to meet this increasing electricity demand. However, reinforcing the grid to expand the capacity is expensive. Alternatively, using smart energy management and V4ES, the need for grid reinforcement can be delayed or avoided.

This KPI reflects the potentially avoided (localized) investment costs in the electricity grid, which would have been necessary to prevent congestion and capacity constraints when adding EV chargers or renewable energy sources. The calculations consider methods that grid operators use to determine their grid costs. These calculations are, where possible (and relevant), on a country specific basis.

The actual value of this KPI is location and grid specific and varies due to several factors including e.g. existing grid infrastructure, customer location with respect to the grid supply point, local demand, and generation profiles, etc. The calculation of the level of grid investment deferral or avoidance is therefore very difficult to evaluate without detailed modelling and data from the Distribution Network Operators on a site by site basis. This knowledge is not available within SEEV4-city partnership. Calculations of any actual avoided or deferred costs strongly depend on the specific local circumstances, and consequently as a method not widely applicable or extrapolated to other locations. A uniform KPI could be somewhat speculative, making it less beneficial than site specific calculations, but it does provide an indication.

For the reasons mentioned above, we use a more generalised evaluation that is based on profiles of electric energy use; the peak power demand in a year and electricity tariff. By using smart charging strategies to lower the peak demand, the difference between the previous peak demand and the new peak demand is calculated in kW. The financial savings of avoided grid investments are therefore calculated in €/kW. Whilst this approach may lack accuracy, it does allow a reasonable evaluation of the deferred or reduced grid investment costs.

The SEEV4-City project OPs cover four different countries. The way grid costs are calculated by the different DNOs in these countries may vary, therefore, desk research was performed to identify practices in each of the four countries, which are outlined below.

United Kingdom

<u>Profiles, reduction in peak demand</u>
Agreed Capacity
When commercial properties are first connected to the electricity distribution network, they are registered as using up to an agreed amount of electrical load. This will be stipulated in the Connection Agreement with the local Distribution Network Operator (DNO) who maintains the electricity network around the properties. This agreed amount of electrical load is known as the Agreed Capacity (measured in kVA). To make this capacity available to customers, they need to pay the DNO a set charge to cover the associated investment and maintenance costs. This charge is known as the Availability or Capacity Charge (measured in pence per kVA). Agreed Capacity is not the same as the physical (cable) power transfer limit in kW set by the electrical capacity of the installation but will be less than or equal to it.

Maximum Demand

The DNO needs to know if customers stay within this agreed amount of electrical load. This is measured through your meter, which records your highest consumption in any half hour each month, and this is known as the Maximum Demand. This element is particularly important because if you exceed your Maximum Demand you will be charged at the higher kVA level, either monthly or annually, depending on how your DNO sets their charges. This surcharge is known as the Exceeded capacity charge.

Measuring Demand

Many suppliers present your maximum monthly demand on the invoices; however, this only shows the maximum throughout the entire month' [10]. The DNO for the area within which Northumbria University is located is Northern Powergrid.

<u>Costs</u>

Northern Powergrid current charges for a LV Half Hourly Metered (domestic) supply [11]:

- Capacity Charge 2.08 p/kVA/day
- Exceeded capacity charge 4.58 p/kVA/day
- Fixed or Standing Charge 17.93 p/MPAN/day
- Charge for actual power consumed is time of day dependant ranging from 5.254 to 1.575 p/kWh.
- Green charge 1.093 p/kWh

The Netherlands

<u>Profiles, reduction in peak demand</u>

For the Netherlands, profiles of electric energy use and production on the low voltage grid are used to calculate what the maximal power demand in a year will be. The following profiles are used:

- Basic electricity demand: yearly profile 2019, made by Nedu [12]
- EV charging demand: profiles based on real charging data (based on reports from HvA and ElaadNL)
- PV production: measured meteodata by KNMI (Dutch national weather institute)
- EV smart charging: optimization profile

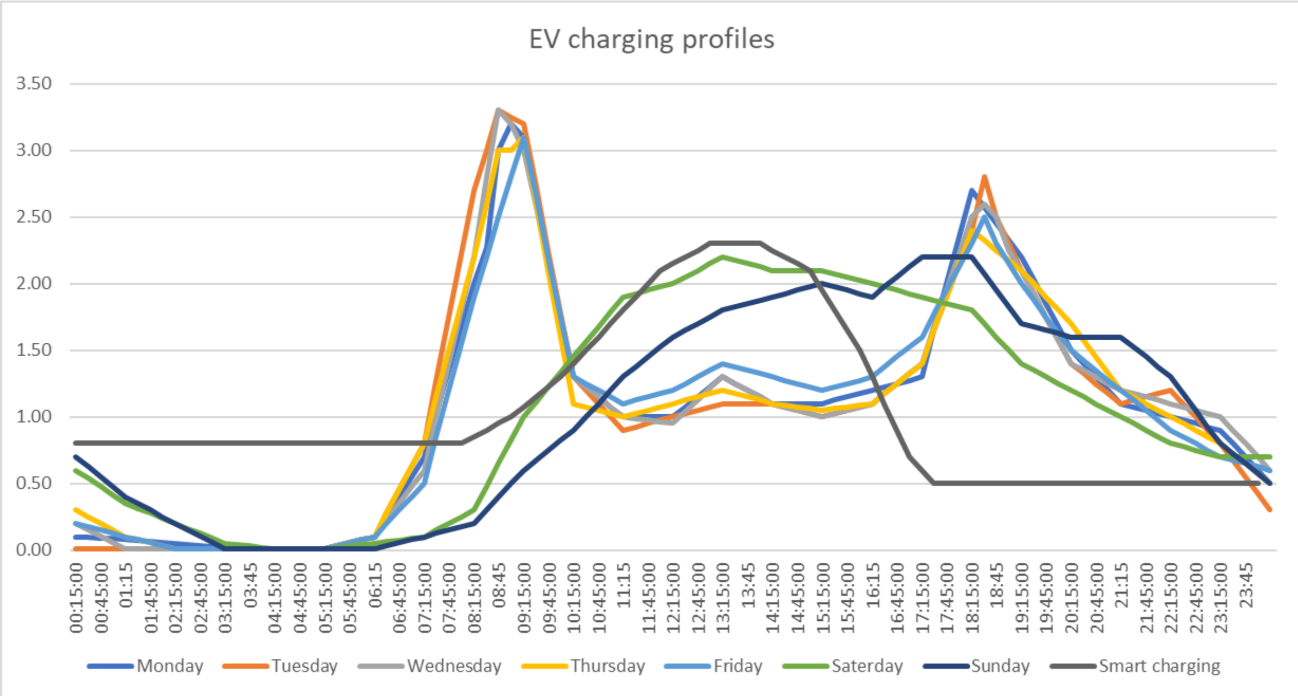

Figure 8 - EV charging profiles

The profiles are used in the EVEC model, with a resolution of a quarter of an hour. For calculating the power usage for every quarter of an hour, we use the yearly energy demand on the low voltage grid in 2030 as given in the report Enpuls_2018 [13]. These energy demands are 21,100 GWh for dwellings, 8,000 GWh for small enterprises, and 700 GWh/yr for street lighting, and 7,400 GWh for charging electric vehicles. There is also an estimated 12 GW of PV systems connected to the LV grid, generating 10,810 GWh/yr.

Costs

Unofficially grid investment numbers are provided by a DNO, indicating 100 €/kW for grid investments.

Note: this approach of €/kW does not consider the differentiation between each individual local capacity connection and potentially corresponding localised grid reinforcement costs. For example, existing old(er) homes and (office) buildings may have a smaller capacity than a new(er) build and therefor may require an upgrade sooner, thus the cost/kW will be different than for new(er) build where you have to invest anyway.

This number is comparable to the results as reported in Cired_2019, being 24 to 102 €/EV. Although in the report “Slim laden must have bij groei elektrisch Vervoer” [14] a much higher number of 916 €/kW is used.

Belgium

Profiles, reduction in peak demand

Costs

Currently, peak demand costs are calculated based on the highest 15-minute average demand peak measured within the year. For billing purposes, the actual measured peak demand is reduced using a flattening coefficient:

E1=B+[C/(D+peak_measured)]

Where, for the area of Flanders around Kortrijk (Gaselwest Distribution Network Operator), the following values are:

B = 0.1

C = 796.5

D = 885

X = €28.6967257 (MV) or € 101.5289704 (LV)

Billing costs for peak demand are then calculated as:

Costs=X[€/(kW*year)]*E1[-]*peak_measured [kW]

Figure 9 shows the impact of the flattening coefficient for various peak demand values between 100 kW and 4000 kW. The consequence of this is that a reduction in peak demand is most strongly encouraged at low peak demand values, as shown in Figure 10.

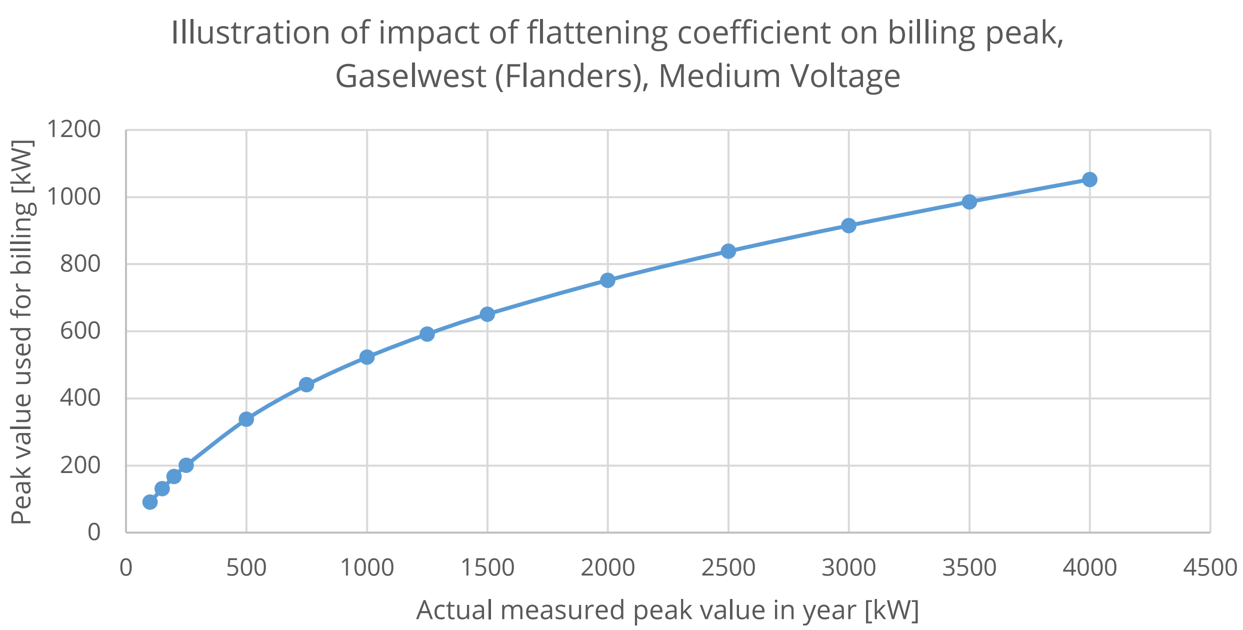

Figure 9 - Example impact of the flattening coefficient as used in Flanders.

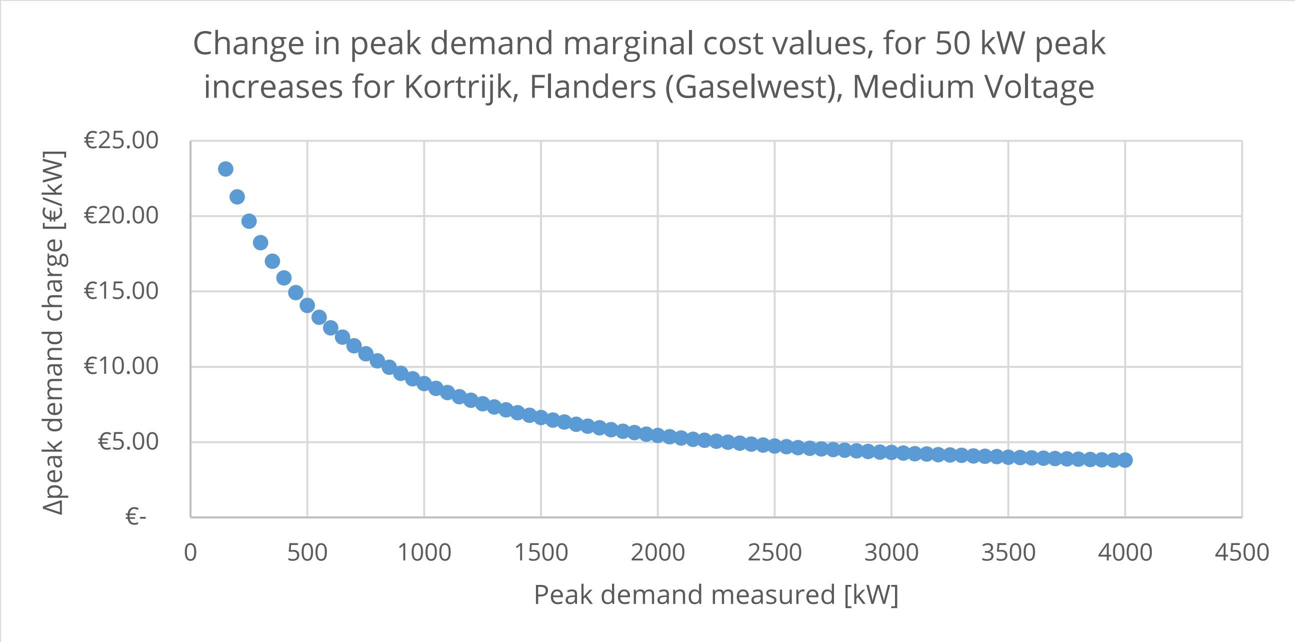

Figure 10 - Reduction in marginal cost values for peak demand changes

The Flemish Energy Regulator (VREG) has been holding consultations [15] with stakeholders about a change in the peak demand charge, to consider for example a monthly peak demand value, instead of the single annual peak. To date, any such rule and billing change has not yet been approved.

In the overall scheme, peak demand charges are approximately 23% of the total energy bill, the remainder being the energy component, public service charges, transmission costs, and taxes [16]. Consequently, reducing the peak demand is currently not very cost-effective for many companies.

Norway

Profiles, reduction in peak demand

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 in addition on the sum of the above.

(A) Basic power cost

The Oslo car park is a service industry, for which the 3rd quarter 2019 basic power cost ('Forbruk') was 37.9 Øre/KwH. In addition, there is a fixed connection charge of 39.20 Kr/month, known as the 'Fastbelop' [17]

(B) Grid Rent

The costs associated with the development and operation of the electricity grid are charged to the part of the electricity bill called the grid rent. Charges include (a) a fixed monthly fee ('Fastledd'), (b) an energy link ('Energiledd') that varies depending on whether it is winter or summer and (c) a power link ('Effektledd') with three different prices depending on the season.

The fixed monthly fee (a) is straightforward, amounting to 340 Kr/month per facility [18]

The energy link (b) is a fee is paid per consumed kWh. In the five months from November to March, a fee of 7 øre / kWh is paid, while in the months of April to September a fee of 3.9 øre / kWh is paid [18].

The power link charge (c) is a price paid per kW / month, being Kr150/kW in the months December to February, Kr 80/kW in March and November, and Kr 23/kW in the period from April to October. The power link charge is applied to the measured power in kW during the hour of highest power consumption during the invoice month. This means that the one hour when the most electricity is used determines how much power applies for the whole of the month [18]. Measures taken to reduce peak demand, such as storage, can save money.

(C) Forbruksavgift
A tax called 'Forbruksavgift' is levied on all electric power supplied in Norway, including power supplied free of charge which power distribution companies or generators use for internal purposes. Where one is dealing with a service business the tax rate is 15.83 øre per kWh [19].

<u>Costs</u>
Unofficially grid investment numbers provided by a Norwegian DNO have not been identified at this stage.

3. Measurements Template

The overview in Table 2 is used to capture the baseline and final measurement data for each OP as well as the difference between the two measurements provided in the last column. This template is included in each of the pilot reports. The collection of tables for all OPs is collated in the report 'KPI Results: Baselines and Final Results'.

Table 2 Measurements Template

		(i) Initial stage	(ii) End of Project	
		Value	**Value**	**Compared to (i)**
A. CO_2 Reduction				
A.1	Pilot CO_2 footprint	X	X	X
A.1.1	CO_2 related to baseline demand	X	X	X
A.1.2	CO_2 related to use of battery: EV	X	X	X
A.1.2.1	CO_2 related to use of battery: Ebikes	X	X	X
A.1.3	CO_2 related to use of battery: BSS	X	X	X
A.1.4	CO_2 savings by PV production	X	X	X
A.1.5	ICE replacement CO_2 savings (EV)	X	X	X
A.1.5.1	ICE replacement CO2 savings (Ebike)	X	X	X
A.1.6	Zero Emission kilometres increase (EV)	X	X	X
A.1.6.1	Zero Emission kilometres increase (Ebike)	X	X	X
A.2	Grid Services	X	X	X
A.2.1	FCR – Frequency Containment Reserve	X	X	X
A.2.2	Battery as back-up services (replacement of diesel generators)	X	X	X

		(i) Initial stage	(ii) End of Project	
		Value	**Value**	**Compared to (i)**
B. Energy Autonomy Increase				
B.1	Self Sufficiency	X	X	X
B.2	Self Consumption	X	X	X
B.3	PV to Baseline Demand	X	X	X
B.4	PV to EV	X	X	X
B.4.1	PV to Ebike	X	X	X
B.5	PV to BSS	X	X	X
B.6	PV to Grid	X	X	X

		(i) Initial stage	(ii) End of Project	
		Value	**Value**	**Compared to (i)**
C. Grid Investment Deferral				
C.1	Peak Demand Value	X	X	X

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Appendices: Sub-KPIs A.1 & B Methodologies

As indicated in the chapters for KPIs A.1 and B, the project recognises the potential value in identifying the benefits of individual energy system components (such as PV, BSS and EV battery as storage) for design decisions for a specific location. The SEEV4-City project has therefore chosen to define several sub-KPIs for the purpose of capturing potentially additional insights in relation to CO_2 and Energy Autonomy objectives and the role these different components may play. The methodology for calculating their contributions is described below.

Overview sub-KPI A.1 & B Methodologies

I. Sub-KPIs A.1 *Emission Savings*

- **A.1.1 CO_2 related to baseline demand**
- **A.1.2 CO_2 related to use of battery: EV**
- **A.1.2.1 CO_2 related to use of battery: Ebikes**
- **A.1.3 CO_2 related to use of battery: BSS**
- **A.1.4 CO_2 savings by PV production**
- **A.1.5 ICE replacement CO_2 savings (EV)**
- **A.1.5.1 ICE replacement CO_2 savings (Ebike)**
- **A.1.6 Zero Emission kilometres increase (EV)**
- **A.1.6.1 Zero Emission kilometres increase (Ebike)**

II. Sub-KPIs B *Energy Autonomy*

- **B.2 Self-consumption**
- **B.3 PV to Baseline Demand**
- **B.4 PV to EV**
- **B.4.1 PV to Ebike**
- **B.5 PV to BSS**
- **B.6 PV to Grid**

I. Sub-KPIs for A.1 Emissions Savings

As stated in section 2, for calculating the total CO_2 emissions related to the energy demand in a pilot we use

$$CO_2^{pilot} = \sum_{t=1}^{T^s}(e_t^{CO2} * P_t^{grid} * \Delta t) \tag{A.1}$$

In the following sub KPI's we calculate how this CO_2 is divided over the different components in the pilot:

- $CO_2^{baseline}$ CO_2 related to base demand,
- CO_2^{EV} CO_2 related to use of battery EV/V2G,
- CO_2^{Ebike} CO_2 related to use of battery Ebike,
- CO_2^{BSS} CO_2 related to use of fixed battery BSS.

And for completeness, also the savings of CO_2 by PV generation:

- CO_2^{PV} CO_2 savings by PV production

If we have these calculations, we can also calculate the total CO_2 emissions related to the pilot with these sub KPIs:

$$CO_2^{pilot} = CO_2^{baseline} + CO_2^{EV} + CO_2^{Ebike} + CO_2^{BSS} - CO_2^{PV} \tag{A.1a}$$

Pilot data requirements:

Name	Unit	Notes
Archetype electricity demand ($P_t^{baseline} * \Delta t$)	kWh	Timestamp needed
EV energy exchange ($P_t^{EV} * \Delta t$)	kWh	Timestamp needed
Ebike energy exchange ($P_t^{Ebike} * \Delta t$)	kWh	Timestamp needed
Battery energy exchange ($P_t^{BSS} * \Delta t$)	kWh	Timestamp needed
PV generation ($P_t^{PV} * \Delta t$)	kWh	Timestamp needed

A.1.1 – CO_2 related to baseline demand

To calculate this, we use the grid CO_2 mix for every timestep multiplied by electric baseline energy demand:

$$CO_2^{baseline} = \sum_{t=1}^{T^s}(e_t^{CO2} * P_t^{baseline} * \Delta t) \tag{A.1.1a}$$

Where,

- e_t^{CO2} is the emission factor of the national energy mix (average emission factor) at timestep t;
- $P_t^{baseline}$ is the baseline power demand in timestep t;

- T^s is the total number of timesteps. For calculating the yearly CO_2 footprint this is for one year;
- Δt is the duration of a timestep, preferably 15 minutes or 1 hour (and P * Δt = energy in the period Δt, in kWh);

Pilot data requirements:

Name	Unit	Notes
Baseline energy demand ($P_t^{baseline} * \Delta t$)	kWh	Timestamp needed

A.1.2 – CO_2 related to use of battery: EV

$$CO_2^{EV} = \sum_{t=1}^{T^S}(e_t^{CO2} * P_t^{EV} * \Delta t) \tag{A.1.2a}$$

Where,

- e_t^{CO2} is the emission factor of the national energy mix (average emission factor) at timestep t;
- P_t^{EV} is the power to or from the battery in the EV in timestep t (positive if power is going into the battery, negative if power is going out of the battery);
- T^s is the total number of timesteps. For calculating the yearly CO_2 footprint this is for one year;
- Δt is the duration of a timestep, preferably 15 minutes or 1 hour (and P * Δt = energy in the period Δt, in kWh);

Pilot data requirements:

Name	Unit	Notes
EV energy exchange ($P_t^{EV} * \Delta t$)	kWh	Timestamp needed

A.1.2.1 – CO_2 related to use of battery: Ebikes

$$CO_2^{bike} = \sum_{t=1}^{T^S}(e_t^{CO2} * P_t^{Ebike} * \Delta t) \tag{A.1.2b}$$

Where,

- e_t^{CO2} is the emission factor of the national energy mix (average emission factor) at timestep t;
- P_t^{Ebike} is the power to or from the battery in the Ebikes in timestep t (positive if power is going into the battery, negative if power is going out of the battery);
- T^s is the total number of timesteps. For calculating the yearly CO_2 footprint this is for one year;
- Δt is the duration of a timestep, preferably 15 minutes or 1 hour (and P * Δt = energy in the period Δt, in kWh);

Pilot data requirements:

Name	Unit	Notes
Ebike energy exchange ($P_t^{Ebike} * \Delta t$)	kWh	Timestamp needed

A.1.3 – CO_2 related to use of battery: BSS

As specified before, the CO_2eq of the grid energy mix varies at different times. Similarly, the moment of charging and discharging differs as this is inherent to the use of battery storage as an energy buffer. Energy stored in an EV battery, which is subsequently used for non-driving purposes or exported to the grid, is to be considered the same as energy stored in static batteries for the purpose of calculation. During the cycle of charging and discharging batteries some losses occur. These are taken into consideration in the calculation method. Any possible battery degradation because of charging and discharging is left out of scope. Although the project recognizes some degradation may occur over longer periods of time, it is not feasible for OPs to monitor in terms of its impact on the battery lifetime and translation to a CO_2 impact for the project run. To identify the effect of storing the energy in the battery the impact calculation needs to consider the different CO_2eq's of the grid's energy mix at both times. This could result in either a positive or negative impact in CO_2 emissions.

Calculation method:

$$CO_2^{BSS} = \sum_{t=1}^{T^s}(e_t^{CO2} * P_t^{BSS} * \Delta t) \tag{A.1.3a}$$

Where,

- e_t^{CO2} is the emission factor of the national energy mix (average emission factor) at timestep t,
- P_t^{BSS} is the power by the battery in timestep t (positive if power is going into the battery, negative if power is going out of the battery);
- T^s is the total number of timesteps. For calculating the yearly CO_2 footprint this is for one year;
- Δt is the duration of a timestep, preferably 15 minutes or 1 hour (and P * Δt = energy in the period Δt, in kWh);

Pilot data requirements:

Name	Unit	Notes
BSS energy exchange ($P_t^{BSS} * \Delta t$)	kWh	Timestamp needed

A.1.4 – CO_2 savings by PV production

For calculating CO_2 savings by PV production, we use

$$CO_2^{PV} = \sum_{t=1}^{T^s}(e_t^{CO2} * P_t^{PV} * \Delta t) \quad \text{(A.1.4a)}$$

Where,

- e_t^{CO2} is the emission factor of the national energy mix (average emission factor) at timestep t,
- P_t^{PV} is the power produced by the PV system in timestep t,
- T^s is the total number of timesteps. For calculating the yearly CO_2 footprint this is for one year;
- Δt is the duration of a timestep, preferably 15 minutes or 1 hour (and P * Δt = energy in the period Δt, in kWh);

Pilot data requirements:

Name	Unit	Notes
PV generation (P_t^{PV} * Δt)	kWh	Timestamp needed

A.1.5 – ICE replacement CO_2 savings (EV)

CO_2 savings with ICE car replacement can be achieved by replacing the ICE car by an EV, which is a more energy-efficient and therefore more CO_2-efficient alternative.

The following values are used (Figure 11):

	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 11 - Life Cycle GHG Emissions in g/km of a Diesel Car and BEV [20].

A diesel car will have 217 gCO_2/km direct emissions (combustion of diesel) and 27 gCO_2/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 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.

As the "driving" component of the EV results in extra demand at the site, the CO_2 emissions associated with this are already covered by the sub-KPI 1.2. Therefore, the net EV CO_2 emissions become 24 gCO_2/km (CO_2 emissions due to manufacturing of the EV – CO_2 emissions saved by recycling the EV battery).

Consequently, the calculation per year for CO_2 savings due to car replacement is:

$$Car\ replacement\ CO_2\ savings = \sum_{t=1}^{TS}({d_t^{CO2}}_{replacement} - {d_t^{CO2}}_{original}) * D_t \quad \text{(A.1.5a)}$$

Where,

- d_t^{CO2} is the emission factor per km for the vehicle in question for each timestep
  - 244 gCO_2/km for a diesel ICE car
  - 217 gCO_2/km for a petrol ICE car[2]
  - 24 gCO_2/km for an EV (non-driving emissions)
- D_t is the distance driven in km over that timestep

Name	Unit	Notes
D_t	km	Timestamp not needed: daily total

A.1.5.1 – ICE replacement CO_2 savings (Ebike)

CO_2 savings with ICE car replacement can be achieved by replacing the ICE car by an Ebike, which is a more energy-efficient and therefore more CO_2-efficient alternative.

Consequently, the calculation per year for CO_2 savings due to car replacement is:

$$Car\ replacement\ CO_2\ savings = \sum_{t=1}^{TS}({d_t^{CO2}}_{replacement} - {d_t^{CO2}}_{original}) * D_t \quad \text{(A.1.5b)}$$

Where,

- d_t^{CO2} is the emission factor per km for the vehicle in question for each timestep
  - 244 gCO_2/km for a diesel ICE car
  - 8 gCO_2/km for an Ebike (non-driving emissions)[3]
- D_t is the distance driven in km over that timestep

Name	Unit	Notes
D_t	km	Timestamp not needed: daily total

A.1.6 – Zero Emission kilometres increase (EV)

Providing the ZE km increase factor is one of the additional objectives defined for SEEV4-City as a project. Determining the amount of ZE km for the SEEV4-City Operational Pilots (and thus how much it has increased by adopting the new solution) means we must assess the amount of renewable energy used to charge Electric Vehicles.

[2] Based on: https://www.co2emissiefactoren.nl/lijst-emissiefactoren/

[3] Few sources make the full breakdown of driving versus non-driving emissions of Ebikes; this value includes driving (=charging) emissions, which makes this a conservative estimate. See a.o. https://iiw.kuleuven.be/apps/lev/eindrapport.pdf

The project acknowledges there are two scenarios that may apply (or a combination of both):

a) charging EVs from the grid (depending on the grid's RE %)
b) charging EVs from locally generated RE (i.e. circumventing the grid)

For both we need to know the amount of kWh's used to charge EVs from the grid and/ or how much was used to charge from local RE.

To calculate how much of the energy of the grid is going into the EV, and how much of the PV system, we first must calculate the total supply:

$$P_t^{totalsupply} = P_t^{PV} - \min(0, P_t^{EV}) - \min(0, P_t^{BSS}) + \max(0, P_t^{grid}) \quad \text{(A.1.6a)}$$

From this we can calculate the fraction of grid energy to the EV:

$$P_t^{grid,EV} = if(and(P_t^{grid} > 0, P_t^{EV} > 0), \frac{P_t^{grid}}{P_t^{totalsupply}} * P_t^{EV}) \quad \text{(A.1.6b)}$$

The fraction of RE in the grid energy mix is from the ENTSO-e data, and is the fraction of kWh produced by PV+wind+biomass+hydro to the total amount of kWh produced per timestep:

$$F_t^{grid,RE} = \frac{P_t^{wind}+P_t^{solar}+P_t^{hydro}+P_t^{biomass}}{P_t^{nationalgrid}} \quad \text{(A.1.6c)}$$

The fraction of PV going to the EV is given by:

$$PV_t^{EV} = \text{if}(P_t^{EV} < 0{,}0, \min\left(P_t^{EV}, \frac{P_t^{PV}}{P_t^{totalsupply}} * P_t^{EV}\right) \quad \text{(A.1.6d)}$$

The amount of zero emission kilometres driven is defined as the amount of kWh charged into the EV from RE sources, multiplied by the number of kilometres the EV can drive per kWh.

$$ZEkm = \sum_{t=1}^{T^s}(F_t^{grid,RE} * P_t^{grid,EV} + PV_t^{EV}) * EV^{km} \quad \text{(A.1.6e)}$$

Where

- ZE_{km} is the total amount of km provided by RE;
- EV^{km} is the amount of km that an EV can drive on one kWh. This amount depends on type of car and the use during driving. For the calculations an average value of 6.2 km/kWh is used, taken from reference [Auke Hoekstra [20]];
- P_t^{PV} is the PV generation at timestep t,
- P_t^{EV} is the power exchange by the EV at timestep t, is positive when energy is going into the battery, and negative if energy is going out of the battery;
- P_t^{Ebike} is the power demand by the Ebike at timestep t, is positive when energy is going into the battery;
- P_t^{BSS} is the power exchange by the BSS at timestep t, is positive when energy is going into the battery, and negative if energy is going out of the battery;

- P_t^{grid} is the power exchange with the grid at timestep t, is positive when energy is going into the pilot, and negative if energy is going out of the pilot;
- $P_t^{totalsupply}$ is total energy supplied by PV and battery (EV and/or BSS) and grid;
- $P_t^{grid,EV}$ is the fraction of the energy of the grid that is going into the EV;
- PV_t^{EV} is the fraction of the energy of the local PV system that is going into the EV;
- T^s is the total number of timesteps;
- Δt is the duration of a timestep, preferably 15 minutes or 1 hour.

<u>Pilot data requirements:</u>

Name	Unit	Notes
Grid energy exchange ($P_t^{grid} * \Delta t$)	kWh	Timestamp needed
EV energy exchange ($P_t^{EV} * \Delta t$)	kWh	Timestamp needed
Battery energy exchange ($P_t^{BSS} * \Delta t$)	kWh	Timestamp needed
PV generation ($P_t^{PV} * \Delta t$)	kWh	Timestamp needed

A.1.6.1 – Zero Emission kilometres increase (Ebike)

There are two scenarios that may apply (or a combination of both):

a) charging EVs from the grid (depending on the grid's RE %)
b) charging EVs from locally generated RE (i.e. circumventing the grid)

For both we need to know the amount of kWh's used to charge Ebikes from the grid and/ or how much was used to charge from local RE.

To calculate how much of the energy of the grid is going into the Ebike, and how much of the PV system, we first have to calculate the total supply:

$$P_t^{totalsupply} = P_t^{PV} - \min(0, P_t^{EV}) - \min(0, P_t^{BSS}) + \max(0, P_t^{grid}) \tag{A.1.6a}$$

From this we can calculate the fraction of grid energy to the Ebike:

$$P_t^{grid,Ebike} = if\left(and\left(P_t^{grid} > 0, P_t^{EV} > 0\right), \frac{P_t^{grid}}{P_t^{totalsupply}} * P_t^{Ebike}\right) \tag{A.1.6b}$$

The fraction of RE in the grid energy mix is from the ENTSO-e data, and is the fraction of kWh produced by PV+wind+biomass+hydro to the total amount of kWh produced per timestep:

$$F_t^{grid,RE} = \frac{P_t^{wind} + P_t^{solar} + P_t^{hydro} + P_t^{biomass}}{P_t^{nationalgrid}} \tag{A.1.6c}$$

The fraction of PV going to the Ebike is given by:

$$PV_t^{Ebike} = \text{if}(P_t^{Ebike} < 0{,}0, \min\left(P_t^{EV}, \frac{P_t^{PV}}{P_t^{totalsupply}} * P_t^{Ebike}\right) \quad \text{(A.1.6d)}$$

The amount of zero emission kilometres driven is defined as the amount of kWh charged into the Ebike from RE sources, multiplied by the number of kilometres the EV can drive per kWh.

$$ZEkm = \sum_{t=1}^{T^s}(F_t^{grid,RE} * P_t^{grid,EV} + PV_t^{EV}) * Ebike^{km} \quad \text{(A.1.6e)}$$

Where,

- ZE_{km} is the total amount of km provided by RE;
- $Ebike^{km}$ is the amount of km that an Ebike can drive on one kWh. This amount depends on type of ebike and the use during driving. For the calculations an average value of 130 km/kWh is used, taken from [21];
- P_t^{PV} is the PV generation at timestep t,
- P_t^{EV} is the power exchange by the EV at timestep t, is positive when energy is going into the battery, and negative if energy is going out of the battery;
- P_t^{Ebike} is the power demand by the Ebike at timestep t, is positive when energy is going into the battery;
- P_t^{BSS} is the power exchange by the BSS at timestep t, is positive when energy is going into the battery, and negative if energy is going out of the battery;
- P_t^{grid} is the power exchange with the grid at timestep t, is positive when energy is going into the pilot, and negative if energy is going out of the pilot;
- $P_t^{totalsupply}$ is total energy supplied by PV and battery (EV and/or BSS) and grid;
- $P_t^{grid,EV}$ is the fraction of the energy of the grid that is going into the EV;
- PV_t^{EV} is the fraction of the energy of the local PV system that is going into the EV;
- T^s is the total number of timesteps;
- Δt is the duration of a timestep, preferably 15 minutes or 1 hour.

<u>Pilot data requirements:</u>

Name	Unit	Notes
Grid energy exchange ($P_t^{grid} * \Delta t$)	kWh	Timestamp needed
EV energy exchange ($P_t^{EV} * \Delta t$)	kWh	Timestamp needed
Ebike energy exchange ($P_t^{Ebike} * \Delta t$)	kWh	Timestamp needed
Battery energy exchange ($P_t^{BSS} * \Delta t$)	kWh	Timestamp needed
PV generation ($P_t^{PV} * \Delta t$)	kWh	Timestamp needed

II. Sub-KPIs for B - Energy Autonomy

As sub-KPIs for KPI B we focus on self-consumption as well as a subdivision of how much of the PV production is going to the different components, being the baseline demand, EV battery and the BSS. The remaining energy generated by the PV, if there is any, will go into the grid. As the EV, in V2G, and the BSS can both demand and supply energy to the baseline and the grid, we will use the total demand and total supply within the pilot boundaries.

B.2 – Self-consumption

Another definition often used when talking about the use of PV locally is the degree of self-consumption, which represents the percentage of local generation that supplies the demand to the total amount of energy locally generated:

$$Self - consumption = \frac{Amount\ of\ local\ PV\ production\ consumed}{Total\ PV\ energy\ generation} = \frac{C+ES^{+}}{B+C} \tag{B.2a}$$

This may also be derived algebraically in Excel from sampled data using the expressions:

$$Self - consumption = \frac{\sum_{t=1}^{T^s} min\left(P_t^{PV}, \frac{P_t^{PV}}{P_t^{supply}} * P_t^{demand}\right)}{\sum_{t=1}^{T^s} P_t^{PV}} \tag{B.2b}$$

Where,

- $min\left(P_t^{PV}, \frac{P_t^{PV}}{P_t^{supply}} * P_t^{demand}\right)$ yields the amount of PV production locally consumed;
- P_t^{supply} is total energy supplied by PV and battery (EV and/or BSS), formula B.2;
- P_t^{demand} is total energy demand, by baseline and battery (EV, Ebike and/or BSS), formula B.3;
- P_t^{PV} is PV generation;
- T^s is the total number of timesteps;
- Δt is the duration of a timestep, preferably 15 minutes or 1 hour.

Pilot data requirements:

Name	Unit	Notes
PV generation ($P_t^{PV} * \Delta t$)	kWh	Timestamp needed

B.3 – PV to Baseline Demand

To calculate how much of the local PV is going to the baseline demand, we use the following formula:

$$PV^{baseline} = \sum_{t=1}^{T^s} \min(P_t^{baseline}, \min(P_t^{PV}, \frac{P_t^{PV}}{P_t^{totalsupply}} * P_t^{baseline})) \tag{B.3a}$$

Where,

- P_t^{PV} is the PV generation at timestep t;
- $P_t^{baseline}$ is energy consumed, being archetype electricity demand;
- $P_t^{totalsupply}$ is total energy supplied by PV and battery (EV and/or BSS) and grid;

- T^s is the total number of timesteps;
- Δt is the duration of a timestep, preferably 15 minutes or 1 hour.

Pilot data requirements:

Name	Unit	Notes
PV generation ($P_t^{PV} * \Delta t$)	kWh	Timestamp needed

B.4 – PV to EV

To calculate how much of the local PV is going into the EV, we use

$$PV^{EV} = \sum_{t=1}^{T^s} \text{if}(P_t^{EV} < 0{,}0, \min(P_t^{EV}, \frac{P_t^{PV}}{P_t^{totalsupply}} * P_t^{EV}) \quad \text{(B.4a)}$$

Where,

- P_t^{PEV} is the PV generation at timestep t;
- P_t^{EV} is energy going into the EV battery;
- $P_t^{totalsupply}$ is total energy supplied by PV and battery (EV and/or BSS) and grid;
- T^s is the total number of timesteps;
- Δt is the duration of a timestep, preferably 15 minutes or 1 hour.

Pilot data requirements:

Name	Unit	Notes
Archetype electricity demand ($P_t^{baseline} * \Delta t$)	kWh	Timestamp needed
EV energy exchange ($P_t^{EV} * \Delta t$)	kWh	Timestamp needed
Battery energy exchange ($P_t^{ESS} * \Delta t$)		Timestamp needed
PV generation ($P_t^{PV} * \Delta t$)	kWh	Timestamp needed

B.4.1 – PV to Ebike

To calculate how much of the local PV is going into the Ebike, we use

$$PV^{Ebike} = \sum_{t=1}^{T^s} \text{if}(P_t^{Ebike} < 0{,}0, \min(P_t^{Ebike}, \frac{P_t^{PV}}{P_t^{totalsupply}} * P_t^{Ebike}) \quad \text{(B.4b)}$$

Where,

- P_t^{PV} is the PV generation at timestep t;
- P_t^{Ebike} is energy going into the Ebike battery;
- $P_t^{totalsupply}$ is total energy supplied by PV and battery (EV and/or BSS) and grid;

- T^s is the total number of timesteps;
- Δt is the duration of a timestep, preferably 15 minutes or 1 hour.

Pilot data requirements:

Name	Unit	Notes
Archetype electricity demand ($P_t^{baseline} * \Delta t$)	kWh	Timestamp needed
EV energy exchange ($P_t^{ebike} * \Delta t$)	kWh	Timestamp needed
Ebike energy exchange ($P_t^{Ebike} * \Delta t$)	kWh	Timestamp needed
Battery energy exchange ($P_t^{BSS} * \Delta t$)	kWh	Timestamp needed
PV generation ($P_t^{PV} * \Delta t$)	kWh	Timestamp needed

B.5 – PV to BSS

To calculate how much of the local PV is going into the BSS, we use

$$PV^{BSS} = \sum_{t=1}^{T^s} \text{if}(P_t^{BSS} < 0{,}0, \min(P_t^{BSS}, \frac{P_t^{PV}}{P_t^{totalsupply}} * P_t^{BSS}) \qquad \text{(B.5a)}$$

Where,

- P_t^{PV} is the PV generation at timestep t;
- P_t^{BSS} is energy going into the BSS;
- $P_t^{totalsupply}$ is total energy supplied by PV and battery (EV and/or BSS) and grid;
- T^s is the total number of timesteps;
- Δt is the duration of a timestep, preferably 15 minutes or 1 hour.

Pilot data requirements:

Name	Unit	Notes
Archetype electricity demand ($P_t^{baseline} * \Delta t$)	kWh	Timestamp needed
EV energy exchange ($P_t^{EV} * \Delta t$)	kWh	Timestamp needed
Battery energy exchange ($P_t^{BSS} * \Delta t$)		Timestamp needed
PV generation ($P_t^{PV} * \Delta t$)	kWh	Timestamp needed

B.6 – PV to Grid

To calculate how much of the local PV is going into the grid, we use the above calculated values:

$$PV_t^{grid} = PV_t^{PV} - PV_t^{baseline} - PV_t^{EV} - PV_t^{Ebike} - PV_t^{BSS} \quad \text{(B.6a)}$$

And for totals:

$$PV^{grid} = P^{PV} - PV^{baseline} - PV^{EV} - PV_t^{Ebike} - PV^{BSS} \quad \text{(B.6a)}$$

Pilot data requirements:

Name	Unit	Notes
Archetype electricity demand ($P_t^{baseline} * \Delta t$)	kWh	Timestamp needed
EV energy exchange ($P_t^{EV} * \Delta t$)	kWh	Timestamp needed
Ebike energy exchange ($P_t^{Ebike} * \Delta t$)	kWh	Timestamp needed
Battery energy exchange ($P_t^{BSS} * \Delta t$)	kWh	Timestamp needed
PV generation ($P_t^{PV} * \Delta t$)	kWh	Timestamp needed