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CHESS
SET UP

Deliverable 4.3
INTEGRATION WITH THE ELECTRICAL SYSTEM

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D4.3 Integration with the electrical system

1. Introduction

The CHESS SETUP concept aims to achieve an energy efficient system to supply heating and hot water in buildings mainly from renewable sources. The proposed system is based on the optimal combination of solar energy production, heat storage and heat pump use.

What this means is that the proposed system will provide flexibility on the energy demand side, balancing fluctuations in demand profiles where possible, and will therefore also have an impact in the electrical grid.

When including a high amount of heat pumps into the system, new peaks and fluctuations can be generated in the power system. Traditionally, a change in electric demand has to be compensated by a change in electric generation but with the introduction of fluctuating renewable energy sources like wind and solar, electricity generation is also changing in time depending on the weather conditions, which brings additional challenges to the existing power system (Fischer, Lindberg, Mueller, Wiemken, Wille-Haussmann, & , 2014).

For this reason, the incorporation of some kind of energy storage (thermal or electric) can play an important role in shifting demands to reduce peaks in the electrical grid and to help the integration of renewable energy into the grid.

In this study, different scenarios will be developed for Corby's pilot electric grid and at a larger scale for both countries participating with pilot projects (Spain and the UK) to analyse the impact of a major implementation of the system and how can it boost the implantation of new renewable installations (solar photovoltaic and wind power).

The focus will be on the residential sector, starting with Corby's pilot and using the same methodology for Spanish and British electrical grids. A typical summer and winter day will be examined for all scenarios to understand the impact in these very different circumstances both in terms of energy demand and generation.

Electric grid

The security of electricity supply with large integration of renewable energy sources (RES) depends on maintaining a balance between generation and load. Today this is mostly controlled by adjusting the output of conventional generators which means having carbonized electricity for large amounts of time, specifically at demand peaks.

Figure 1 shows three groups of graphics for a typical winter day in the UK power network:

- Hourly demand & price
- Environmental impact
- Supply from each energy source

It is clear that nuclear and hydro provide the base load while gas and carbon power plants provide the flexibility to adapt the generation (supply) to the load (demand) rapidly with the corresponding increase in CO_2 emissions.

Figure 1. Hourly electricity demand, price, environmental impact and supply of UK electricity (National Grid - Elexon, 2017)

Various techno-economic studies suggest two alternatives of managing this balance with higher shares of RES, either by grid reinforcement (improving grid transmission capacity) or demand-side management (DSM), where DSM methods have shown to be more cost effective (Carmo, C., Nielsen, M., 2014). It is essential to increase the system flexibility in order to ensure the integration of intermittent RES.

DSM methods are characterized by an electrification of the building and transport sectors operated according to the maintenance of supply and ensuring the end-users comfort and needs (Carmo, C., Nielsen, M., 2014).

The vision of a smart grid (SG) is defined as: "*an electric grid able to deliver electricity in a controlled, smart way from points of generation to consumers that are considered a non integral part of the SG since they can modify their purchasing patterns and behaviour according to the received information, incentives and disincentives...*" The focus on consumer flexibility is a central point of demand response (DR) and DSM as well as decentralized energy management approaches (Fischer, D., Madani, H., 2017).

A wider approach suggests extending the focus of a smart electric grid towards a whole energy system approach including not only electric demand and generation but as well the heat and transportation sector (Fischer, D., Madani, H., 2017).

2. Heat Pumps in a grid context

In the context of a SG, heat pumps (HP) are seen as part of the demand side that can be actively managed to support the realization of a smart grid. Coupling heat pumps to thermal storage or actively using buildings, thermal inertia offers the possibility to decouple electricity consumption from heat demand, which brings flexibility in operation that can be used in a smart grid (Fischer, D., Madani, H., 2017).

2.1. Flexibility in the power system

The need for flexibility in the power system is frequently motivated by an increase in renewable energy and the resulting need for an ability to react or plan ahead for safe and efficient power system operation (Fischer, D., Madani, H., 2017).

For an individual device the definition of flexibility provided by Euroelectric highlights the important properties as seen from electric point of view:

"On an individual level flexibility is the modification of generation, injection and/or consumption patterns in reaction to an external signal (price signal or activation) in order to provide a service within the energy system. The parameters used to characterise flexibility include the amount of power modulation, the duration, the rate of change, the response time, the location, etc." (Fischer, D., Madani, H., 2017).

The potential of the heat pumps to provide flexibility to the power system depends on different factors (Figure 2).

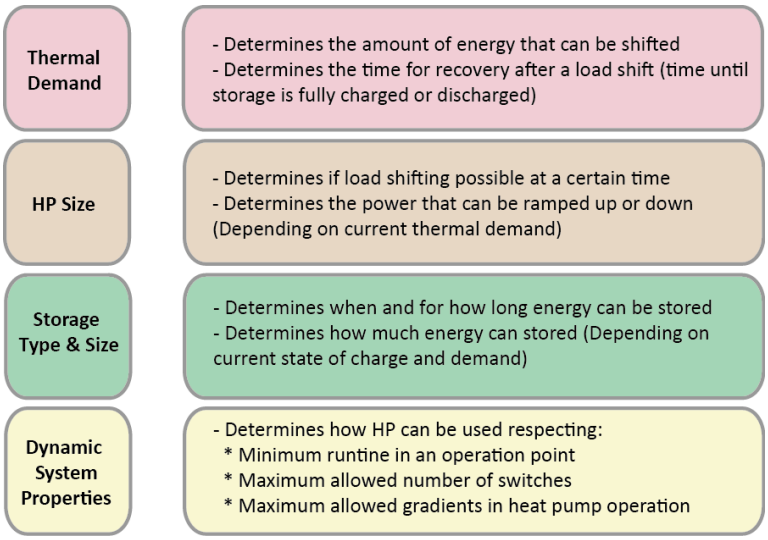


Figure 2. Points that influence flexible operation of heat pumps systems
(Fischer, D., Madani, H., 2017)

Appropriate controls and communication interfaces between the heat pump unit, the building energy management system and the power system are required. If these are given, the potential flexibility is mainly determined by the thermal demand, the heat pump size, the storage size, the dynamic system properties and the flexibility requirements from the power system (Fischer, D., Madani, H., 2017).

The heat pump performance can vary significantly depending on a variety of parameters such as the local climate, the operation mode, the operation period, the heat demand of the building and the building heating system, e.g. radiators, radiant floor heating or fancoils. In the case of a ground source heat pump system, additional parameters associated to the boreholes influence its performance like the soil type, depth of borehole, water velocity in the pipes, etc. (Carvalho, A., Moura, P., Vaz, G., Almeida, A., 2015).

2.2. Applications of heat pumps in a smart grid

Integration into a smart grid will change the way heat pumps are used. This leads to new requirements for HP control and design. The fields of application and conditions under which the heat pumps operate vary significantly; they can be categorized in three domains, these applications overlap and are partly mutually dependent (Figure 3):

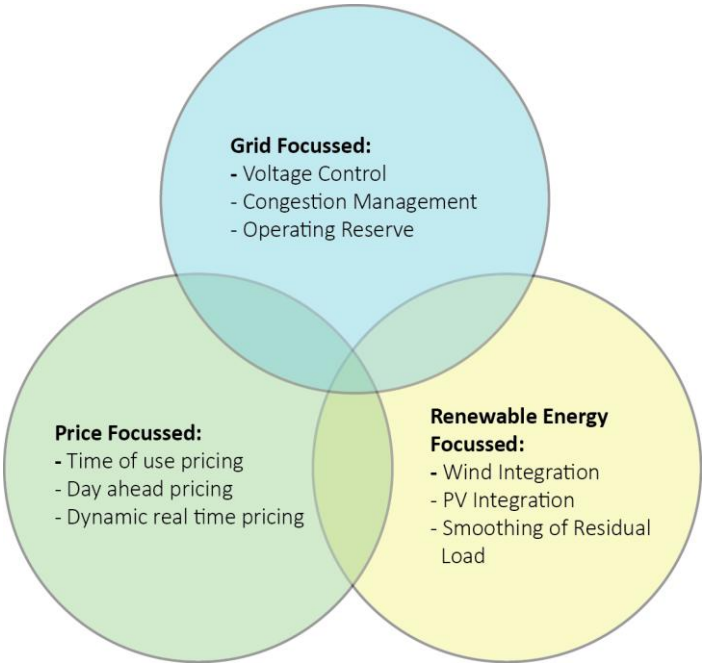


Figure 3. Main fields of applications with heat pumps in a smart grid context, regarding the use-cases presented in academic literature (Fischer, D., Madani, H., 2017)

An overview over studies in the area, their key findings and results are presented in Table 1.

Table 1. Summary of the main applications and the commonly selected approaches and results (Fischer, D., Madani, H., 2017)

Applications		Target	Findings
Grid	**Voltage Control**	• Keep voltage in tolerance band • Reduce critical hours • Reduce grid reinforcement	• Significant reduction of voltage problems with appropriate controls. • If HP is not controlled properly, could lead to voltage problems. • Limited beneficial effects of storage increase.
	Congestion Management	• Keep transformer load within tolerance	• Critical situations in the distribution grid appear mainly in summer (PV) or cold winter (HP). • Controls can help reduce load peaks in most cases but not always. • HP can help reduce grid problems induced by PV, but potential is limited.

	Operating Reserve	• Providing reserve power	• Grid reinforcement due to increased HP penetration can be avoided of limited with appropriate controls. • Pools of heat pumps are able to operate on the reserve market. • Focus of studies on development and demonstration of control strategies. • A bidding and reference tracking strategy is proposed as controls.
Renewable Energy	**Wind Integration**	• Increase wind consumption • Decrease fluctuations and peaks • Reduce carbon emissions	• Mostly focus on aggregated load profile. • Reduced need for peak power plants based on flexible HP operation. • Reduced imbalances. • Correlation of wind availability and space heating demand (northern/central Europe).
	PV Integration	• Increase self-consumption rate • Reduce load peaks • Reduce voltage problems • Reduce carbon emissions	• Mostly focus on individual household. • Increased self-consumption through heat pumps. • Reduced PV-feed in peaks at noon. • Seasonal discrepancy between PV production and heat demand limits self-consumption. • Variable speed HP increase self-consumption for small PV sizes. • Limited impact of increased storage size on self-consumption. • Efficiency losses reported.
	Residual Load	• Smooth load curve • Reduce peaks	• Significant reduction of peaks and valley filling achieved • Reduction of power gradients. • Reduce cost of electric generation.
Price	**Variable Electricity Prices**	• Minimize annual cost of energy	• Most studies focus on decentralized control/scheduling algorithms. • Total electricity purchase cost reduced. • Positive and negative impact on efficiency reported. • Significant load shifting achieved through price signals.

The higher is the RES electricity generation share, the higher and faster penetration of HP systems for domestic hot water, space heating and even space cooling can be expected, therefore higher carbon and primary energy savings can be achieved (Carvalho, A., Moura, P., Vaz, G., Almeida, A., 2015).

2.3. Operation & Controls

The role heat pumps will play in the power system will also influence the way heat pumps are operated and controlled. The main control task of the HP, the supply of thermal energy to meet the comfort requirements, will be extended when integrating the heat pumps into the power system. This will result in two tasks required from future heat pump controllers:

- Planning and scheduling (mostly day-ahead) of the HP operation ahead of time as a reaction to a forecast or broadcasted signal (e.g. day-ahead prices)
- Change of operation as a reaction to real time signal

The control approach of the HP and storage is selected depending on the application. For all applications controls should ensure user comfort requirements, while maximizing its use. The objectives are to achieve the thermal comfort of the building occupants at:

- Minimum cost of operation

- Maximum efficiency of the system
- Maximum self-consumption
- Maximum benefits for the power system

Regulatory requirements and the time scales also strongly influence the choice of controls and integration approach. For the control of HP systems in a SG context three boundary levels and resulting control tasks exist:

1) Power system level: This include integration and control of individual buildings or entire heating networks, (renewable) electricity generation and consumption devices in the context of electricity grids and markets.
2) Building level: This includes control of the HP, thermal storages, heating distribution systems, indoor temperature, on-site renewable energy sources as solar PV and solar thermal.
3) HP unit level: This includes the control of the refrigerant cycle including fans, valves and compressor.

In a SG the different systems have to interact. This can be implemented in an open loop way, where the high level controller sends requests or set-points to the low level system, without having state feedback. In a closed loop implementation feedback is provided to from the lower to the higher control level, the higher control level might receive information about the outputs and states of the controlled system, which it uses to adjust the control signals. Control hierarchy as assumed in most HP articles is mostly hierarchically organized, (cascaded) (Fischer, D., Madani, H., 2017).

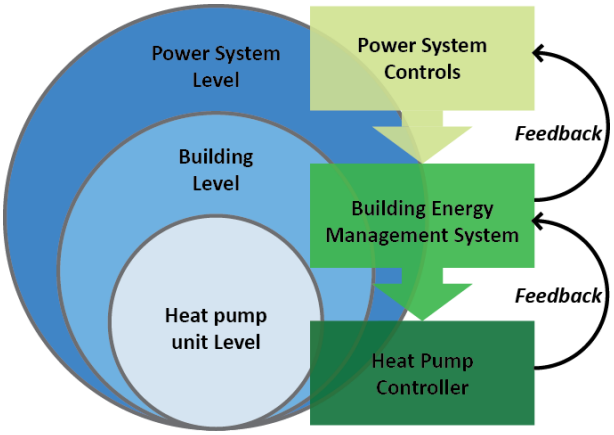


Figure 4. Control hierarchy and levels of integration
(Fischer, D., Madani, H., 2017)

Analysing the SG barely from the electric grid perspective will lead to missing how HP system efficiency and indoor comfort will be affected by potential changes in HP control. Oppositely, if the focus is only on heat pump efficiency without considering the characteristics and expectations needed in the future electric system, it will lead to considerable costs and waste of resources in the power system (Fischer, D., Madani, H., 2017).

2.4. Smart Energy Systems

By combining the electricity, thermal, and transport sectors, the grids and storages in these sectors can improve the energy system flexibility and compensate for the lack of flexibility

from renewable resources such as wind and solar. (Vad Mathiesen, B., Lund, H., Wenzel, H., Ostergaard, P., 2015)

In the grids, the storage and connections between sectors is comprised of:

- Smart electricity grids to connect flexible electricity demands such as heat pumps and electric vehicles to the fluctuating renewable resources such as wind and solar power.
- Smart thermal grids (district heating and cooling) to connect the electricity and heating sectors. This enables thermal storage to be utilised for creating additional flexibility and heat losses in the energy system to be recycled as well as the integration of fluctuating renewable heat sources.

Based on these fundamental infrastructures, a Smart Energy System is a design in which smart electricity and thermal grids are combined and coordinated to exploit synergies to achieve an optimal solution for each individual sector as well as for the overall energy system, "*short and long term storage options, such as batteries and large thermal storages, as well as solid, gaseous and liquid storages are key components in 100% renewable energy systems and so are the infrastructures and grids that enable such storage"* (Vad Mathiesen, B., Lund, H., Wenzel, H., Ostergaard, P., 2015).

It should be noted that synergies and feasible solutions are not achieved simply by combining these infrastructures and storage options automatically. The design and configuration has to be carefully investigated (Vad Mathiesen, B., Lund, H., Wenzel, H., Ostergaard, P., 2015).

3. The Need for Energy Storage, Applications, and Potentials in Europe

3.1. The Need for Energy Storage

A massive increase in renewable energy generation, the electrification of the heating and cooling sector, and expanding electric vehicle networks are accelerating the need for efficient, reliable, and economical energy storage solutions that should provide an effective solution to bridge fluctuations in electricity supply and demand.

This will help reducing CO_2 emissions, decreasing import dependency on fossil fuels, and improving the return on renewable energy generation investments.

In an energy system based on renewable energy, there is a need for improved links between different energy carriers to absorb surplus electricity generation and decarbonise sectors.

In 2015, installed large-scale energy storage capacity world-wide was estimated 150 GW, with approximately 96% of this capacity consisting of pumped hydro storage (PHS). The EU-28 installed energy storage capacity is shown in Figure 5 below, with a clear predominance of PHS in the European Union also.

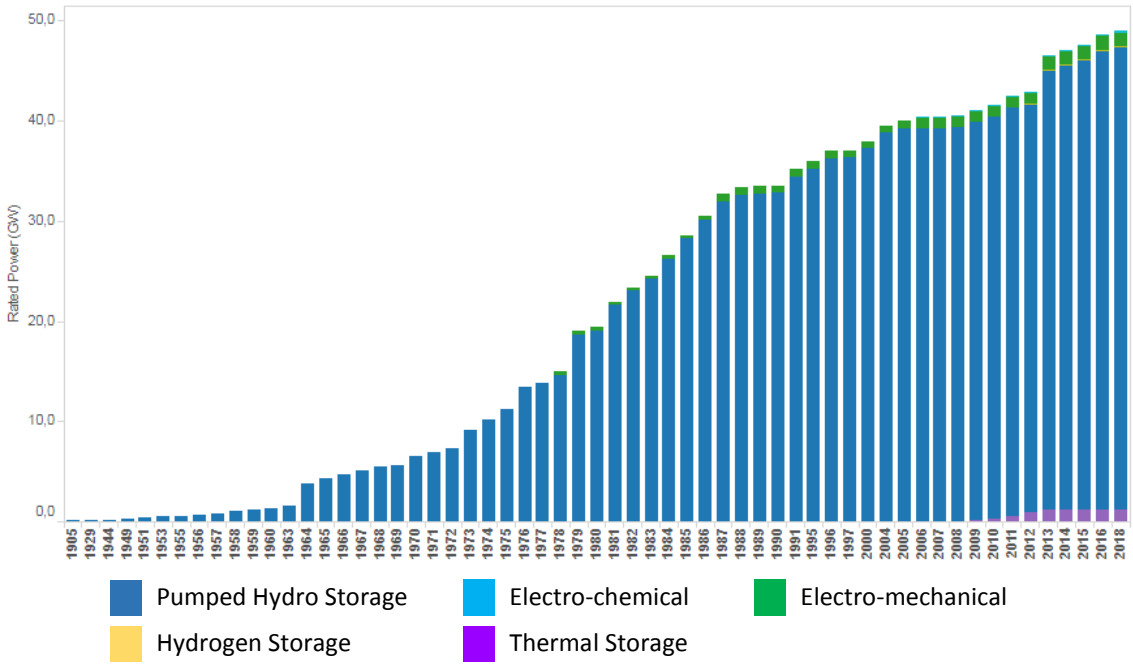


Figure 5. EU-28 Energy Storage Project Installations Over Time, adaptation of DOE database (DOE, Office of Electricity Delivery & Energy, 2016)

The thermal energy storage, large-scale batteries, flywheels, and compressed air energy storage that are the main components of the non PHS energy storage capacity, and which represent a much minor share of implementation than the pumped hydro storage (PHS), are shown in more detail in Figure 6.

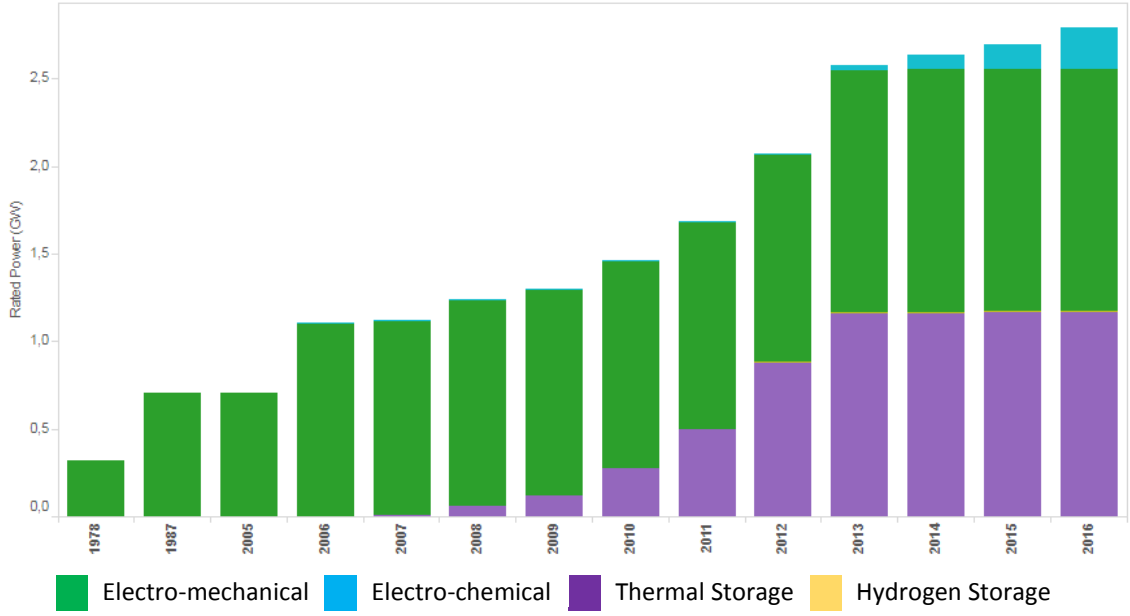


Figure 6. EU-28 Energy Storage Project Installations Over Time excluding PHS, adaptation of DOE database (DOE, Office of Electricity Delivery & Energy, 2016)

3.2. Energy Storage Applications - Electricity Sector

The different energy storage applications can be segmented according to the discharge time and response time, as shown in Figure 7 below.

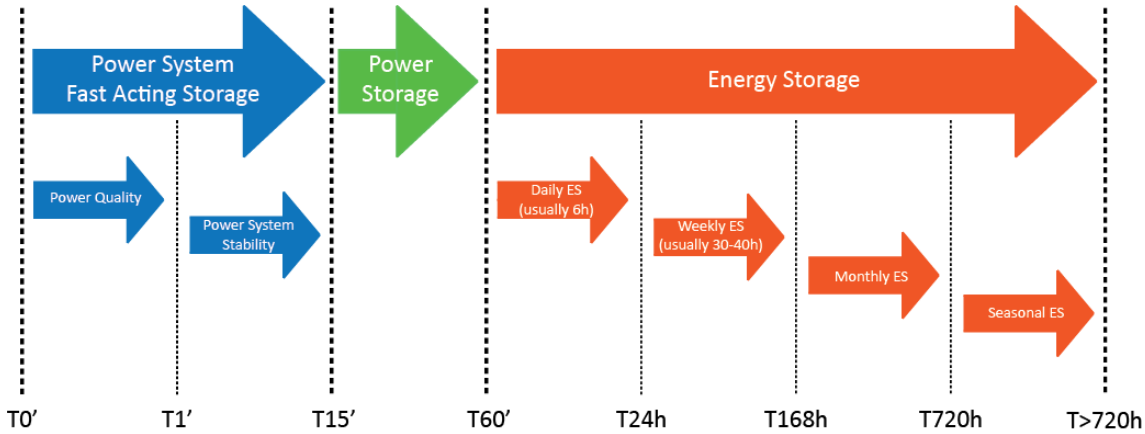


Figure 7. Energy storage applications segmented by discharge time
(EASE/EERA Core Working Group, 2017)

Figure 7 shows that there is a wide range of energy storage applications in terms of the energy that can be stored and therefore for how long will it be available, obviously depending on the demand. The energy storage solutions may vary depending on the purpose of operation.

Table 2 below shows the applications and benefits of energy storage in the electric grid.

Table 2. Overview of energy storage applications in the electricity sector (EASE/EERA Core Working Group, 2017).

Generation/Bulk Services	System Needs/Ancillary Services	Transmission Infrastructure Services	Distribution Infrastructure Services	Customer Energy Management Services
Arbitrage	Primary frequency control	Transmission investment deferral	Capacity support	End-user peak shaving
Electric supply capacity	Secondary frequency control	Angular stability	Contingency grid support	Time-of-use energy price management
Support to conventional generation	Tertiary frequency control	Transmission support	Distribution investment deferral	Particular requirements in power capacity
Ancillary services RES support	Frequency stability of the system		Distribution power quality	Maximising self-production & self-consumption of electricity
Capacity firming	Black start		Dynamic local voltage control	Demand charge management
Curtailment minimisation	Voltage support		Intentional islanding	Continuity of energy supply
Limitation of disturbances	New ancillary services		Limitation of upstream disturbance	Limitation of upstream disturbances
			Reactive power compensation	Reactive power compensation
				EV integration

Some applications observed in Table 2 are described in more detail because of their relevance in the development of the project:

Generation/Bulk Services

- **Electric supply capacity** is the use of energy storage in place of a combustion turbine to provide the system with peak generation capacity.

Transmission infrastructure service

- **Transmission investment deferral** is the use of energy storage to solve transmission congestion issues, thereby deferring transmission infrastructure upgrades.

Distribution infrastructure service

- **Capacity support** is the use of an energy storage unit to shift load, e.g. from peak to base load periods, to reduce maximum currents flowing though constrained grid assets. This support the integration of renewable electricity sources.
- **Distribution investment deferral** is the use of energy storage to defer distribution infrastructure upgrades, thereby solving distribution congestions.

Customer Energy Management Services

- **End-user peak shaving** is the use of energy storage devices by customers peak shaving, or smoothing of own peak demand, to minimise the part of their invoice that varies according to their highest power demand.

- **Time-of-use energy price management** is the use of energy storage to be charged when the rates are low and to be consumed during peak times, with the aim of reducing the invoice of final users.
- **Maximising self-production & self-consumption** in the use of energy storage in markets with high energy costs to increase self-consumption in combination with renewable energy source.
- **Demand charge management** is the use of energy storage to reduce the overall customer costs for electric service by reducing demand charges during peak periods specified by the utility. (EASE/EERA Core Working Group, 2017)

3.3. Energy Storage Applications - Heat Sector

Energy storage has already found widespread commercial utilisation in various low temperatures applications and will play an increasingly important role.

Water storage vessels are used to offset daily fluctuations and increase the share of solar thermal domestic heating systems. Seasonal storage with high storage density being charged either from solar thermal and/or PV could be used to optimise self-supply of heating needs in winter from renewable energy (EASE/EERA Core Working Group, 2017).

3.4. Energy Storage Applications - Energy Sector Interfaces

In addition to the specific benefits of storage applications in the electricity and heat sector, energy storage is able to provide additional service to the energy system by integrating the electricity, heating & cooling, gas, and transport sectors. Such technologies can help provide competitive flexibility to the EU electricity system and can transfer the share of renewable originally generated in the electricity sector to others sectors (EASE/EERA Core Working Group, 2017).

Power-to-heat deals with the conversion of electricity into thermal energy. Various technologies could be applied here at different temperature levels:

- Heat pumps and/or electric boilers in combination with thermal energy storages.
- Night storage heating for DHW charged at times of low electricity prices and providing decentralised renewable heat, or even space heating conditioning.

4. Integration of the CHESS SETUP with the electrical system

4.1. Input data and methodology

Different scenarios have been developed for Corby's pilot electric grid and at a larger scale for both countries participating with pilot projects (Spain and the United Kingdom) to analyse the impact of a major implementation of the system in the residential sector and how can it boost the implantation of new renewable installations (solar photovoltaic and wind power).

A typical summer and winter day have been examined for all scenarios to understand the impact in these very different circumstances both in terms of energy demand and generation.

In Corby's case, 31 houses and 16 flats of the CHESS SETUP Corby's pilot have been analyzed. For the larger UK scenario the total existing dwellings stock has been considered with data from the year 2014 (Department for Business, Energy & Industrial Strategy, 2016) and similarly for Spain as per 2010 data (IDAE, 2011). See Table 3 below.

Table 3. Number of dwellings in study

Location	Total number of dwellings
Corby[1]	47
UK[2]	28,000,000
Spain[3]	17,200,000

Table 4 shows the type and efficiencies of heating (HTG) and Domestic Hot Water (DHW) systems installed in the dwellings of Corby and the UK, as per the report of Energy Consumption in the UK 2016 (Department for Business, Energy & Industrial Strategy, 2016). Table 5 shows this for the case of Spain as per IDAE (IDAE, 2011).

Table 4. Efficiency and scenarios of DHW and HTG systems share in Corby and the UK

DHW & HTG System	Eff.	DHW & HTG system share				
		Corby		UK		
		Current	2050	Current	2050a	2050b
Gas boilers / other fuels	90%	100%	0%	93%	15%	15%
Direct electric	100%	0%	0%	7%	1%	1%
Air Source Heat Pump	300%	0%	0%	0%	42%	0%
CHESS SETUP	400%	0%	100%	0%	42%	84%

[1] Birmingham weather conditions have been considered for Corby's study.
[2] London weather conditions have been considered for UK's study.
[3] Madrid weather conditions have been considered for Spain's study.

Table 5. Efficiency and scenarios of DHW and HTG systems share in Spain

DHW & HTG System	Eff.	DHW & HTG system share		
		Current	UK 2050a	UK 2050b
Gas boilers / other fuels	94%	60%	15%	15%
Direct electric	99%	32%	1%	1%
Air Source Heat Pump	340%	8%	0%	42%
CHESS SETUP	450%	0%	84%	42%

For the year 2050 scenario, in Corby all the DHW & HTG systems are considered to be as per the CHESS SETUP. For the UK 2050 scenario the study considers the share proposed in the report "The future of Heating: Meeting the challenge" (Department of Energy and Climate Change, 2013), assuming two cases:

1) Half CHESS SETUP implementation: 50% of total heat pumps are assumed to be as per the CHESS SESTUP systems and 50% air source heat pump (ASHP).
2) Full CHESS SETUP implementation: 100% of heat pumps are assumed to be as per the CHESS SESTUP.

Note there is still a residual share of gas boilers in use as the phase out is gradual. The same 2050 scenarios have been adopted for the study in Spain.

No diversity has been considered in terms of occupied dwellings and occupancy, so all are actually consuming energy.

In Table 6, it can be observed the share of renewables in the electric production specifically photovoltaic (PV) and wind turbines for each scenario. In Corby's case the currents values are as per the pilot's design, as it has not been built yet. For the UK scenario their values are the actual PV and wind turbines production share in the electricity mix in the UK (National Grid - Elexon, 2017) and in Spain (Red Eléctrica de España S.A., 2017).

Table 6. Share of renewable energies in the electric mix

Share of renewable	Corby		UK		SPAIN	
	Current	2050	Current	2050	Current	2050
PV	88.5%	100%	3.5%	11.4%	3.1%	11.4%
Wind Turbines	0%	0	13.4%	41.9%	18.4%	41.9%

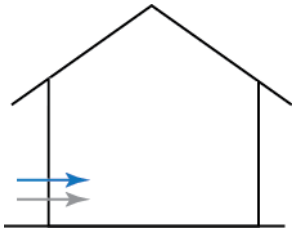
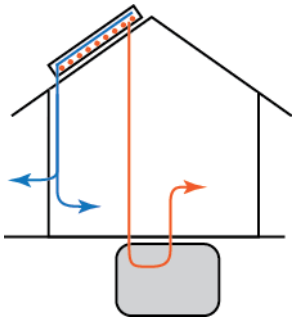
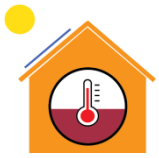
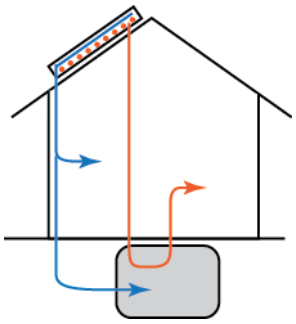
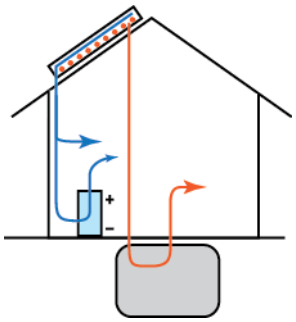
For Corby's 2050 scenario, the study considers 100% of the electricity productions in this site is generated from PV panels, which is not far from the current design scenario. For the UK 2050 scenario, the share of renewables in the electricity mix proposed in the model "Friends of the heart" for the 2050 Energy Calculator (Department of Energy & Climate Change, 2017) has been considered. These same settings have been considered for Spain's 2050 scenario.

In terms of energy storage, this study considers that the CHESS SETUP system with its thermal storage can provide the seasonal efficiencies stated in the tables above. However, in case of surplus electricity that is not used on site, this could potentially be converted into thermal

energy and stored to be used when necessary and upgrading the temperature of the thermal storage thus providing greater heat pump efficiencies [increased coefficient of performance of 0.5 to 1 depending on the amount of energy stored] (as in option 'c' below) or stored in batteries for later usage (as in option 'd' below).

Table 8 summarizes the four different cases that have been considered for comparison in this analysis. Firstly the existing scenario **(a)**, where all the energy requirements are provided by the incoming gas and electric grid. Then, the three possible CHESS SETUP configurations in terms of surplus electricity generation only: **(b)** instant use of electricity and exported to the grid if there is excess generation, **(c)** conversion of surplus electricity into thermal energy to be stored and **(d)** storage of the electrical surplus in batteries.

Table 7. Dwellings current and CHESS Setup energy flows schemes

	Scheme	Description
a) Existing scenario: 		• All the energy requirements are provided by the gas and electricity grid.
b) CHESS (Instant Use): 		• The electricity produced by the panels is used directly to satisfy the instant electrical demand. • The electrical surplus is injected in to the grid. • The heat collected is used to contribute to the thermal requirements (DHW & HTG).
c) CHESS (Thermal storage): 		• The electricity produced by the panels is used directly to satisfy the instant electrical demand. • The electrical surplus is converted into thermal energy to be stored. • The heat collected is used to contribute to the thermal requirements (DHW & HTG).
d) CHESS (Electric Storage): 		• The electricity produced by the panels is used directly to satisfy the instant electrical demand. • The electrical surplus is stored in batteries. • The heat collected is used to contribute to the thermal requirements (DHW & HTG).

The electric storage is defined by the number of dwellings and the batteries capacities. All batteries have been assumed to be BYD 2.46 kWh/dwelling (BYD, 2017), taking Corby's pilot as reference. The share of batteries penetration in the residential stock is assumed as per Table 7 below.

Table 8. Batteries penetration in the residential sector

Batteries penetration	Corby		UK		SPAIN	
	Current	2050	Current	2050	Current	2050
% of dwellings	100%	100%	2.5%	5.0%	2.5%	5.0%

The electricity surplus first charges the batteries and if they are fully charged the energy is injected in the electric grid. In this study the energy stored in the batteries is utilized to decrease the electricity peak consumption of the dwelling.

4.2. Results

A summary of the results obtained in the analysis carried out is shown in Table 9 below. The three sites of implementation are arranged by columns.

The first three rows illustrate the inputs for the different scenarios in terms of existing and proposed systems for space heating and domestic hot water, CHESS SETUP implementation and the share of renewable energy currently and in the year 2050 as per the tables shown in the previous chapter.

The last three rows show a summary of the results obtained from the analysis in terms of the peak electrical demand in the grid, the variation in energy consumption and the equivalent CO_2 emissions for the different scenarios.

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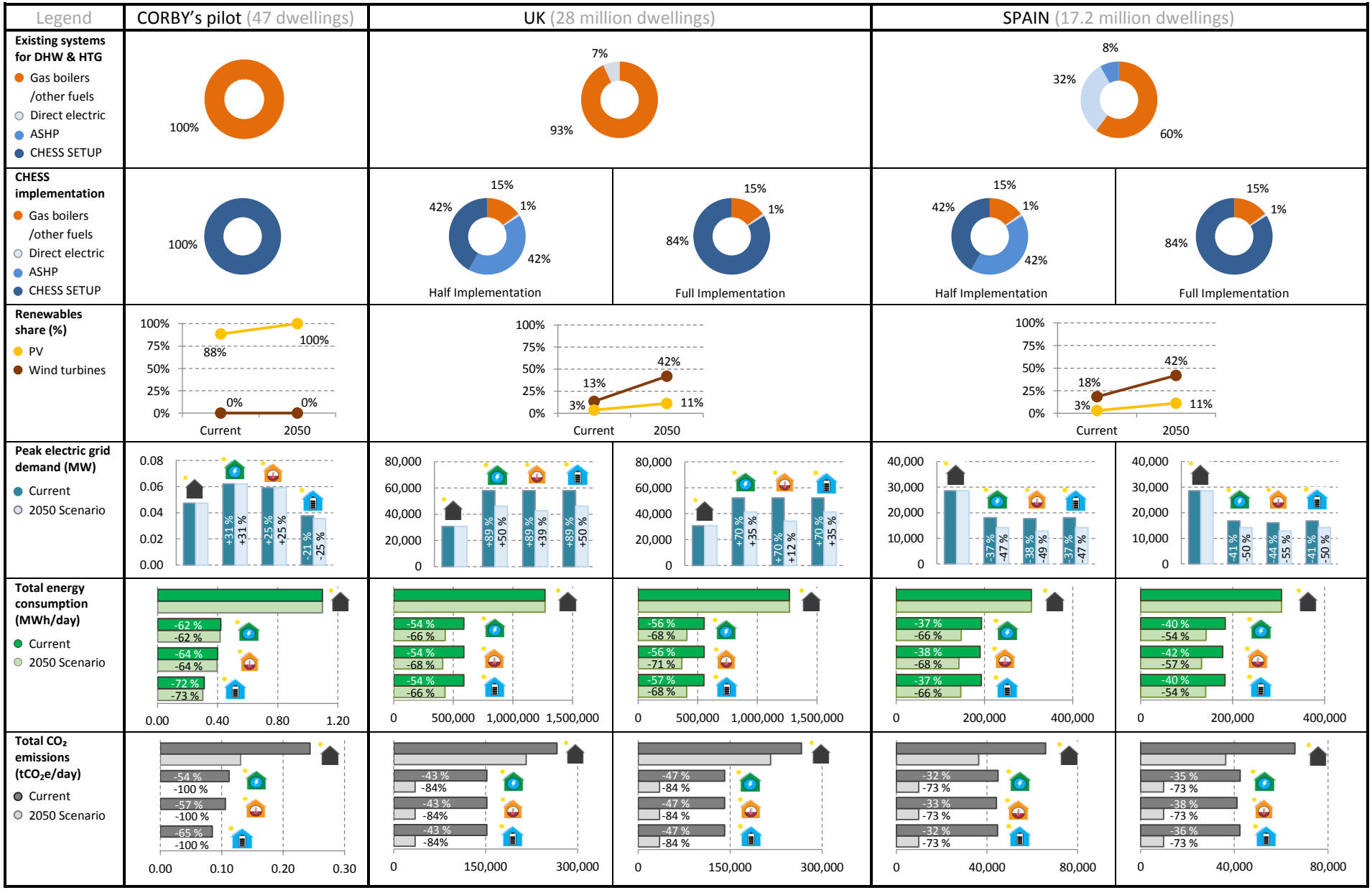
Table 9. Summary of inputs and results



4.2.1 Corby

Considering Corby's pilot is going to be a new build, it has been assumed that the baseline heating and domestic hot water systems are gas boilers with an efficiency of 90% as per the typical UK case. The design scenario is completely designed under the CHESS SETUP system with a seasonal efficiency of 400% (Coefficient of Performance, COP=4) and even 88% of the electricity consumed by the dwellings comes from local PV.

The implementation of the CHESS SETUP results in a clear 31% increase in the peak electric grid of 31% compared to the baseline scenario because of the switch from gas to electricity in the heating and domestic hot water systems, but achieving energy savings in gas and electricity consumption of 62% due to the greater efficiency of the CHESS SETUP.

If the electricity surplus is converted into thermal energy (c), the electric peak load still increases but by a 25% compared to the baseline, and achieving very similar annual energy savings as per the previous scenario (64%). In the case of having batteries (d), the peak would actually decrease by 21% respect to the baseline scenario, also achieving greater energy savings, 72%.

The savings in equivalent CO_2 emissions range between 54% and 65% for the different scenarios.

The projected scenario for the year 2050 defines space heating and domestic hot water systems as per the CHESS SETUP and all electricity comes from renewable energy in Corby's pilot. The results show very similar findings to the current CHESS SETUP scenarios in terms of peak and annual demands and achieve carbon neutrality.

4.2.2 United Kingdom

In this case, the baseline scenario is the existing scenario in the UK, where 93% of the residential heating and domestic hot water systems are fed by gas boilers and the other 7% are direct electric boilers. In terms of renewable energy in the grid, 13.4% of the total energy generation comes from wind turbines and 3.5% comes from PV panels.

As mentioned earlier, two different rates of implementation have been analysed here, assuming a half and a full CHESS SETUP implementation in the DHW & HTG systems.

In the half implementation scenario, there is an increase of the peak of the electric grid of 89% for all the CHESS configurations because in the existing scenario the predominant systems are gas boilers and the installed renewables do not allow for demand shifting at peak times. The total energy consumption decreases 54% compared to the existing scenario and the equivalent CO_2 emissions also decrease by 43% in all cases.

For the 2050 scenario, the peak demand increase is between 39% and 50% and the total energy consumption decreases around 66-68%. In all three cases of CHESS configuration an 84% reduction in the equivalent CO_2 emissions are observed.

In the full implementation case, the results are enhanced, following the same behaviour as the previous.

Overall, the results in the UK, similar to Corby, show that the peak electric demand increases in almost all scenarios as the baseline case is fed predominantly by gas. However, in terms of annual energy (both electricity and gas) and CO_2 emissions, there is a very significant decrease.

4.2.3 Spain

The starting point here varies, as the share of gas boilers for heating and domestic hot water systems in the Spanish stock is predominant but much less than in the UK. There are also more renewables currently, with 18.4% of the total energy generation comes from wind turbines and 3.1% comes from PV panels.

The same methodology has been applied here, applying half and full implementation scenarios.

The results in this case show a significant decrease both in terms of peak power (35-55%) and annual energy and CO_2 savings (>30%). This is due to the fact that the current HTG and DHW systems are more electrified in Spain. Details can be found in the graphs in Table 9.

4.2.4 Typical winter day, Corby

The detail of what is happening in a single day is here analysed. A winter day is illustrated here as it shows quite well the differences in the studied scenarios (due to the space heating demand season) and in Corby's pilot as it has a very significant share of renewables on site.

As mentioned earlier, all scenarios have been analysed for a typical winter and summer day in detail and results can be found in the appendix.

Figure 8 below shows the electricity consumption from Corby's baseline scenario, a base case where all DHW & HTG systems are fed by gas boilers, and the design case for Corby's pilot, where the gas boilers for DHW & HTG systems are replaced as per the CHESS SETUP but not including any electricity generation.

In the baseline case (light blue area) the total electric consumption is clearly lower because the thermal load of the dwelling is covered by gas boilers and the red area shows the electrification of the DHW and HTG systems. The incorporation of electricity generation will have an impact on these results, which can be seen in the next graph (Figure 9).

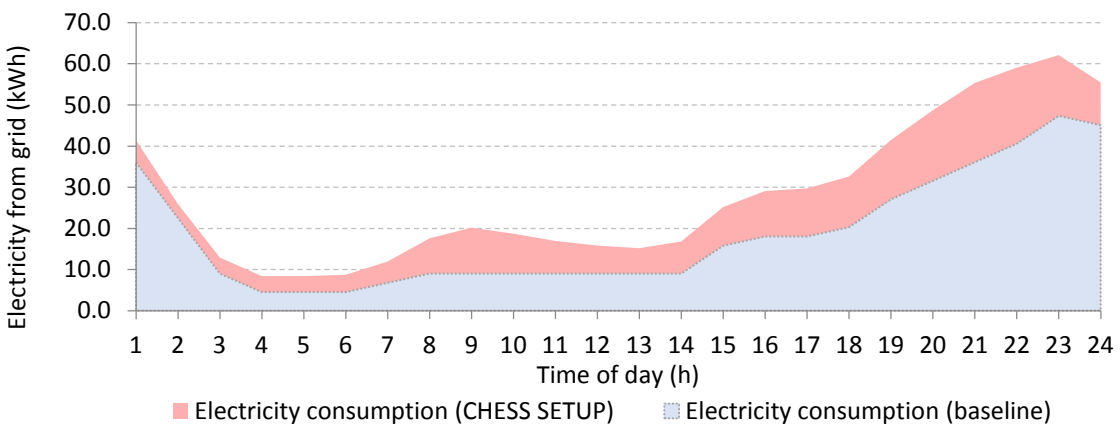


Figure 8. Base Case and Total hourly electric consumption from electrical grid

Figure 9 shows the resulting electricity consumption profiles incorporating the electricity generation from renewables as per Table 9. The three possible CHESS SETUP configurations are shown, where the 'thermal storage' and 'electric storage' options represent the options where any electricity surplus is converted into thermal energy or stored in batteries, rather than the 'instant use' scenario where any extra electricity generation is exported to the grid.

The existing scenario shows quite favourable results with a more constant load because heating and domestic hot water demands are fed by gas boilers. It is also observed that the peaks of electric consumption occur at the first and especially last hours of the day when people are at home and also showering periods. With the CHESS SETUP implementation, several hours around midday (10 am to 3 pm) there is a 'energy positive' scenario, where the dwellings electrical production exceed the total energy consumption.

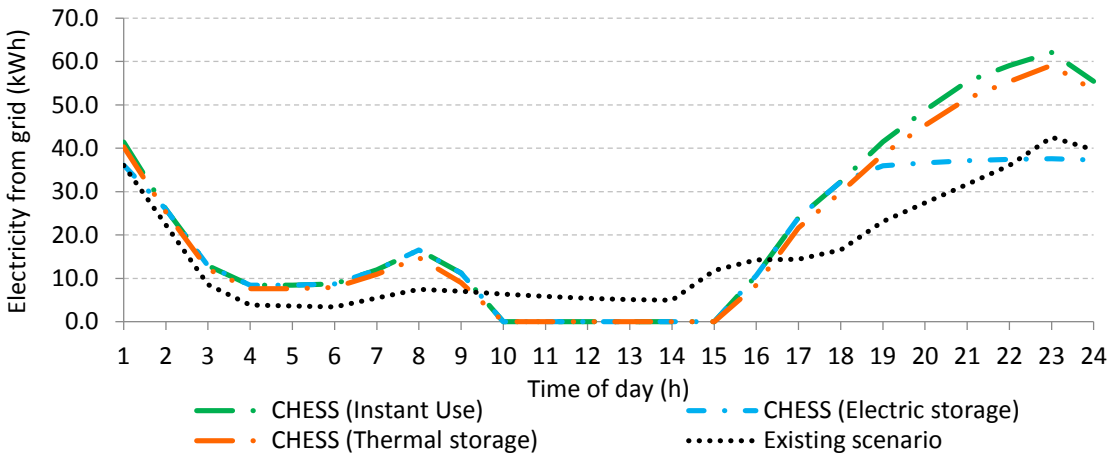


Figure 9. Dwellings existing scenario and CHESS Setup configurations hourly electric grid consumption

The PV panels electricity generation is firstly used to satisfy the instant energy demand of the dwellings. The highest electric average and peak (30% increase) consumptions are obtained with the CHESS SETUP 'instant use' configuration as in this case the entire electric surplus is injected to the electric grid. In the thermal storage configuration, the electric average and peak consumption decreases by 5% respect the instant use configuration because the entire electric surplus it is converted and stored thermally thus increasing the seasonal COP of the HPs with the consequent electrics savings. When the CHESS Setup is configured with electric storage, the peak power needs improve even compared to the existing scenario, thanks to the best use of the electrical energy generated by the PVs and stored in the batteries.

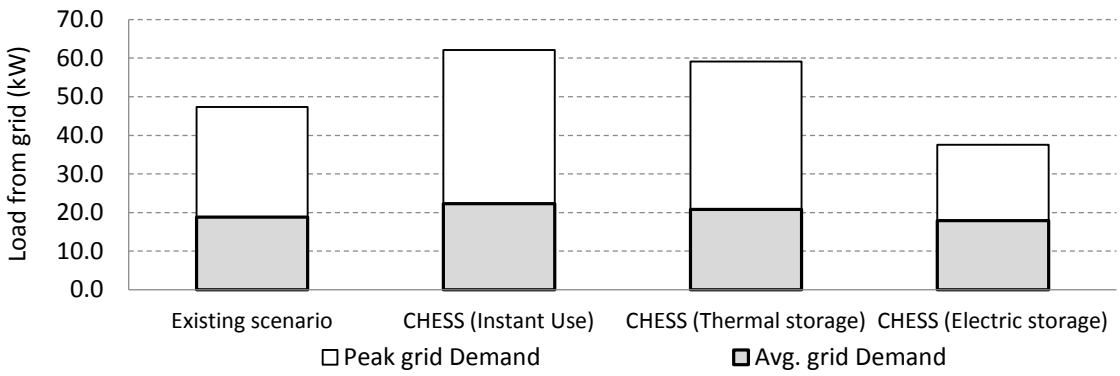


Figure 10. Peak and average electric grid demand

Figure 11 below shows the batteries status for the 'electric storage' scenario in the typical winter day under study, where it can be seen that they almost reach full charge. In the case there is additional surplus electricity that cannot be stored, it would be exported to the grid (as in the typical summer day shown in the appendix).

The energy stored in the batteries is used to minimise the peaks power consumption, which could reduce the power requirements from the grid and enhance the operation of the distribution network.

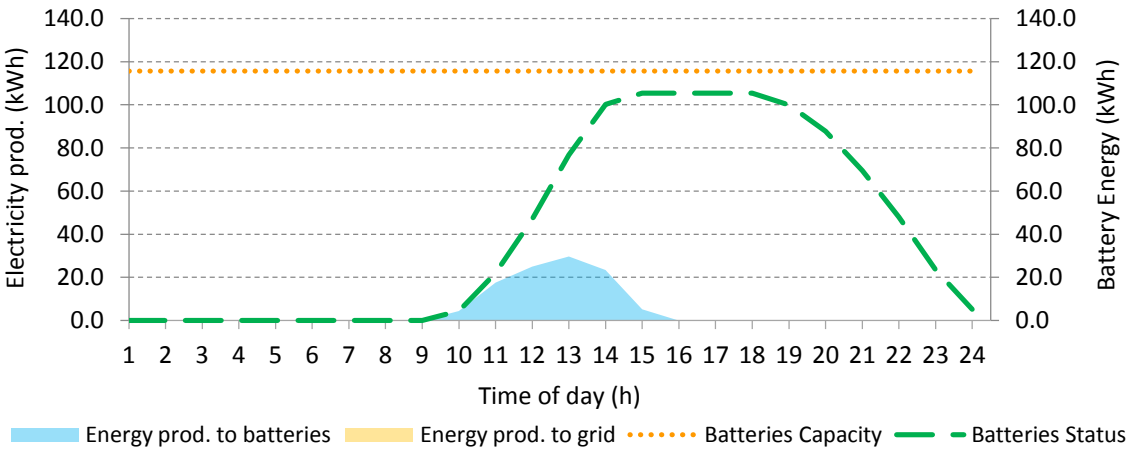


Figure 11. PVs electric production usage and batteries status

The daily electricity demand peaks generally coincide with the electricity price peaks (Figure 12), therefore its reduction would also bring an economic benefit for the end user.

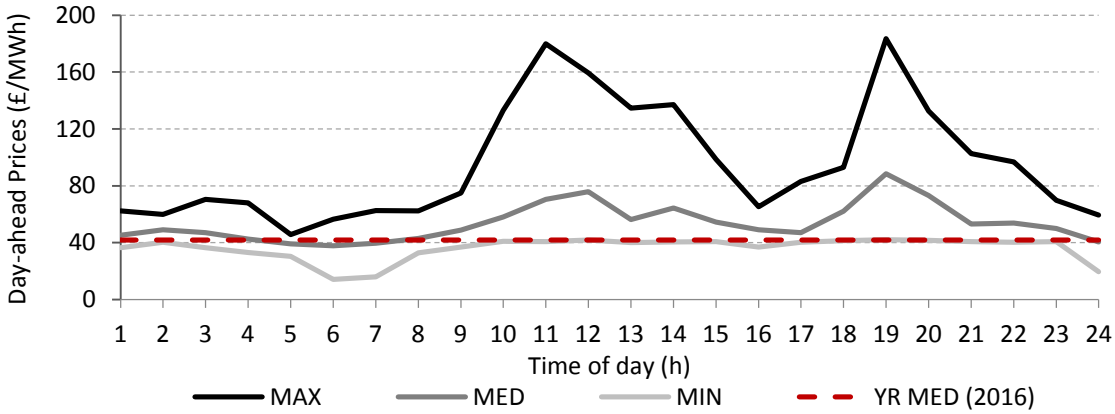


Figure 12. Hourly day-ahead electricity prices

Figure 13 illustrates the daily energy consumption for the different configurations. It can be seen how gas consumption is phased out in all CHESS SETUP options.

In the first case (instant use), part of the electricity produced on site is consumed instantly and part is exported to the grid achieving a total energy saving of 62% compared to the existing scenario. In the thermal storage configuration, the entire electrical surplus is converted in thermal energy and stored and the energy savings are of 64%. In the electric storage configuration, where all the surplus is stored in batteries, resulting in the lowest electrical consumption of the grid achieving a total energy saving of 72% respect the baseline.

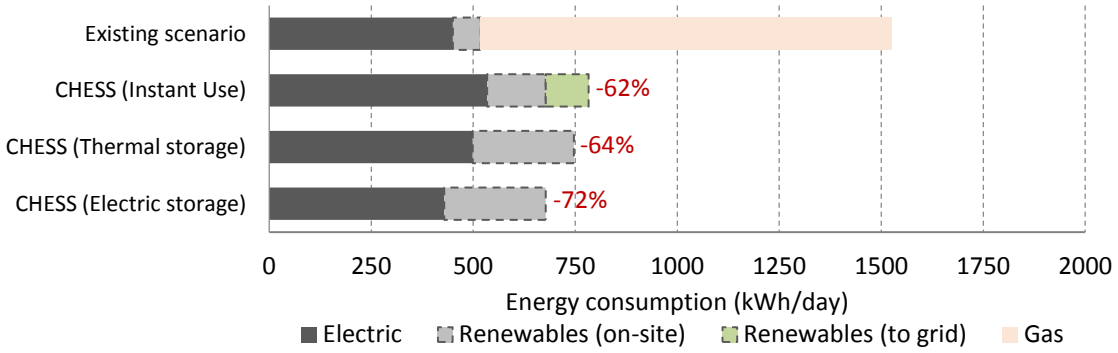


Figure 13. Dwellings totals energy uses/consumption in the existing scenario and each CHESS Setup configurations

Derived from the previous analysis, the results of total equivalent CO_2 emissions per day can be obtained (Figure 14). The existing scenario figures are lower than values from other studies on residential emissions for selected Cities (Simmons C., 2006) and the statistics values of the UK government (Department for Business, Energy & Industrial Strategy, 2017).

The implementation of the CHESS SETUP configurations would achieve savings between 54% and 65% compared to the baseline.

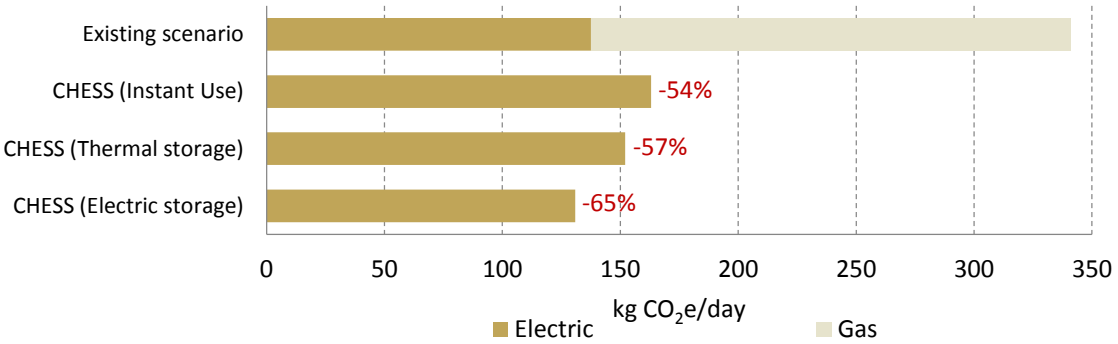


Figure 14. Dwellings totals equivalent CO2 emissions in the existing scenario and each CHESS Setup configurations

5. Conclusions

The analysis carried out shows that there are different possible configurations of the CHESS SETUP that would have a significant impact in the electrical grid, allowing the integration of renewable energy and energy and CO_2 savings. The cases under study are reminded here:

- The existing case or baseline, where heating and domestic hot water demands are covered by systems fed by the incoming gas or electricity from the grid.
- 'Instant use'. On site hybrid solar thermal and photovoltaic panels (PVT) are introduced. Any surplus electricity generation is exported to the grid.
- 'Thermal storage'. PVT as previously. Any surplus electricity generation is converted into heat energy and stored for later usage and to improve the heat pump efficiency.
- 'Electrical storage'. PVT as previously. Any surplus electricity generation is stored in batteries to be used when necessary for any electrical use.

In general, the impact of the CHESS SETUP implementation depends very much on the existing scenario that is taken as reference. For example the results in the UK, similar to Corby, show that the peak electric demand increases in almost all scenarios (see Figure 15) especially in winter when there is heating demand that was previously fed predominantly by gas boilers. However, in terms of annual energy (both electricity and gas) and CO_2 emissions, there is a very significant decrease.

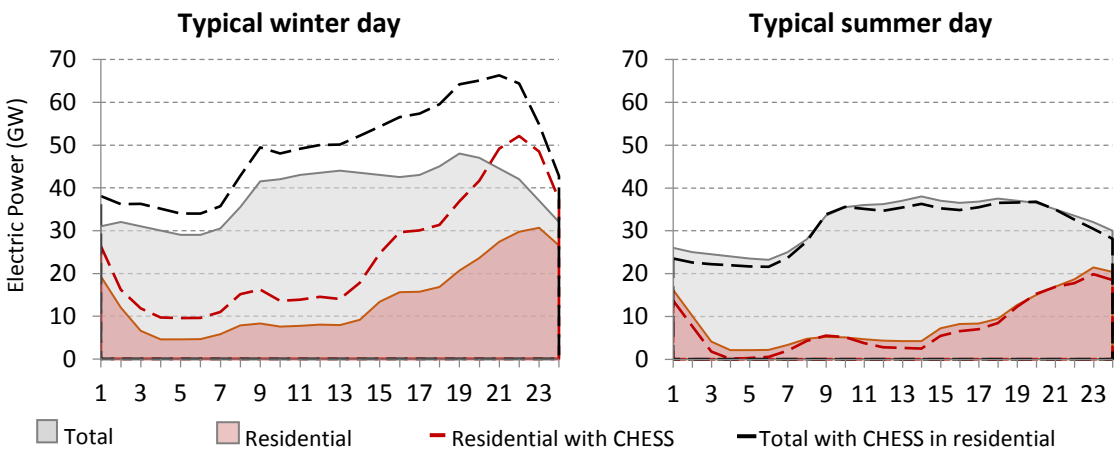


Figure 15. UK national grid hourly electric power consumption

The analysis for Spain instead shows that the peak power demand can be reduced significantly especially in winter (see Figure 16). This is because the existing scenario does account for a significant portion of the heating and domestic hot water systems as electric nowadays but at low efficiencies.

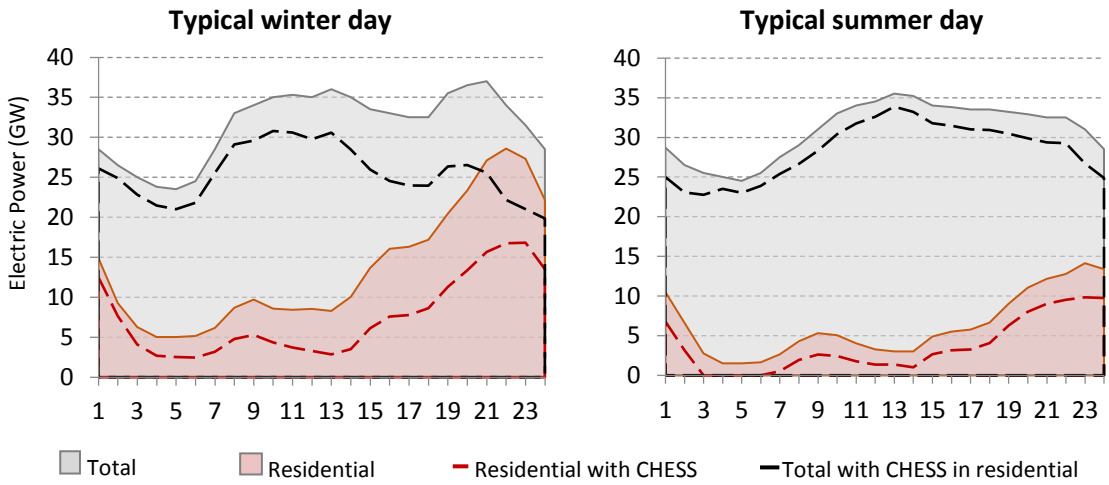


Figure 16. Spain national grid hourly electric power consumption

Overall, the implementation of the CHESS SETUP at a large scale can therefore provide important benefits in terms of energy and CO_2 savings in all scenarios but every case has to be studied in detail in terms of smoothing the power network.

The integration of more renewables would help to enhance the results shown here but would also mean the requirement of greater storage solutions which can be certainly challenging in terms of cost and space limitations in existing sites.

Also, there is further work that could be investigated in other studies that could help to overcome some limitations found in this investigation. These would mainly regard to: analysis the impact in the other sectors than the residential one such as offices and services, study the residential load diversity in detail, understand the infrastructure limitations and potential solutions in terms of sorting renewables generation location in relation to the demand.

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Appendix

1. CORBY pilot's

Location:	Corby (Birmingham)
Global horizontal radiation (kWh/m^2):	1,026
Number of houses	*31*
Number of flats	*16*
Total number of dwellings:	47

Electric consumption	**(kWh/dwelling)**
Current electric consumption	*3,500*
Current Htg consumption	2,523
Current DHW consumption	2,000
Current electric Htg+DHW cons.:	0
CHESS electric Htg+DHW cons.:	*1,131*
Total current electric consumption:	3,500
Total CHESS electric consumption:	*4,631*
Usable Battery Energy	2.46

		Heating (HTG)		**Domestic Hot Water (DHW)**	
Type	**Eff.**	**Base Case**	**Test**	**Base Case**	**Test**
Gas boiler/other fuels	90%	100%	0%	100%	0%
Direct electric	100%	0%	0%	0%	0%
Heat pump	300%	0%	0%	0%	0%
CHESS Setup	400%	0%	100%	0%	100%

Share of renewable

Electric Grid	**PV**	**Wind power**
Corby	88.5 %	0.0 %
UK	3.5 %	13.4 %

1.1. Typical winter day

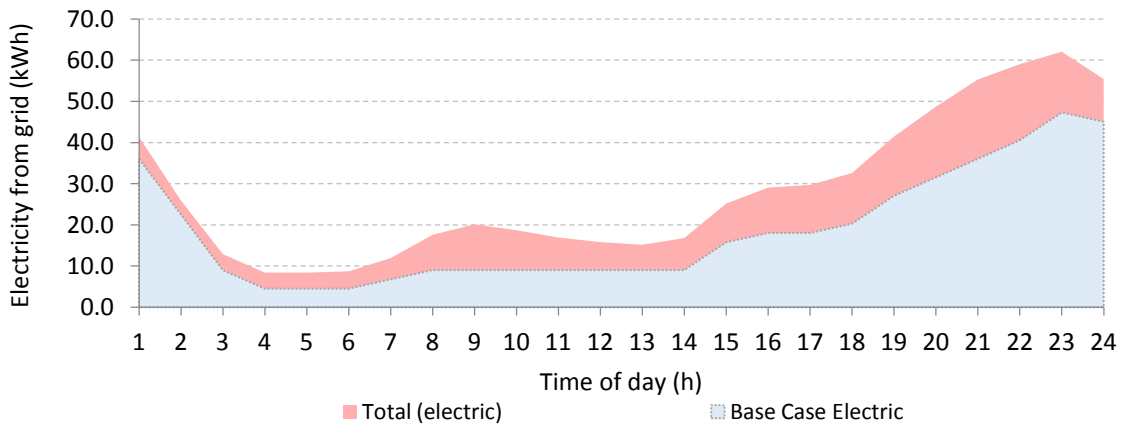

Figure 1. Base Case and Total hourly electric consumption from electrical grid

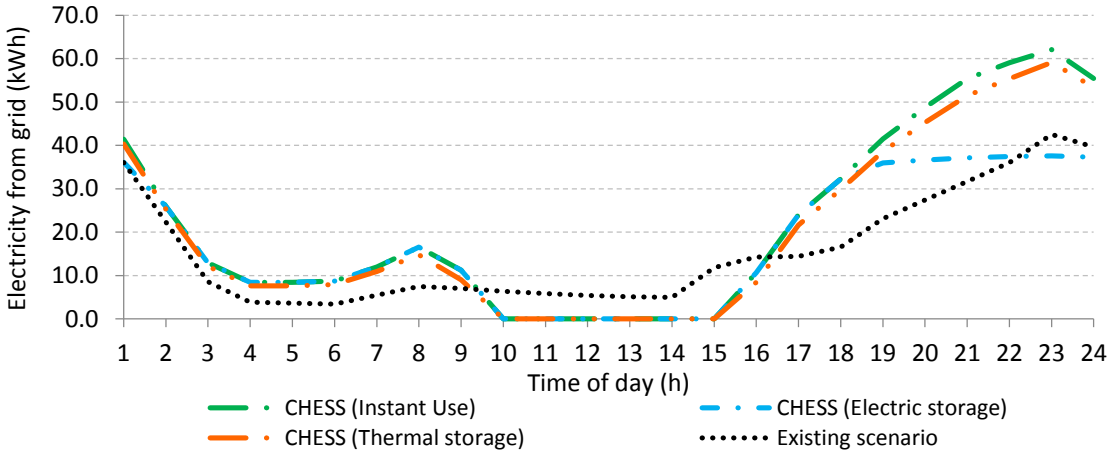

Figure 2. Dwellings existing scenario and CHESS Setup configurations hourly electric grid consumption

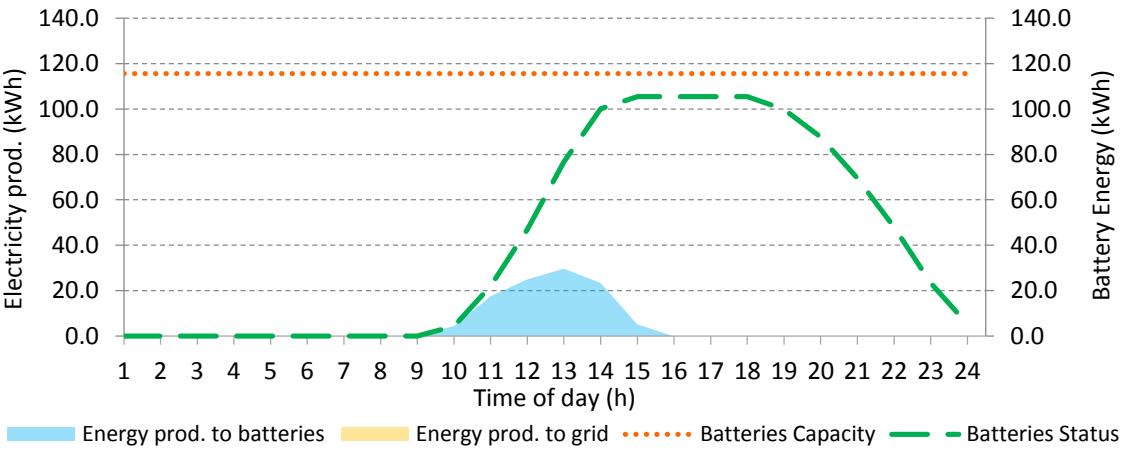

Figure 3. PVs electric production usage and batteries status.

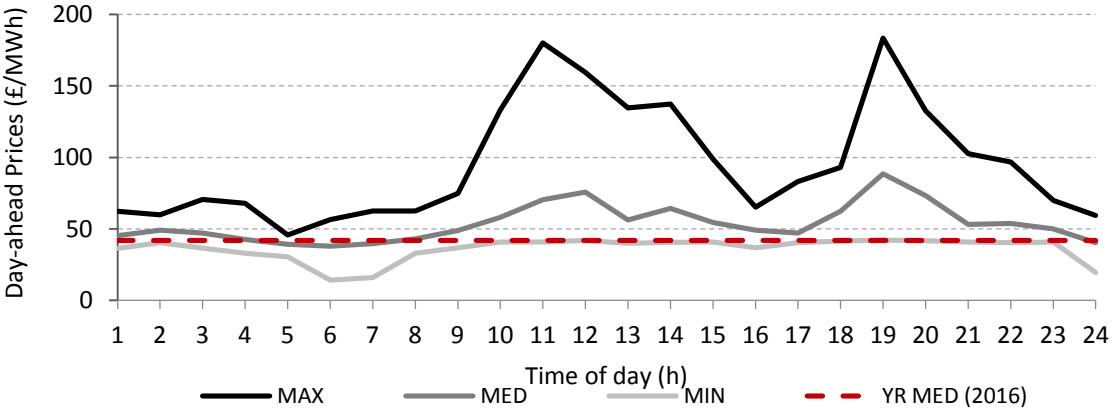

Figure 4. Hourly day-ahead electricity prices

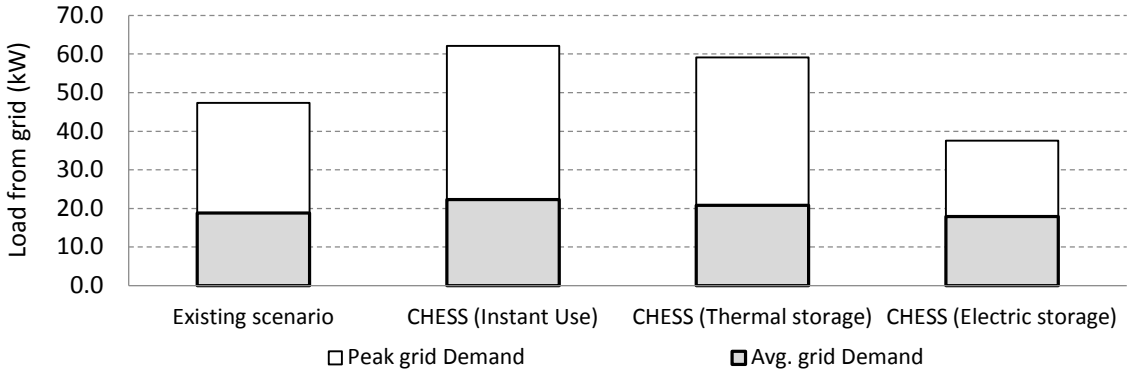

Figure 5. Peak and average electric grid demand

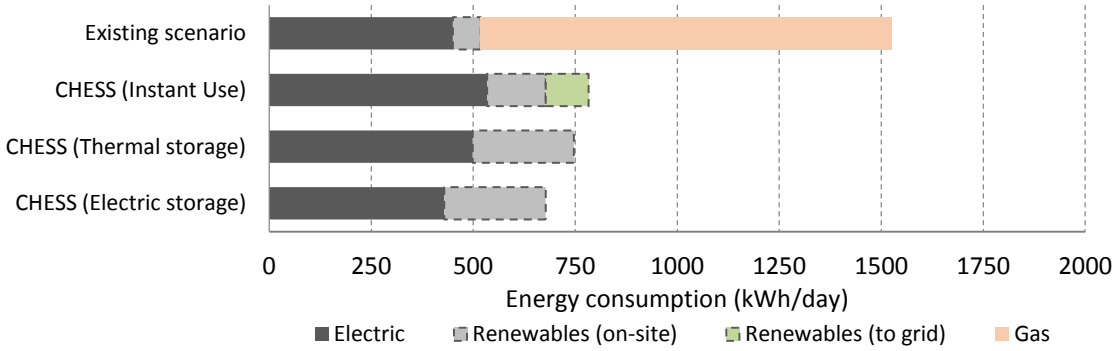

Figure 6. Dwellings totals energy uses/consumption in the existing scenario and each CHESS Setup configurations

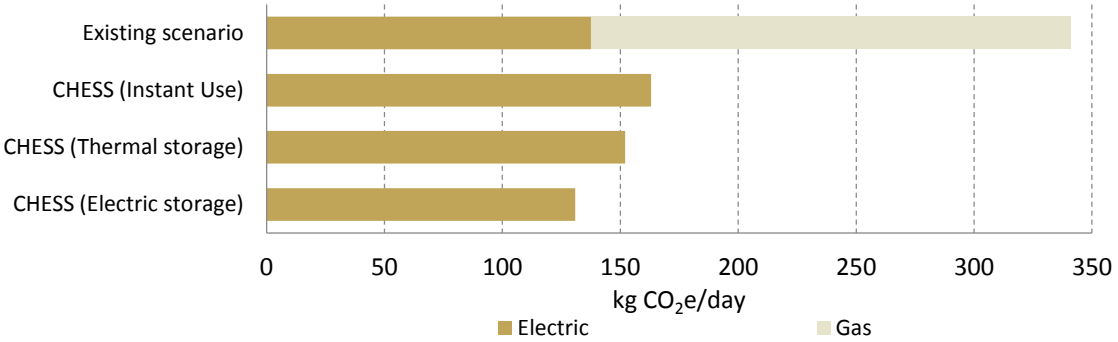

Figure 7. Dwellings totals equivalent CO2 emissions in the existing scenario and each CHESS Setup configurations

1.2. Typical summer day

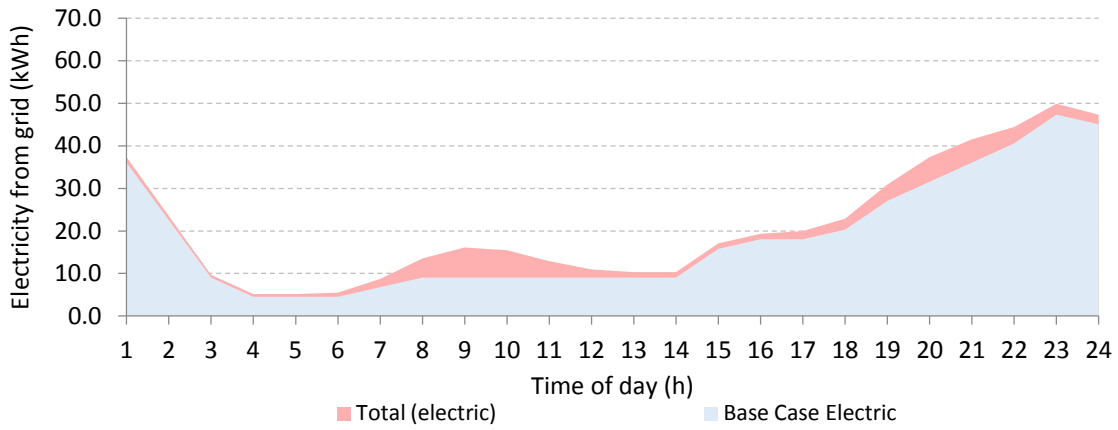

Figure 8. Base Case and Total hourly electric consumption from electrical grid

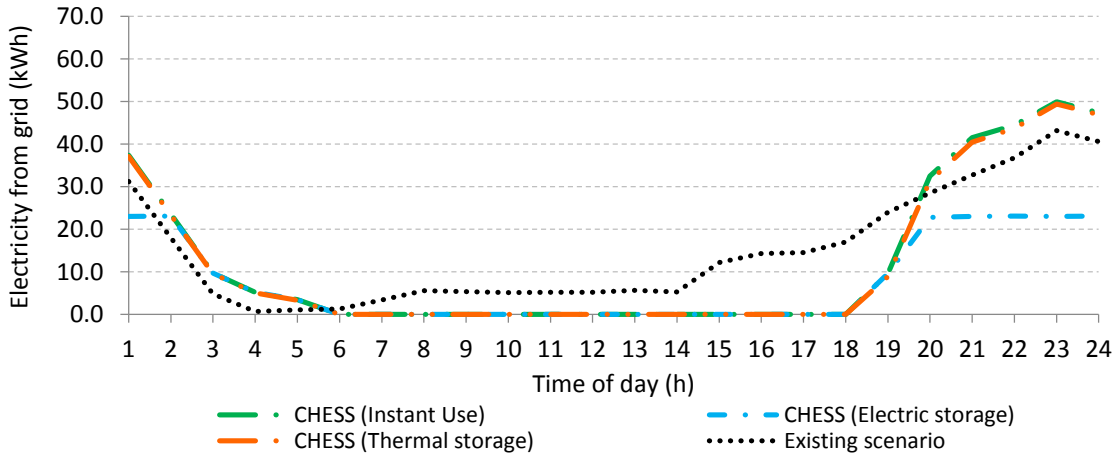

Figure 9. Dwellings existing scenario and CHESS Setup configurations hourly electric grid consumption

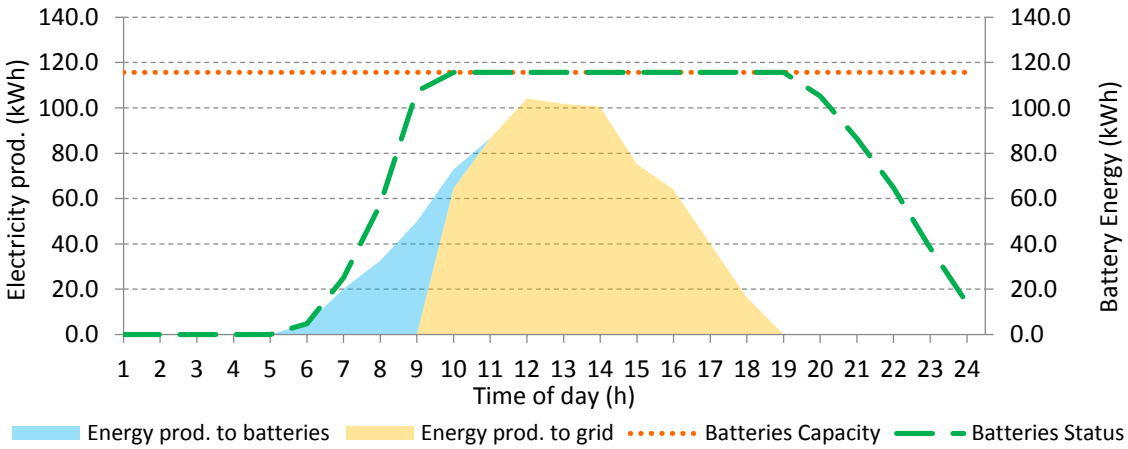

Figure 10. PVs electric production usage and batteries status.

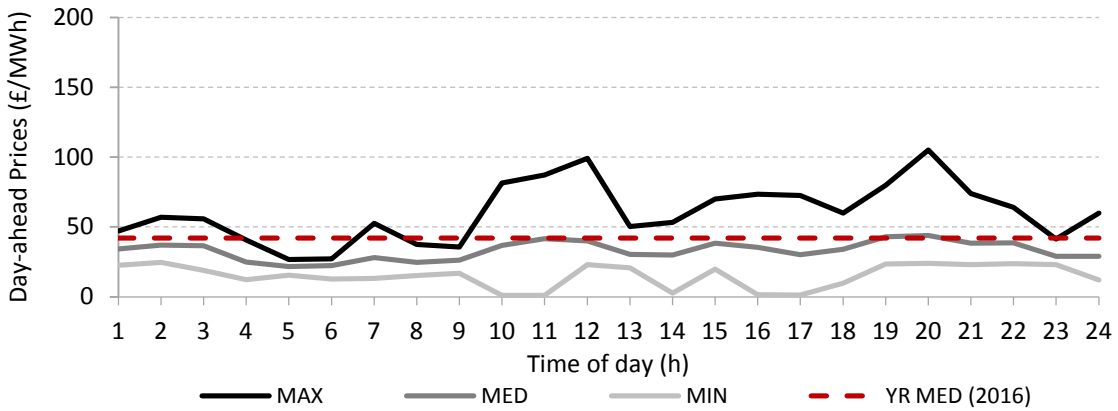

Figure 11. Hourly day-ahead electricity prices

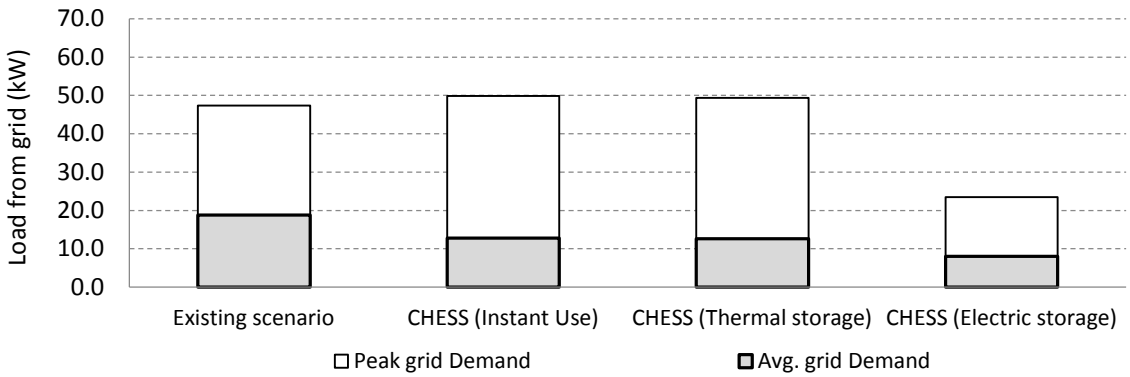

Figure 12. Peak and average electric grid demand

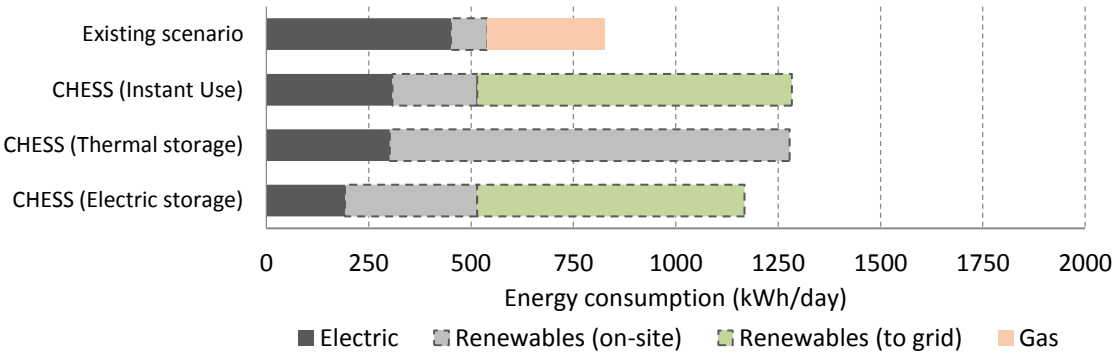

Figure 13. Dwellings totals energy uses/consumption in the existing scenario and each CHESS Setup configurations

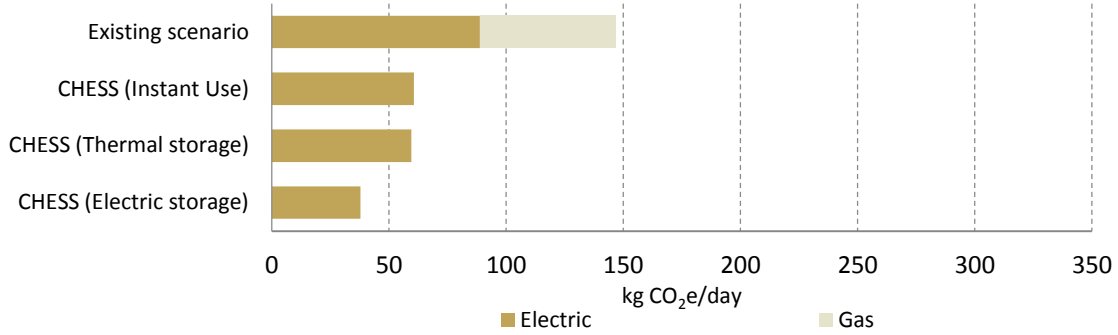

Figure 14. Dwellings totals equivalent CO2 emissions in the existing scenario and each CHESS Setup configurations

2. CORBY pilot's 2050 Scenario

Location:	Colby (Birmingham)
Global horizontal radiation (kWh/m^2):	1,026
Number of houses	*31*
Number of flats	*16*
Total number of dwellings:	47

Electric consumption	**(kWh/dwelling)**
Current electric consumption	*3,500*
Current Htg consumption	2,523
Current DHW consumption	2,000
Current electric Htg+DHW cons.:	0
CHESS electric Htg+DHW cons.:	*1,131*
Total current electric consumption:	3,500
Total CHESS electric consumption:	*4,631*
Usable Battery Energy	2.46

		Heating (HTG)		**Domestic Hot Water (DHW)**	
Type	**Eff.**	**Base Case**	**Test**	**Base Case**	**Test**
Gas boiler/other fuels	90%	100%	0%	100%	0%
Direct electric	100%	0%	0%	0%	0%
Heat pump	300%	0%	0%	0%	0%
CHESS Setup	400%	0%	100%	0%	100%

Share of renewable

Electric Grid	**PV**	**Wind power**
Corby	100.0 %	0.0 %

2.1. Typical winter day

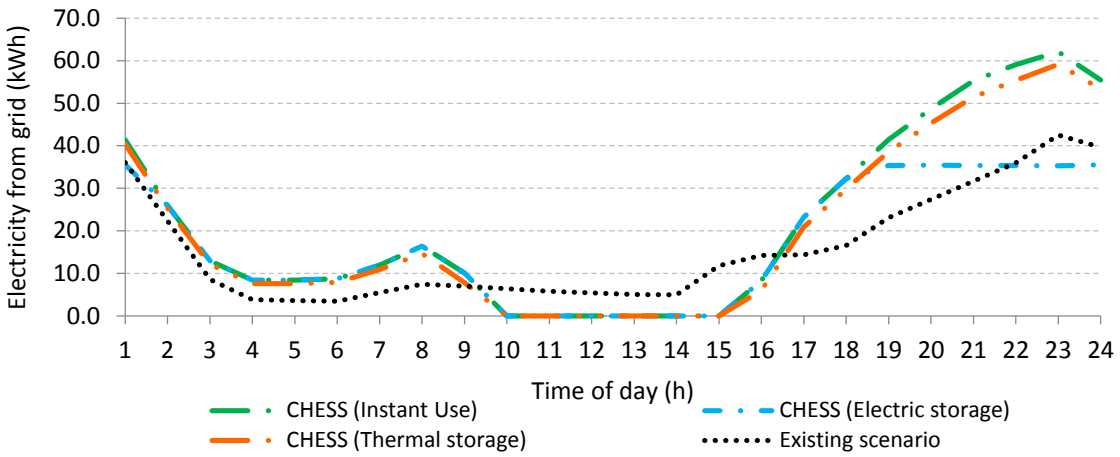

Figure 15. Dwellings existing scenario and CHESS Setup configurations hourly electric grid consumption

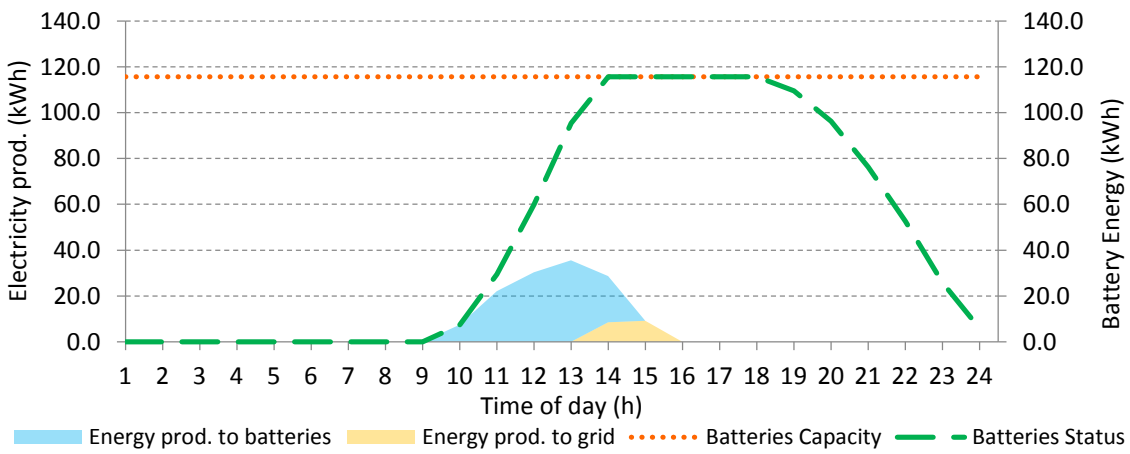

Figure 16. PVs electric production usage and batteries status.

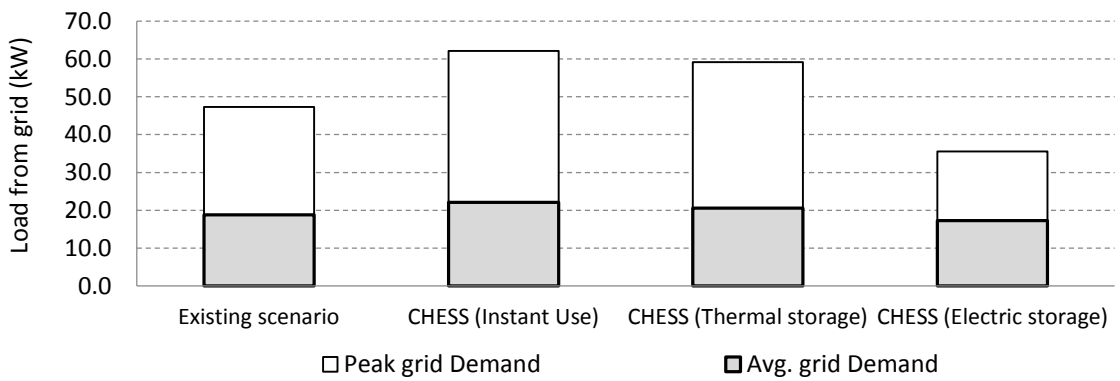

Figure 16. Peak and average electric grid demand

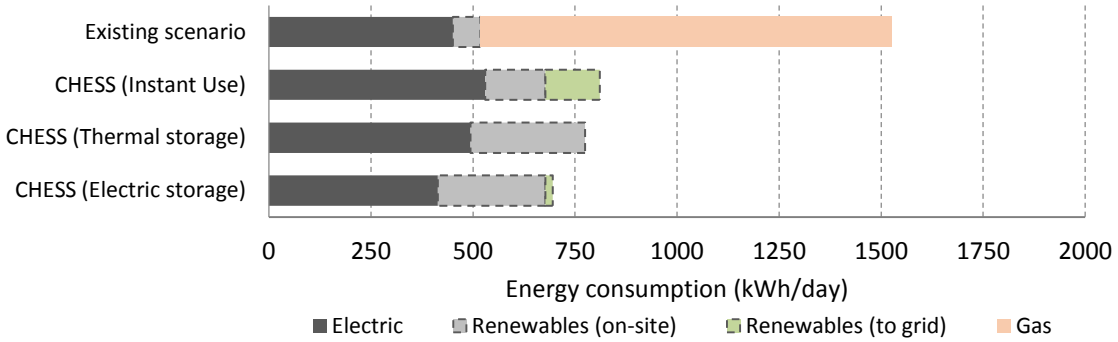

Figure 17. Dwellings totals energy uses/consumption in the existing scenario and each CHESS Setup configurations

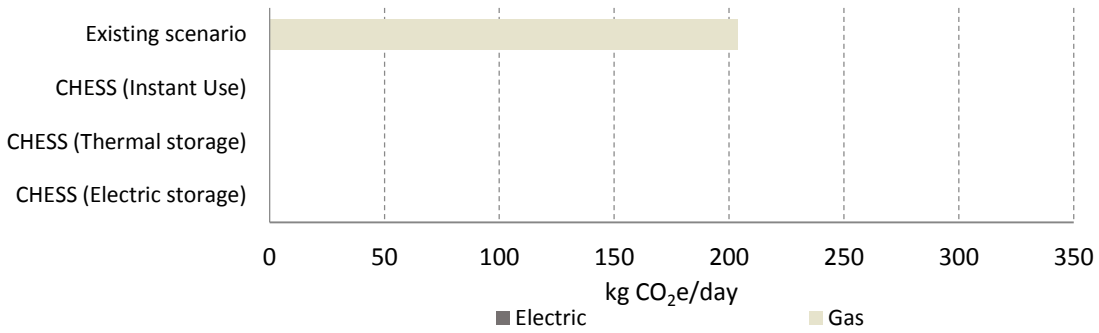

Figure 18. Dwellings totals equivalent CO2 emissions in the existing scenario and each CHESS Setup configurations

2.2. Typical summer day

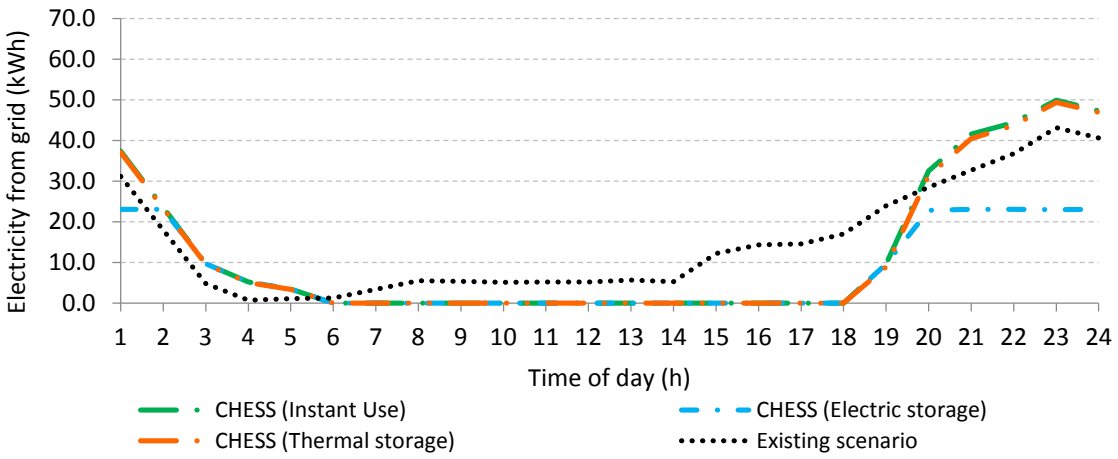

Figure 19. Dwellings existing scenario and CHESS Setup configurations hourly electric grid consumption

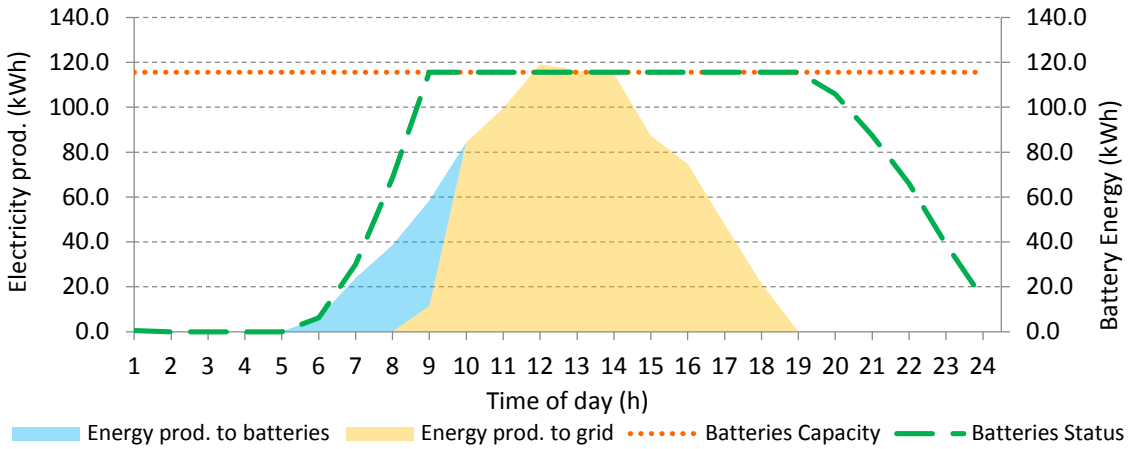

Figure 20. PVs electric production usage and batteries status.

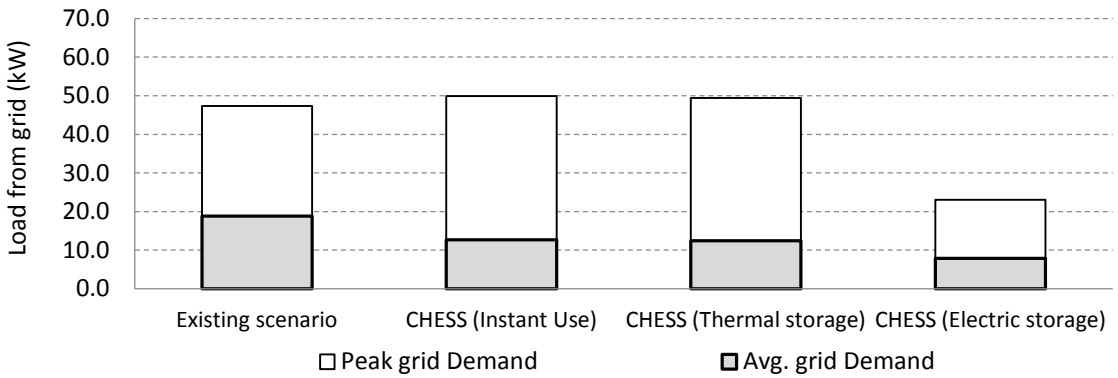

Figure 21. Peak and average electric grid demand

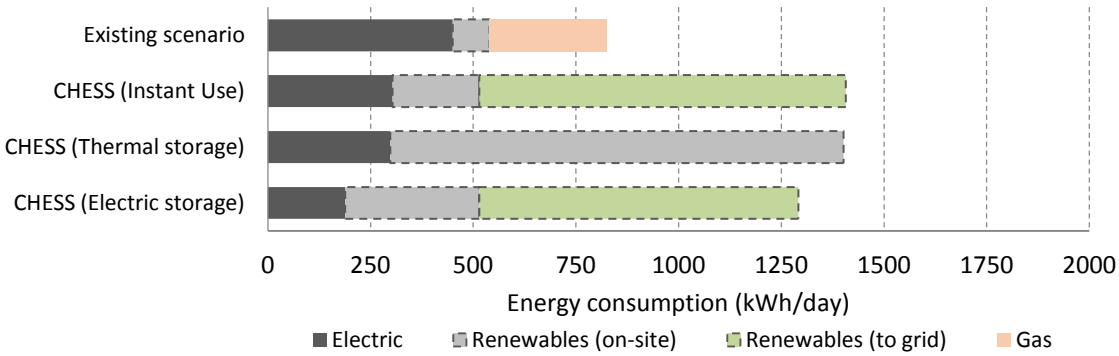

Figure 22. Dwellings totals energy uses/consumption in the existing scenario and each CHESS Setup configurations

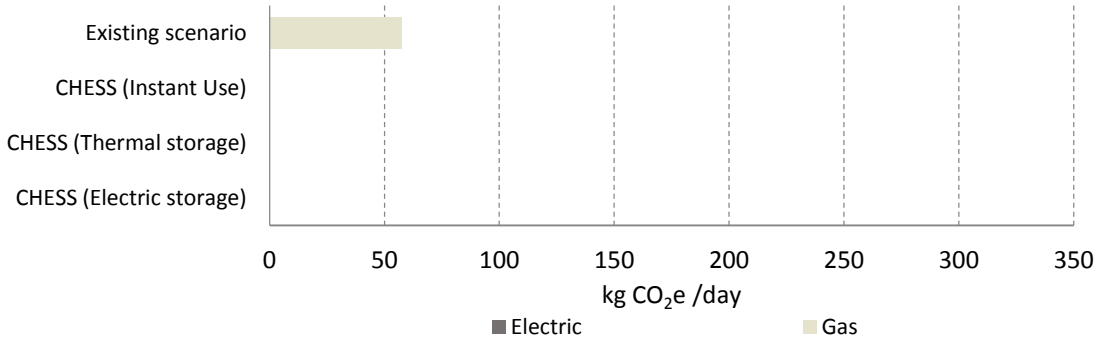

Figure 23. Dwellings totals equivalent CO2 emissions in the existing scenario and each CHESS Setup configurations

3. UK (CHESS 84%/full implementation)

Location:	London
Global horizontal radiation (kWh/m^2):	1,010
Number of houses	
Number of flats	
Total number of dwellings:	28,000,000

Electric consumption	**(kWh/dwelling)**
Current electric consumption	*2,606*
Current Htg consumption	11,455
Current DHW consumption	2,037
Current electric Htg+DHW cons.:	
CHESS electric Htg+DHW cons.:	
Total current electric consumption:	2,606
Total CHESS electric consumption:	*2,606*
Usable Battery Energy	2.46
Battery penetration	*2.5 %*

		Heating (HTG)		**Domestic Hot Water (DHW)**	
Type	**Eff.**	**Base Case**	**Test**	**Base Case**	**Test**
Gas boiler/other fuels	90%	93%	15%	93%	15%
Direct electric	100%	7%	1%	7%	1%
Heat pump	300%	0%	0%	0%	0%
CHESS Setup	400%	0%	84%	0%	84%

Share of renewable

Electric Grid	**PV**	**Wind power**
UK	3.5 %	13.4 %

3.1. Typical winter day

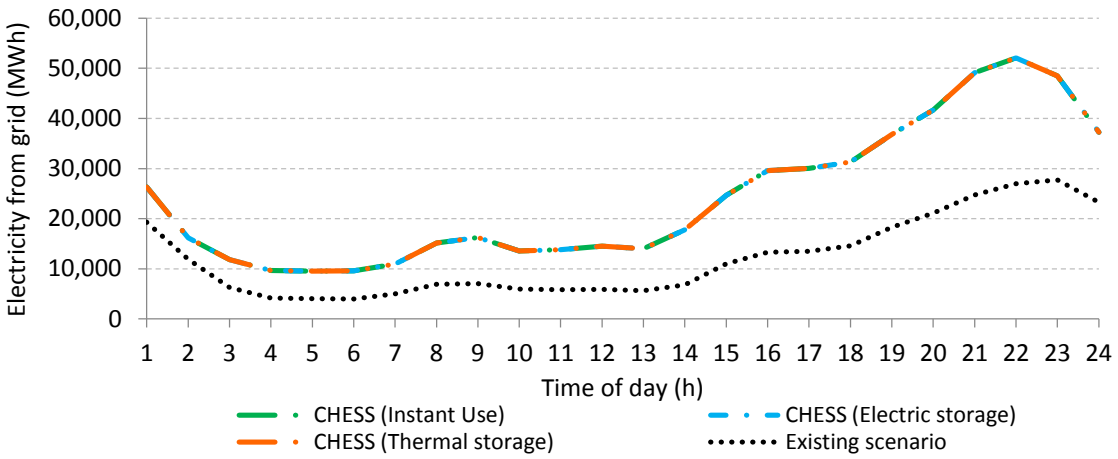

Figure 24. Dwellings existing scenario and CHESS Setup configurations hourly electric grid consumption

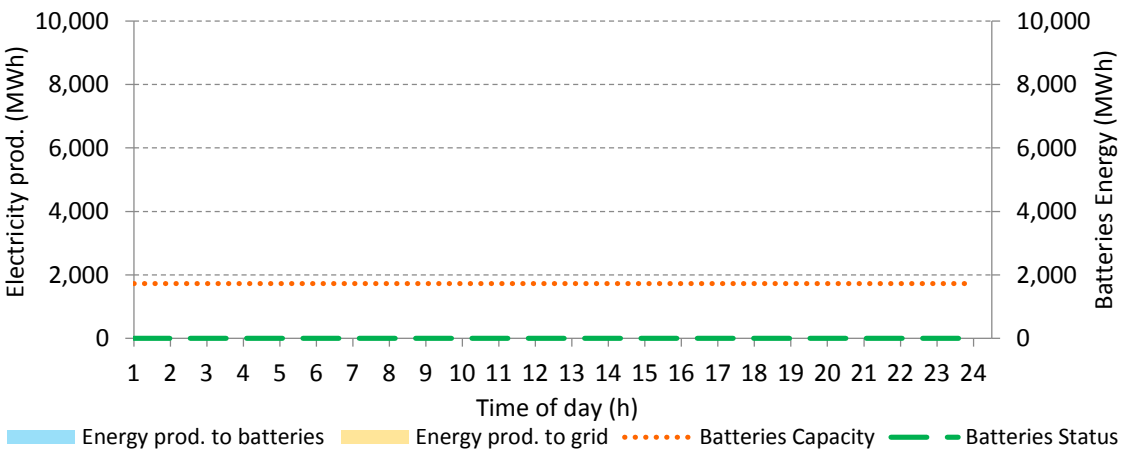

Figure 26. PVs electric production usage and batteries status.

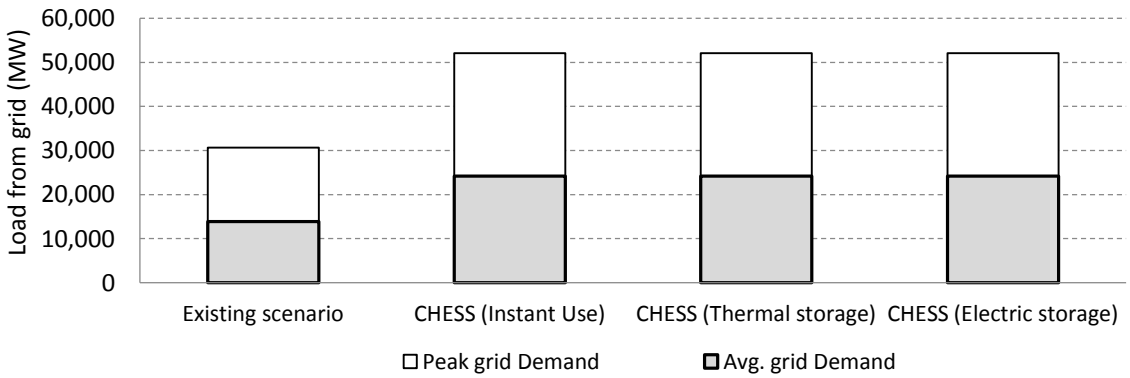

Figure 27. Peak and average electric grid demand

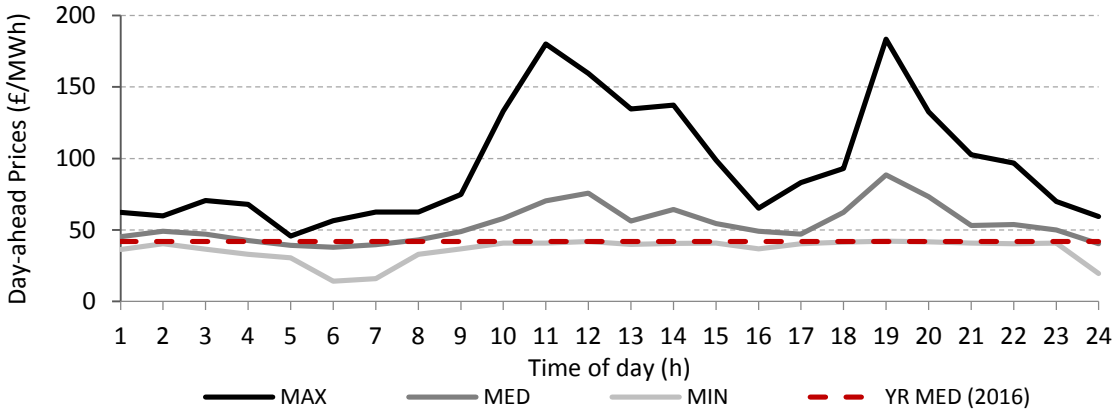

Figure 25. Hourly day-ahead electricity prices

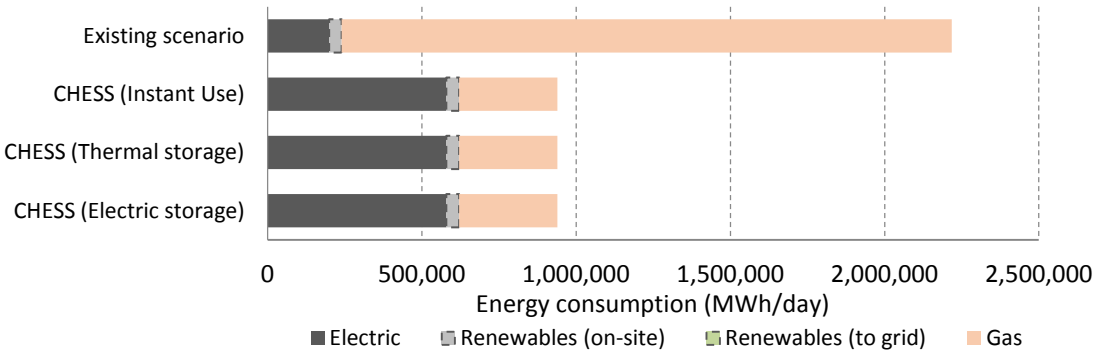

Figure 28. Dwellings totals energy uses/consumption in the existing scenario and each CHESS Setup configurations

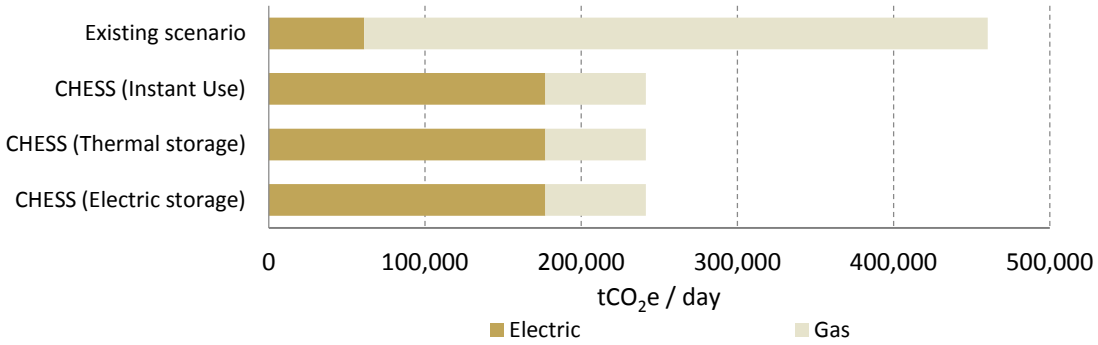

Figure 29. Dwellings totals equivalent CO2 emissions in the existing scenario and each CHESS Setup configurations

Figure 30. Hourly demand, price, environmental impact and supply of UK electricity. (National Grid - Elexon, 2017)

3.2. Typical summer day

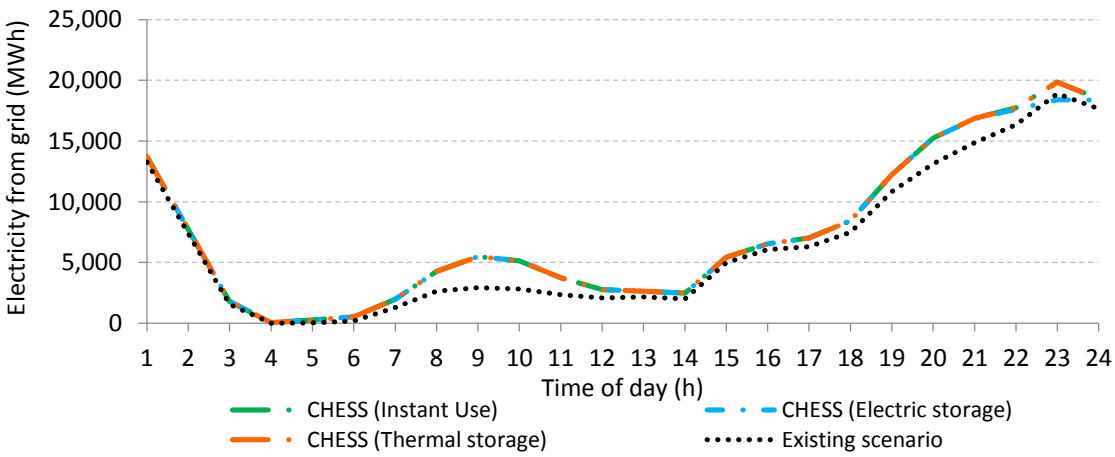

Figure 31. Dwellings existing scenario and CHESS Setup configurations hourly electric grid consumption

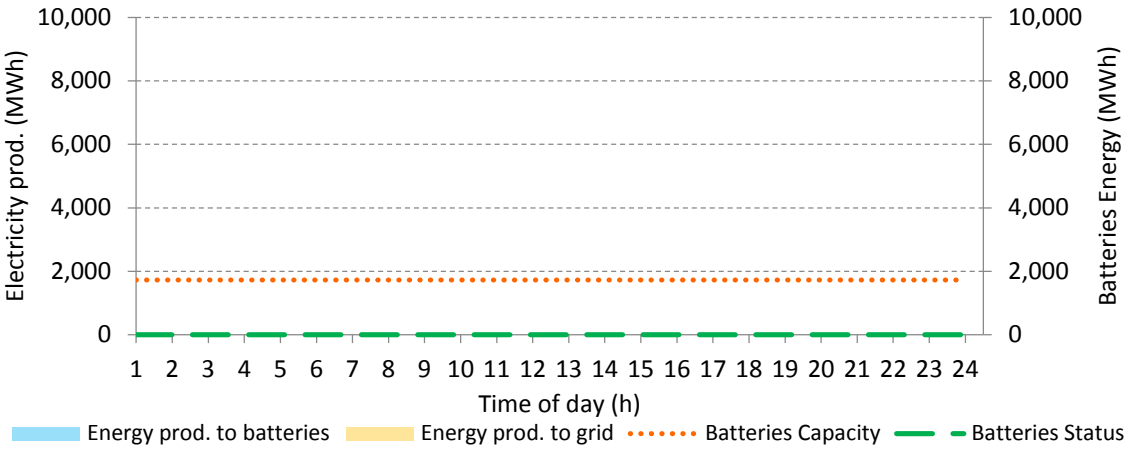

Figure 33. PVs electric production usage and batteries status.

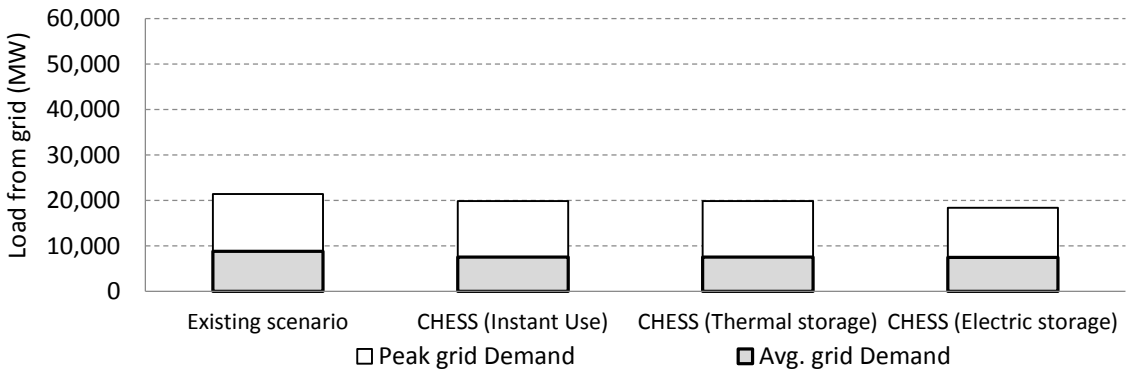

Figure 34. Peak and average electric grid demand

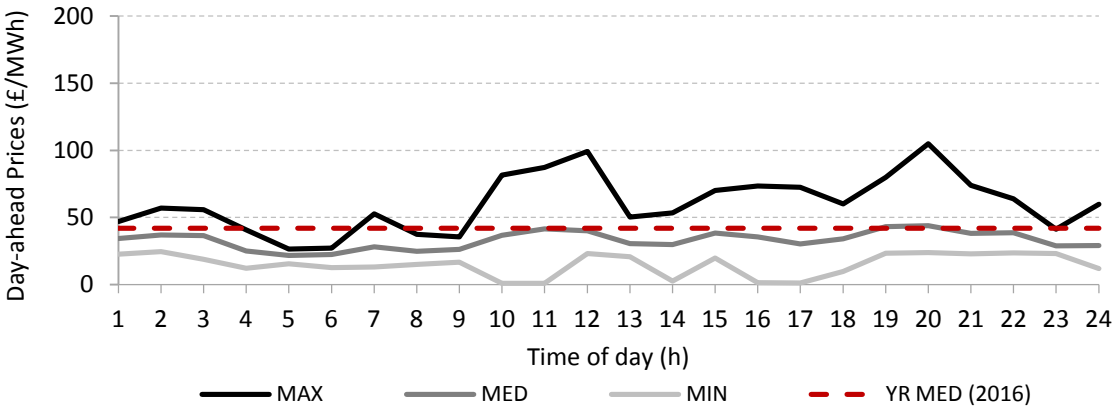

Figure 32. Hourly day-ahead electricity prices

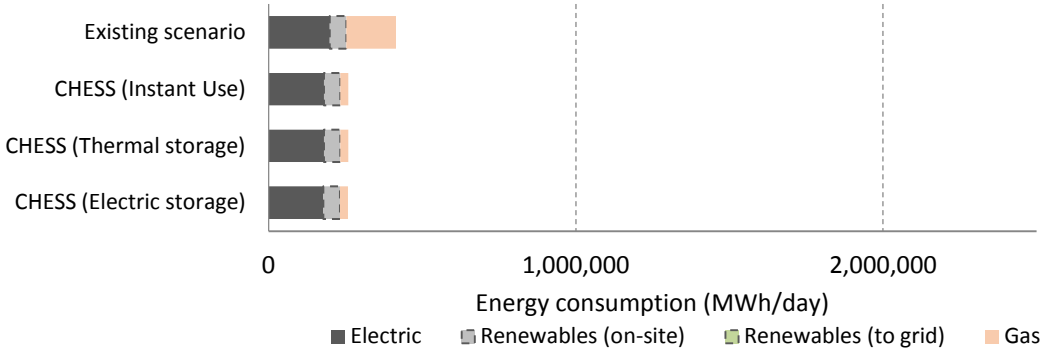

Figure 34. Dwellings totals energy uses/consumption in the existing scenario and each CHESS Setup configurations

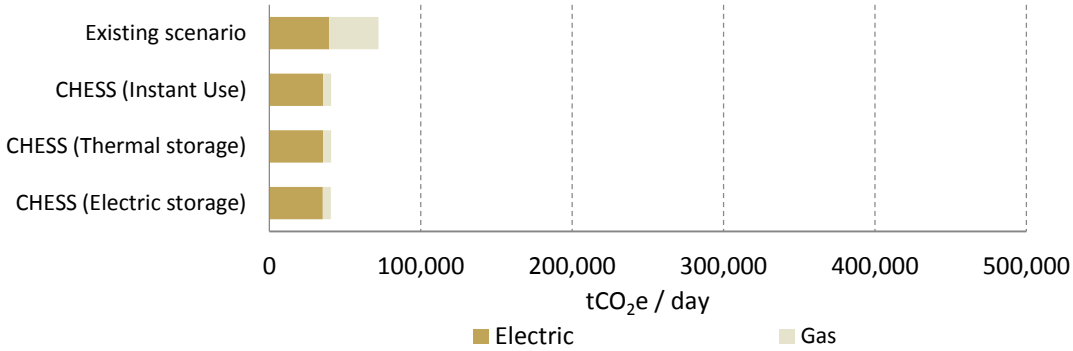

Figure 35. Dwellings totals equivalent CO2 emissions in the existing scenario and each CHESS Setup configurations

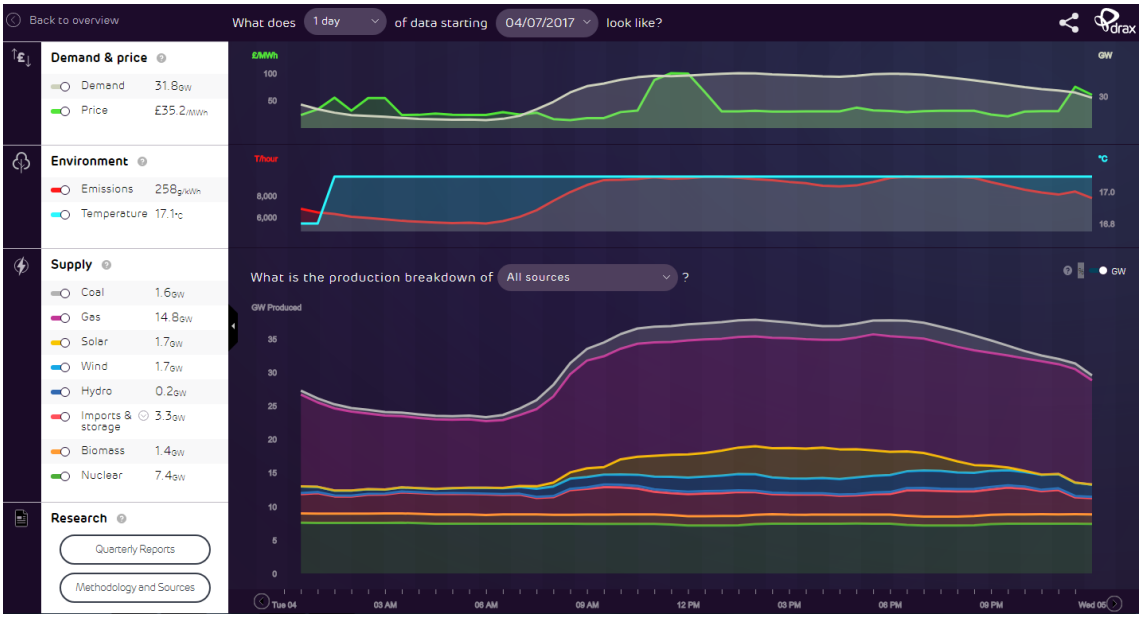

Figure 36. Hourly demand, price, environmental impact and supply of UK electricity.
(National Grid - Elexon, 2017)

4. UK (CHESS 42%/half implementation)

Location:	London
Global horizontal radiation (kWh/m^2):	1,010
Number of houses	
Number of flats	
Total number of dwellings:	28,000,000

Electric consumption	**(kWh/dwelling)**
Current electric consumption	*2,606*
Current Htg consumption	11,455
Current DHW consumption	2,037
Current electric Htg+DHW cons.:	
CHESS electric Htg+DHW cons.:	
Total current electric consumption:	2,606
Total CHESS electric consumption:	*2,606*
Usable Battery Energy	2.46
Battery penetration	*2.5 %*

		Heating (HTG)		**Domestic Hot Water (DHW)**	
Type	**Eff.**	**Base Case**	**Test**	**Base Case**	**Test**
Gas boiler/other fuels	90%	93%	15%	93%	15%
Direct electric	100%	7%	1%	7%	1%
Heat pump	300%	0%	42%	0%	42%
CHESS Setup	400%	0%	42%	0%	42%

Share of renewable

Electric Grid	**PV**	**Wind power**
UK	3.5 %	13.4 %

4.1. Typical winter day

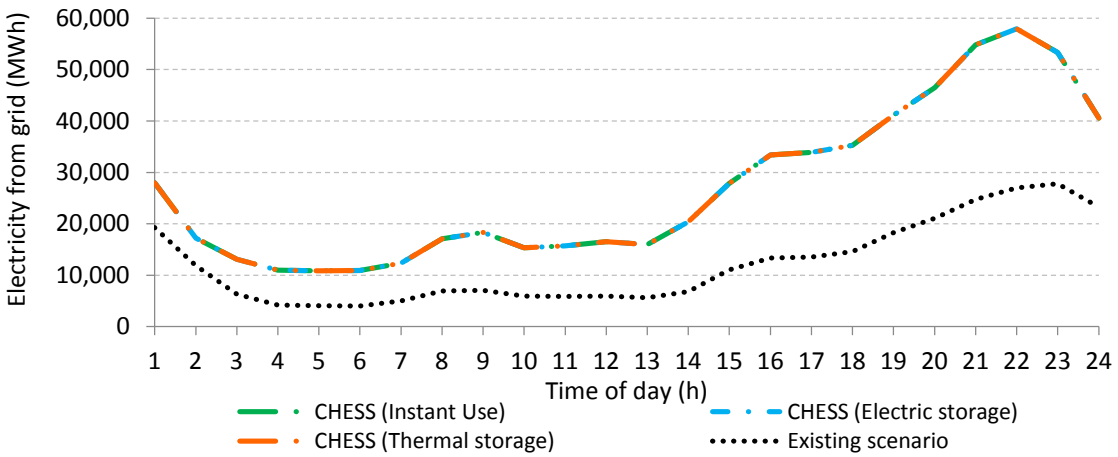

Figure 37. Dwellings existing scenario and CHESS Setup configurations hourly electric grid consumption

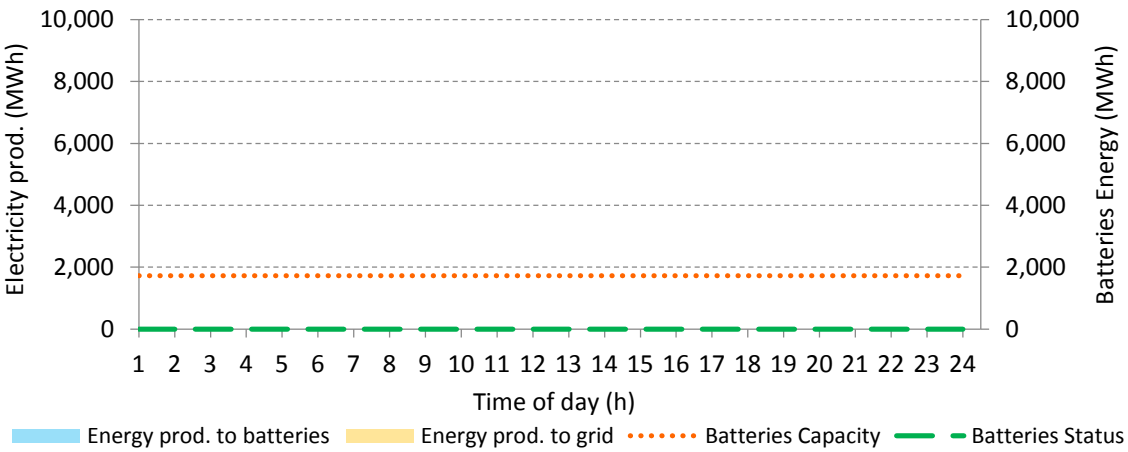

Figure 38. PVs electric production usage and batteries status.

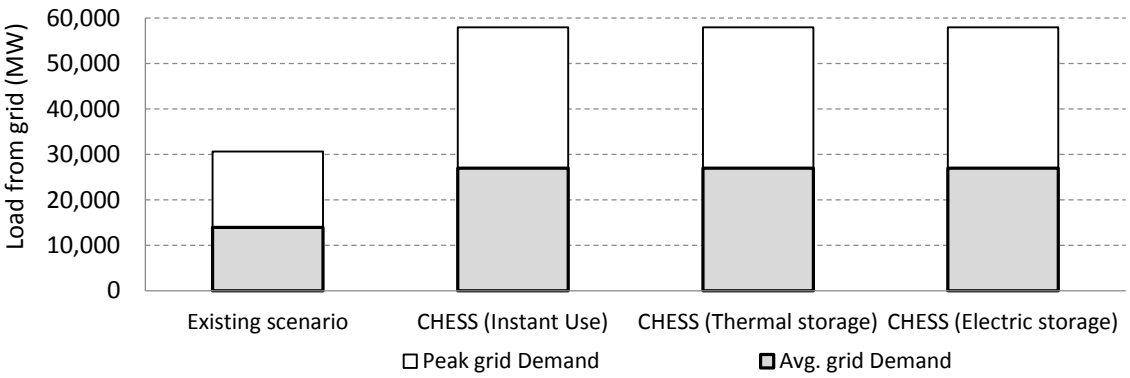

Figure 39. Peak and average electric grid demand

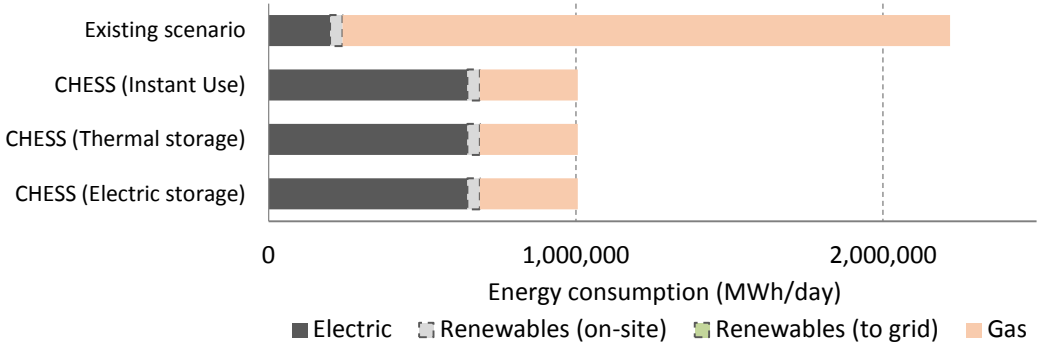

Figure 40. Dwellings totals energy uses/consumption in the existing scenario and each CHESS Setup configurations

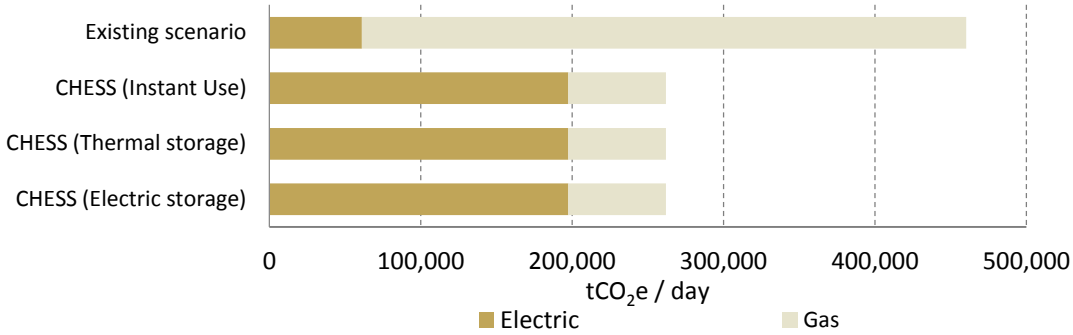

Figure 41. Dwellings totals equivalent CO2 emissions in the existing scenario and each CHESS Setup configurations

4.2. Typical summer day

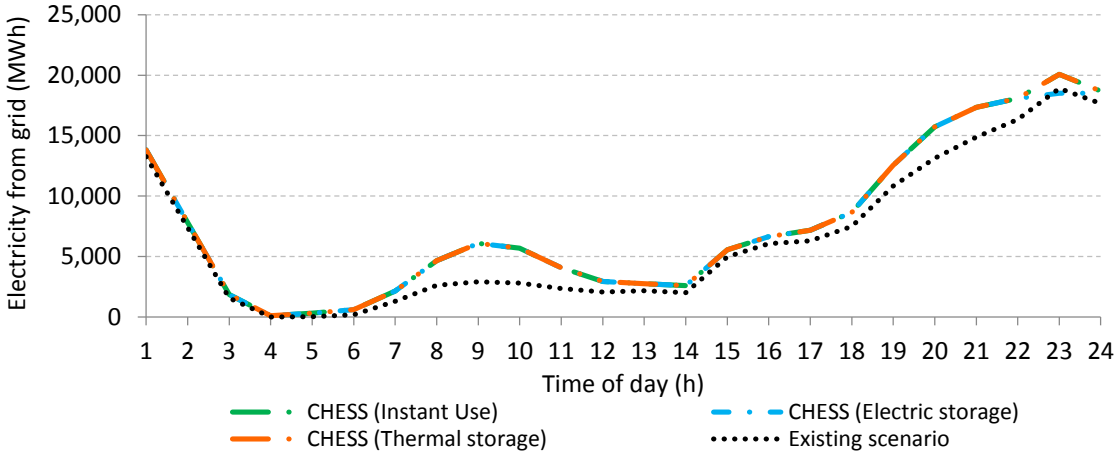

Figure 42. Dwellings existing scenario and CHESS Setup configurations hourly electric grid consumption

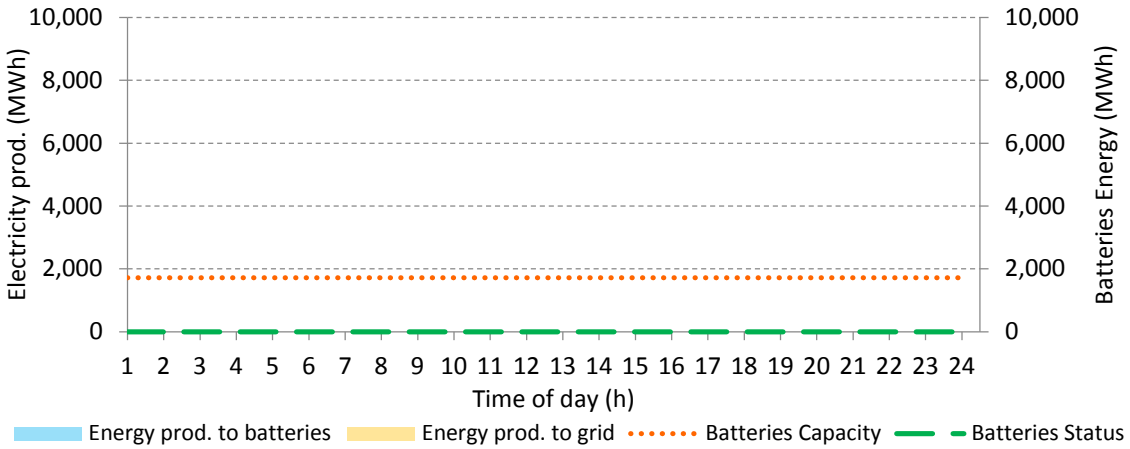

Figure 43. PVs electric production usage and batteries status.

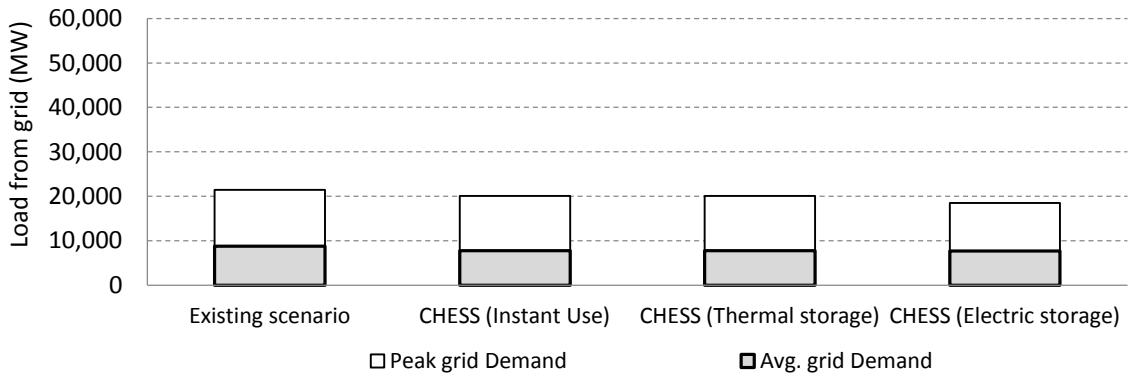

Figure 44. Peak and average electric grid demand

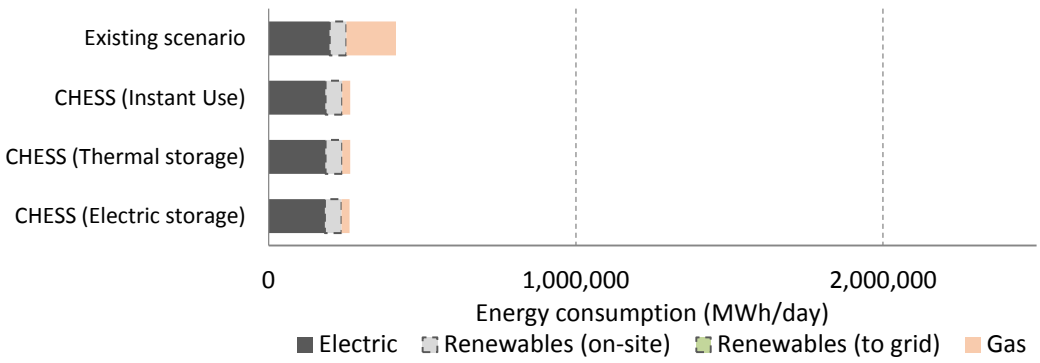

Figure 45. Dwellings totals energy uses/consumption in the existing scenario and each CHESS Setup configurations

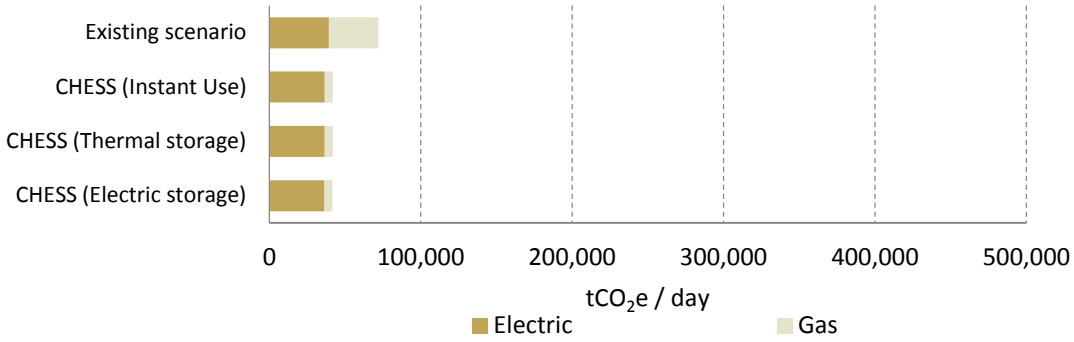

Figure 46. Dwellings totals equivalent CO2 emissions in the existing scenario and each CHESS Setup configurations

5. UK 2050 Scenario (CHESS 84%/full implementation)

Location:	London
Global horizontal radiation (kWh/m^2):	1,010
Number of houses *Number of flats* **Total number of dwellings**:	 28,000,000

Electric consumption	**(kWh/dwelling)**
Current electric consumption	*2,606*
Current Htg consumption	11,455
Current DHW consumption	2,037
Current electric Htg+DHW cons.:	
CHESS electric Htg+DHW cons.:	
Total current electric consumption:	2,606
Total CHESS electric consumption:	*2,606*
Usable Battery Energy	2.46
Battery penetration	*5.0 %*

		Heating (HTG)		**Domestic Hot Water (DHW)**	
Type	**Eff.**	**Base Case**	**Test**	**Base Case**	**Test**
Gas boiler/other fuels	90%	93%	15%	93%	15%
Direct electric	100%	7%	1%	7%	1%
Heat pump	300%	0%	0%	0%	0%
CHESS Setup	400%	0%	84%	0%	84%

Share of renewable

Electric Grid	**PV**	**Wind power**
UK	11.1 %	41.9 %

5.1. Typical winter day

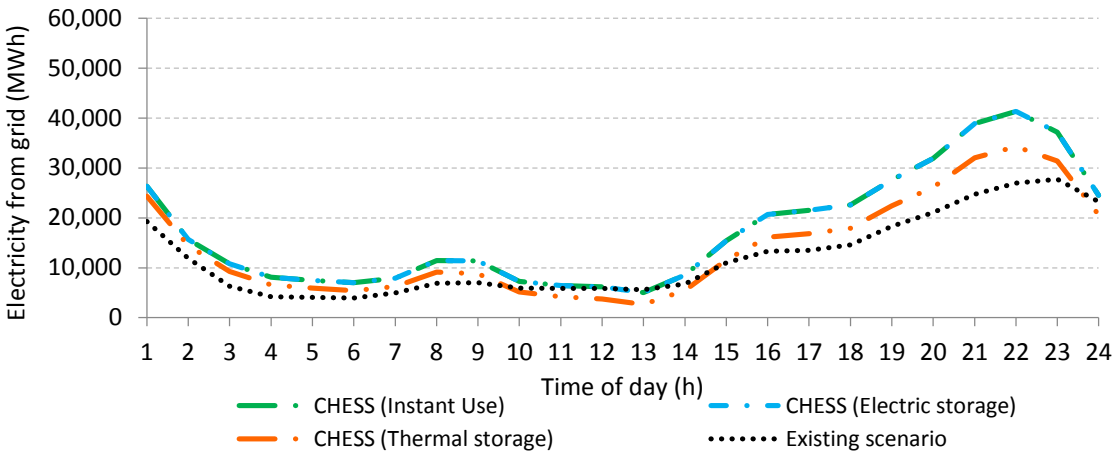

Figure 47. Dwellings existing scenario and CHESS Setup configurations hourly electric grid consumption

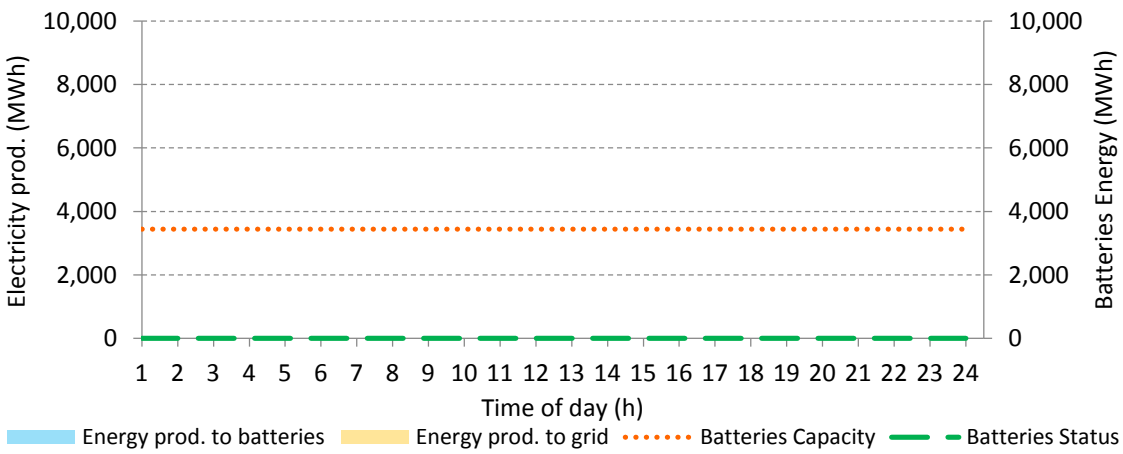

Figure 48. PVs electric production usage and batteries status.

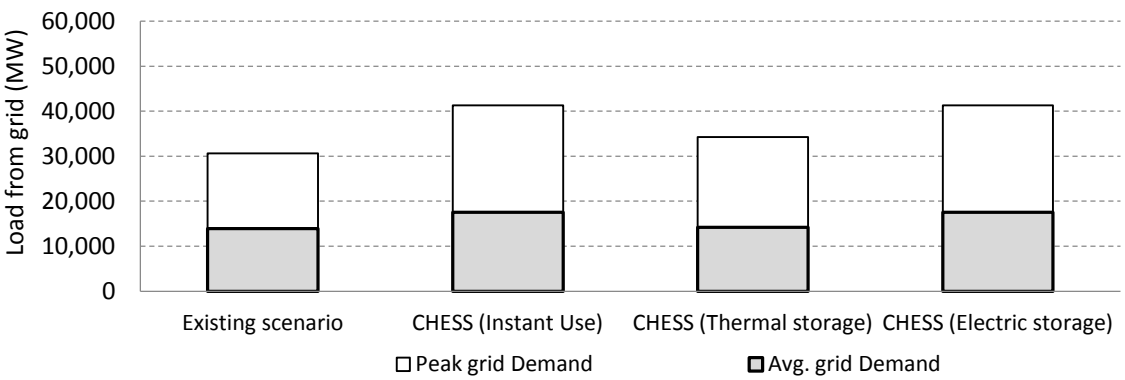

Figure 49. Peak and average electric grid demand

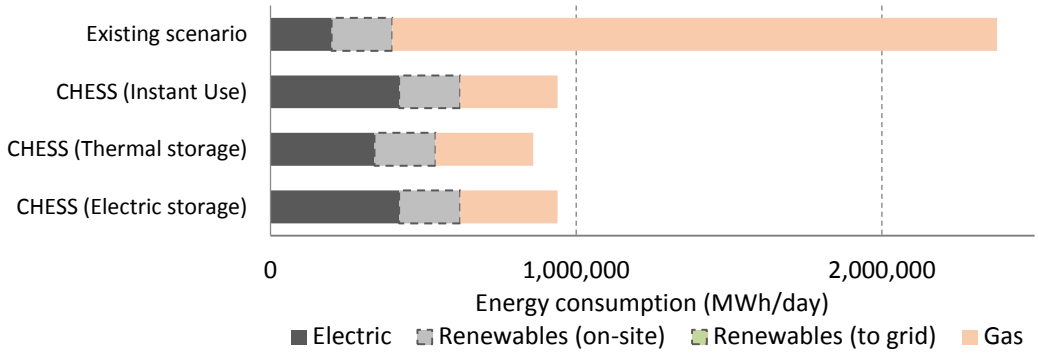

Figure 50. Dwellings totals energy uses/consumption in the existing scenario and each CHESS Setup configurations

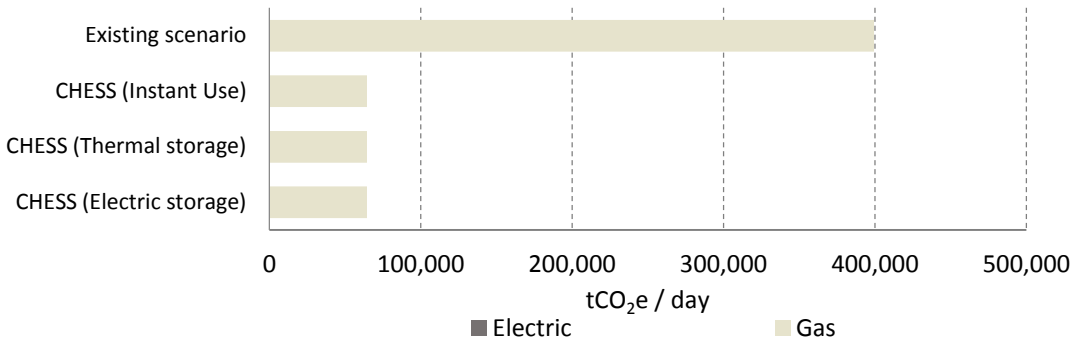

Figure 51. Dwellings totals equivalent CO2 emissions in the existing scenario and each CHESS Setup configurations

5.2. Typical summer day

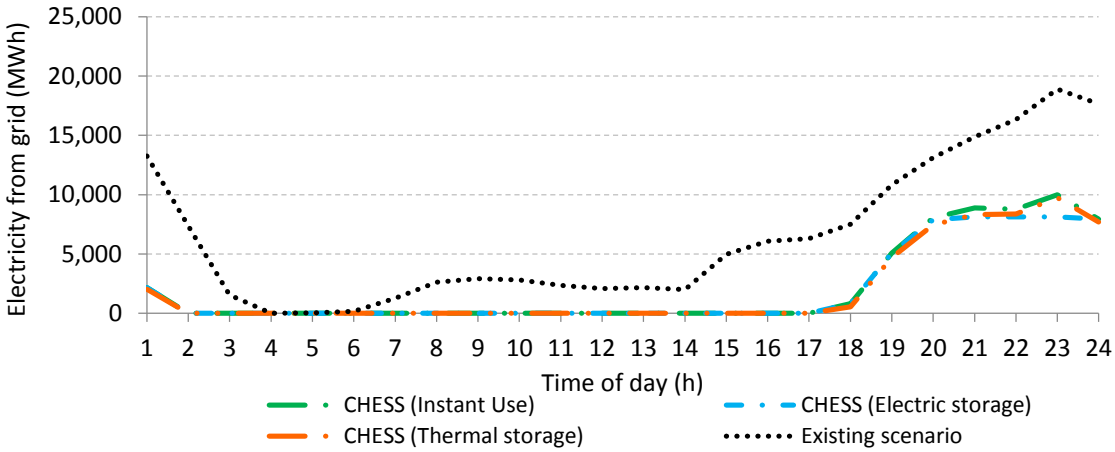

Figure 52. Dwellings existing scenario and CHESS Setup configurations hourly electric grid consumption

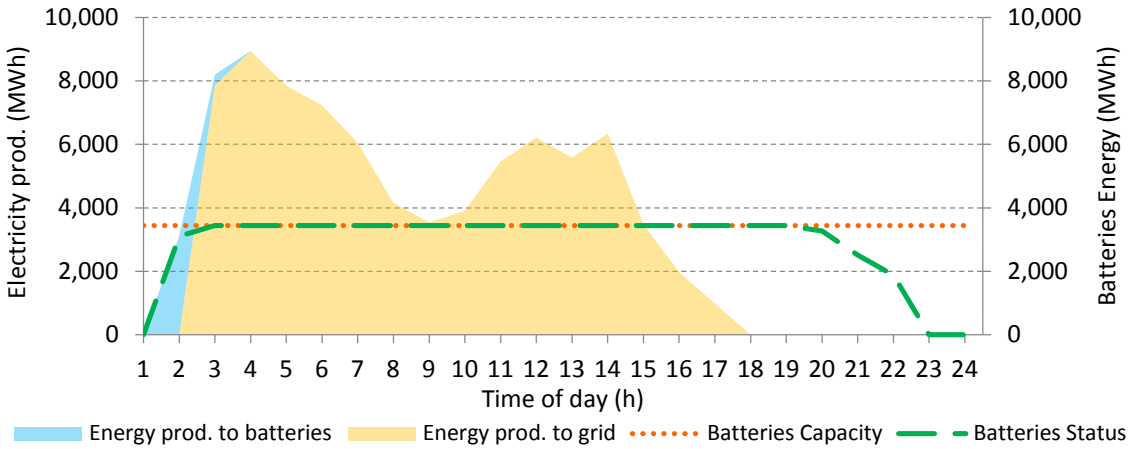

Figure 53. PVs electric production usage and batteries status.

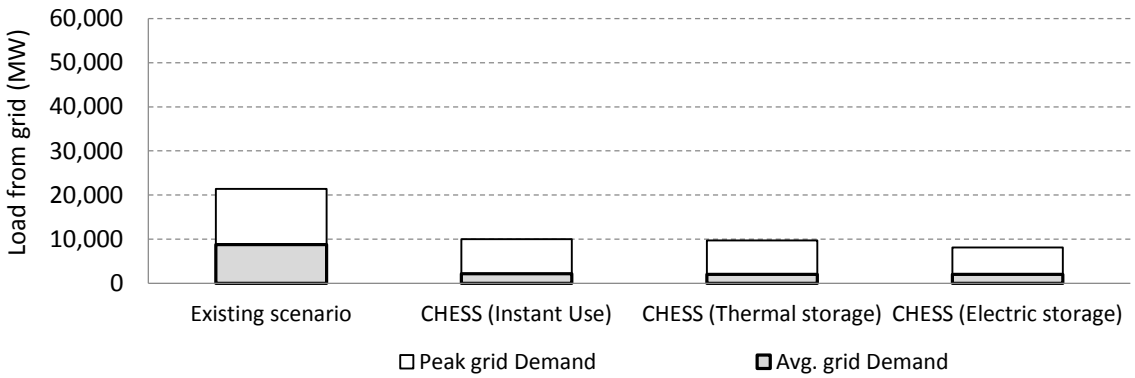

Figure 54. Peak and average electric grid demand

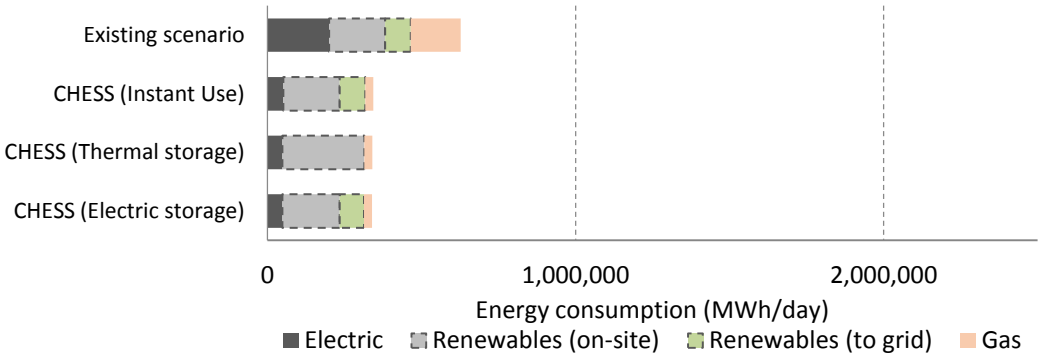

Figure 55. Dwellings totals energy uses/consumption in the existing scenario and each CHESS Setup configurations

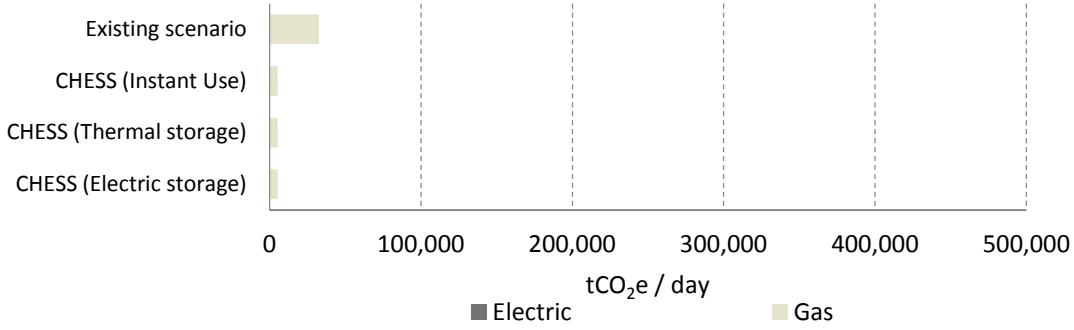

Figure 56. Dwellings totals equivalent CO2 emissions in the existing scenario and each CHESS Setup configurations

6. UK 2050 Scenario (CHESS 42%/half implementation)

Location:	**London**
Global horizontal radiation (kWh/m^2):	1,010
Number of houses *Number of flats* **Total number of dwellings**:	 28,000,000

Electric consumption	**(kWh/dwelling)**
Current electric consumption	*2,606*
Current Htg consumption	11,455
Current DHW consumption	2,037
Current electric Htg+DHW cons.:	
CHESS electric Htg+DHW cons.:	
Total current electric consumption:	2,606
Total CHESS electric consumption:	*2,606*
Usable Battery Energy	2.46
Battery penetration	*5.0 %*

		Heating (HTG)		**Domestic Hot Water (DHW)**	
Type	**Eff.**	**Base Case**	**Test**	**Base Case**	**Test**
Gas boiler/other fuels	90%	93%	15%	93%	15%
Direct electric	100%	7%	1%	7%	1%
Heat pump	300%	0%	42%	0%	42%
CHESS Setup	400%	0%	42%	0%	42%

Share of renewable

Electric Grid	**PV**	**Wind power**
UK	11.1 %	41.9 %

6.1. Typical winter day

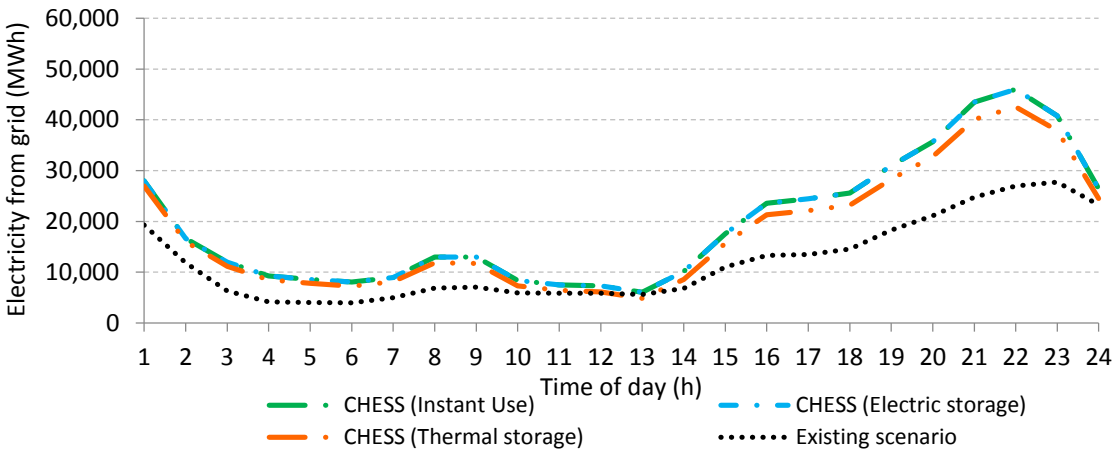

Figure 57. Dwellings existing scenario and CHESS Setup configurations hourly electric grid consumption

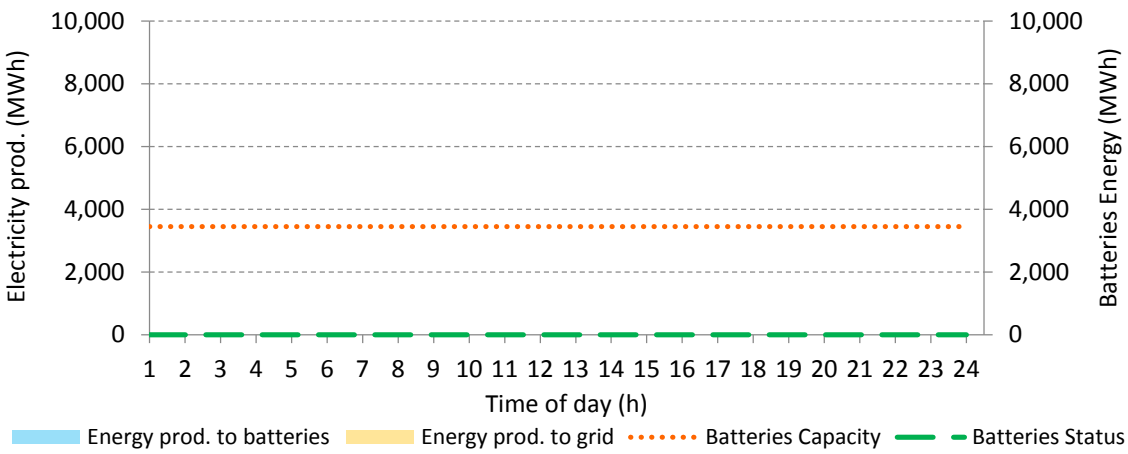

Figure 58. PVs electric production usage and batteries status.

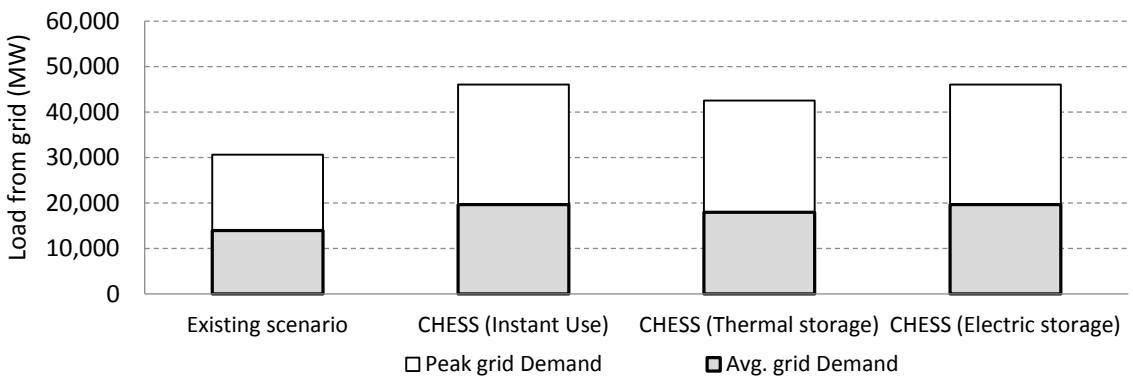

Figure 59. Peak and average electric grid demand

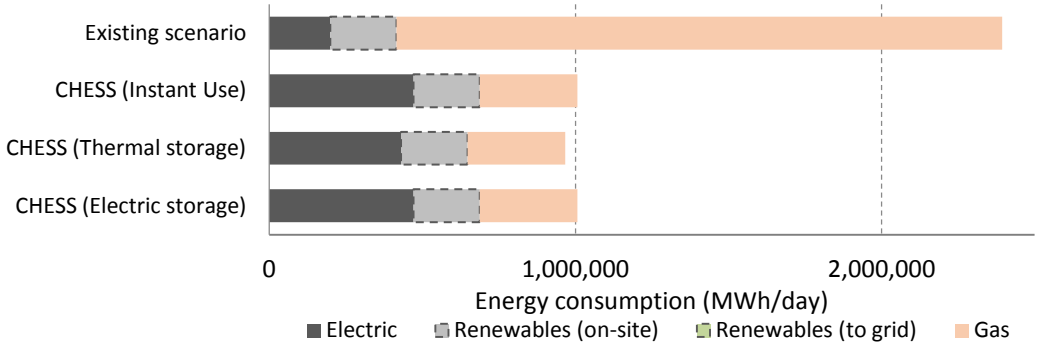

Figure 60. Dwellings totals energy uses/consumption in the existing scenario and each CHESS Setup configurations

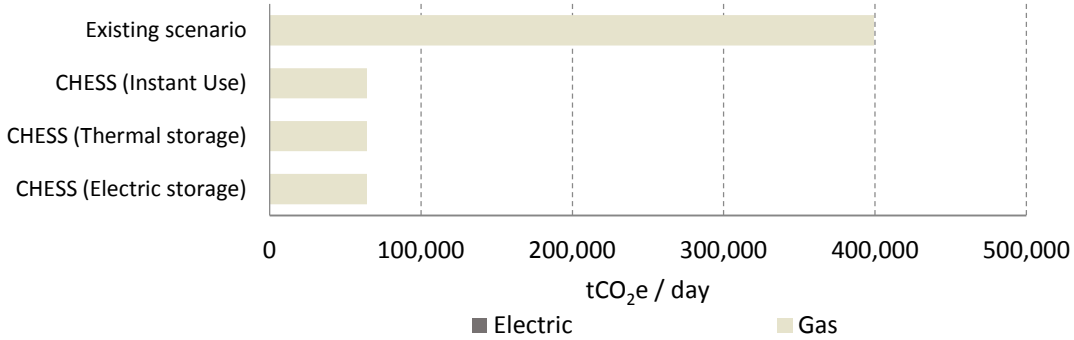

Figure 61. Dwellings totals equivalent CO2 emissions in the existing scenario and each CHESS Setup configurations

6.2. Typical summer day

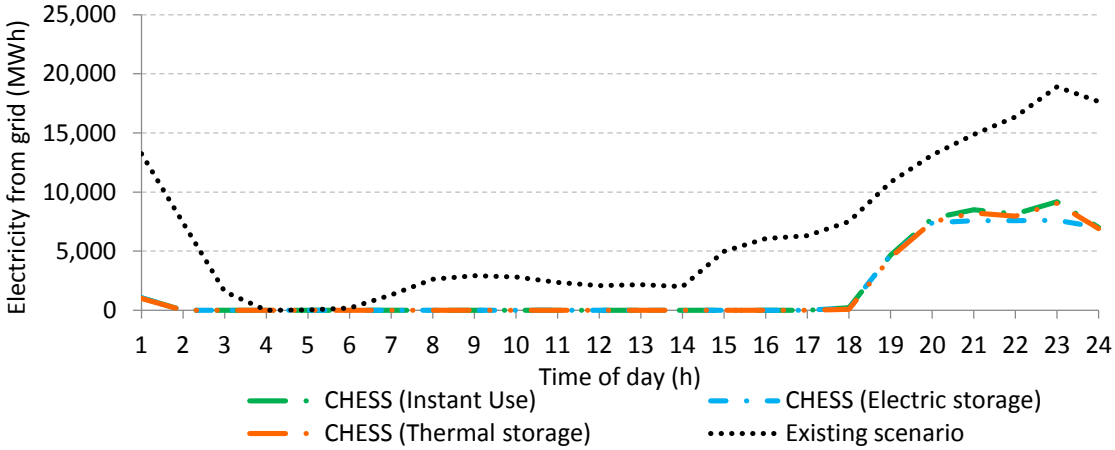

Figure 62. Dwellings existing scenario and CHESS Setup configurations hourly electric grid consumption

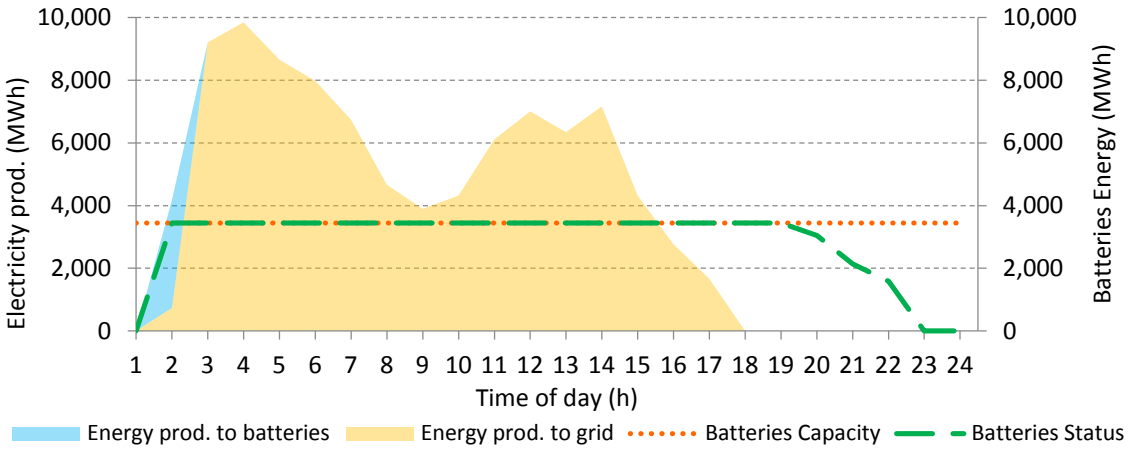

Figure 63. PVs electric production usage and batteries status.

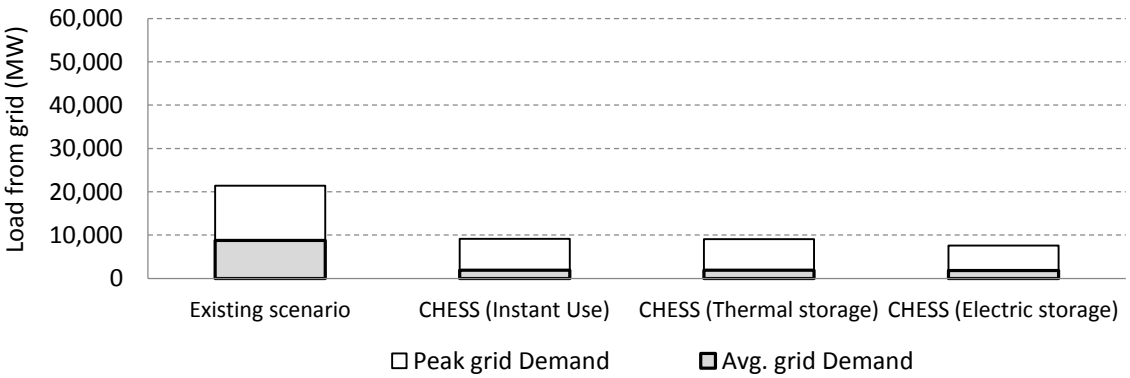

Figure 64. Peak and average electric grid demand

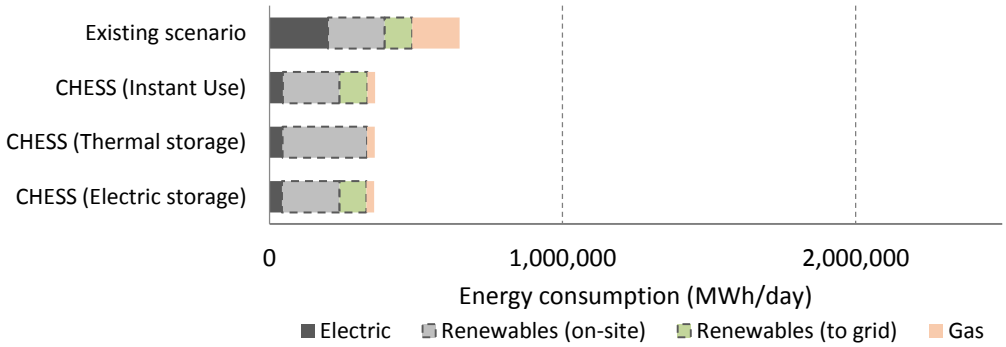

Figure 65. Dwellings totals energy uses/consumption in the existing scenario and each CHESS Setup configurations

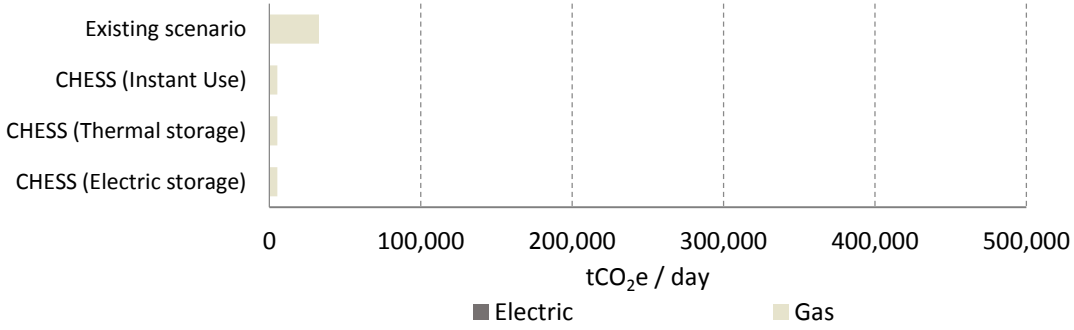

Figure 66. Dwellings totals equivalent CO2 emissions in the existing scenario and each CHESS Setup configurations

7. SPAIN (CHESS 84%/full implementation)

Location:	Madrid
Global horizontal radiation (kWh/m^2):	1,617
Number of houses	
Number of flats	
Total number of dwellings:	17,199,630

Electric consumption	**(kWh/dwelling)**
Current electric consumption	*2,648*
Current Htg consumption	4,661
Current DHW consumption	1,877
Current electric Htg+DHW cons.:	
CHESS electric Htg+DHW cons.:	
Total current electric consumption:	2,648
Total CHESS electric consumption:	*2,648*
Usable Battery Energy	2.46
Battery penetration	*2.45 %*

		Heating (HTG)		**Domestic Hot Water (DHW)**	
Type	**Eff.**	**Base Case**	**Test**	**Base Case**	**Test**
Gas boiler/other fuels	94%	49%	15%	71%	15%
Direct electric	99%	35%	1%	29%	1%
Heat pump	340%	16%	0%	0%	0%
CHESS Setup	450%	0%	84%	0%	84%

Share of renewable

Electric Grid	**PV**	**Wind power**
Spain	3.1 %	18.4 %

7.1. Typical winter day

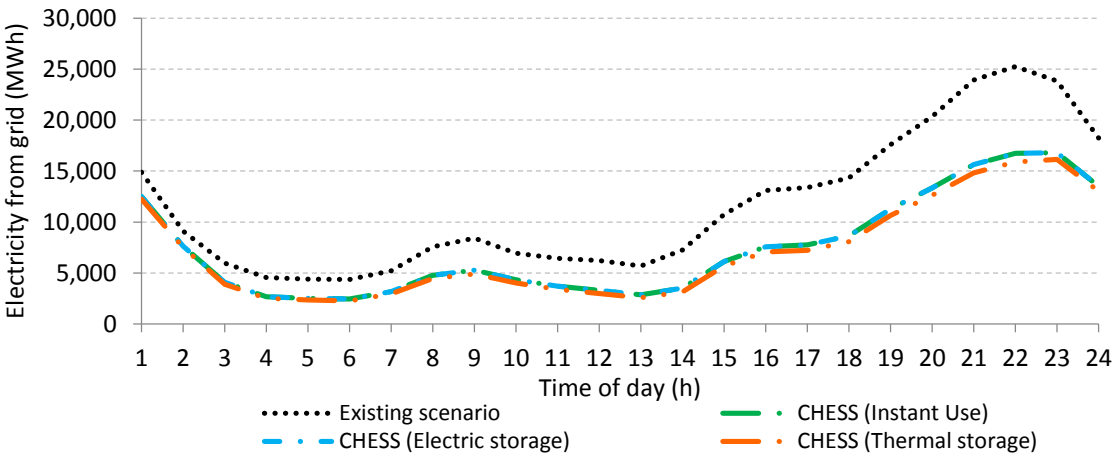

Figure 67. Dwellings existing scenario and CHESS Setup configurations hourly electric grid consumption

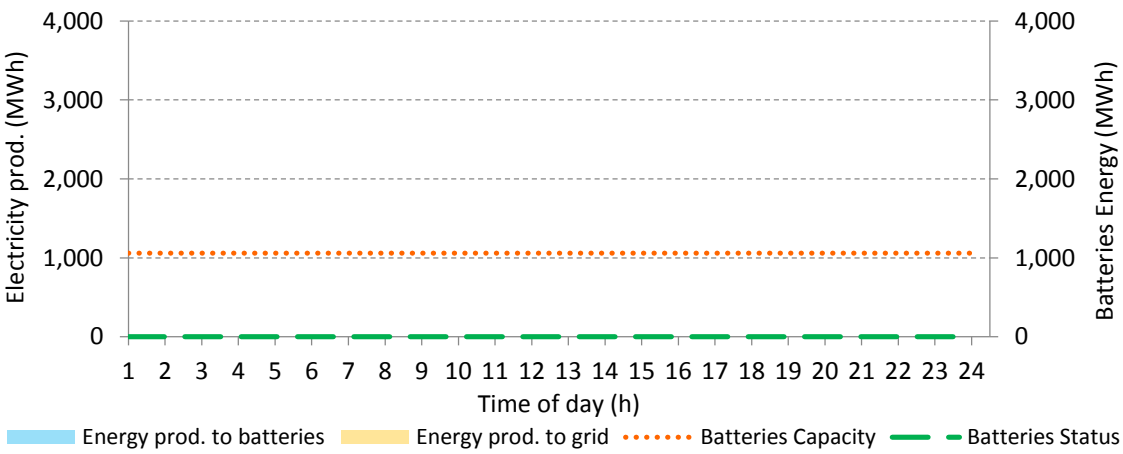

Figure 69. PVs electric production usage and batteries status.

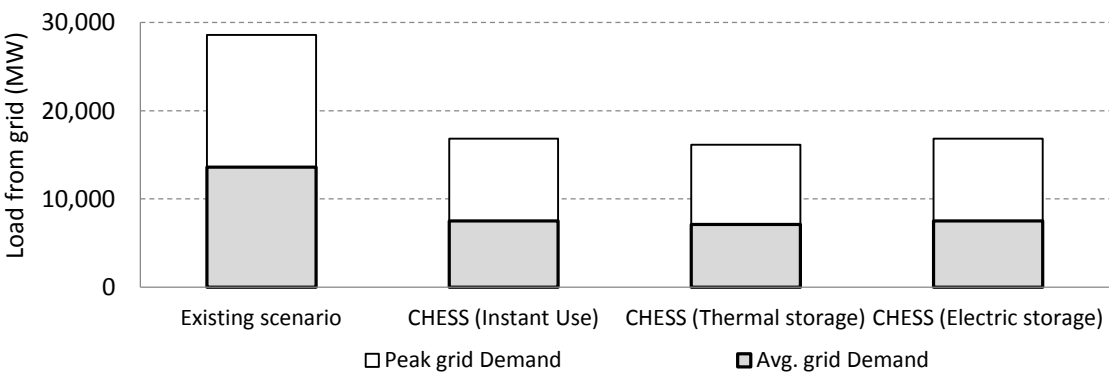

Figure 70. Peak and average electric grid demand

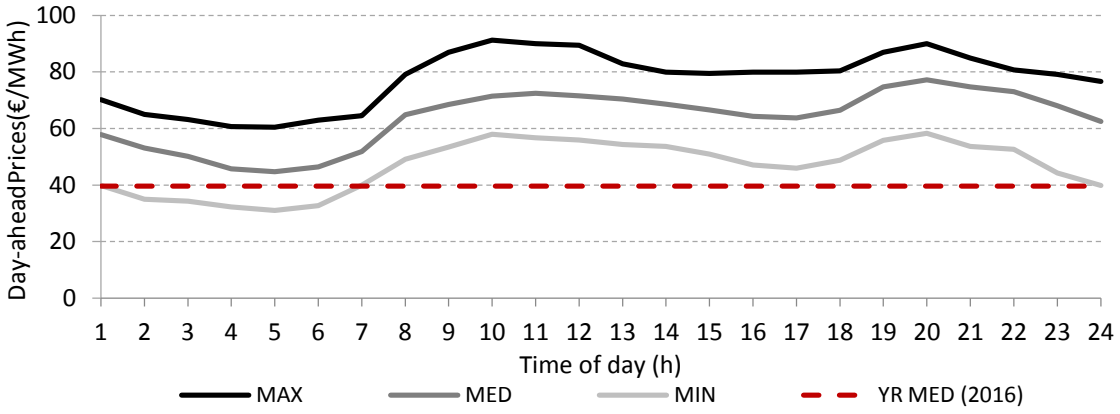

Figure 68. Hourly day-ahead electricity prices

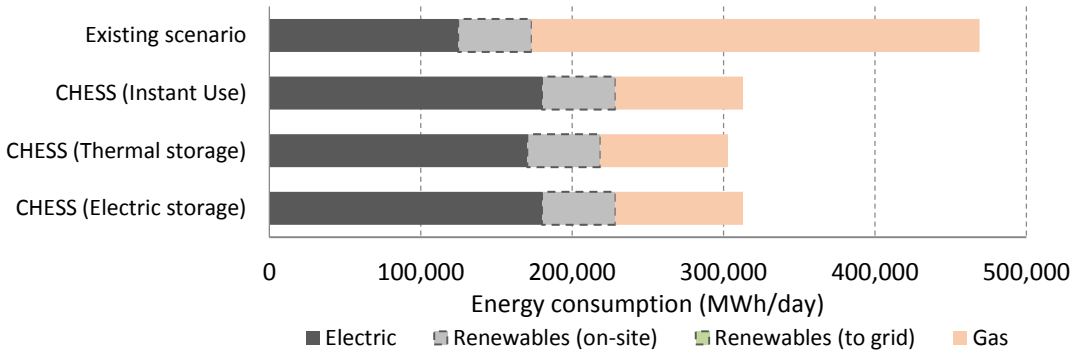

Figure 71. Dwellings totals energy uses/consumption in the existing scenario and each CHESS Setup configurations

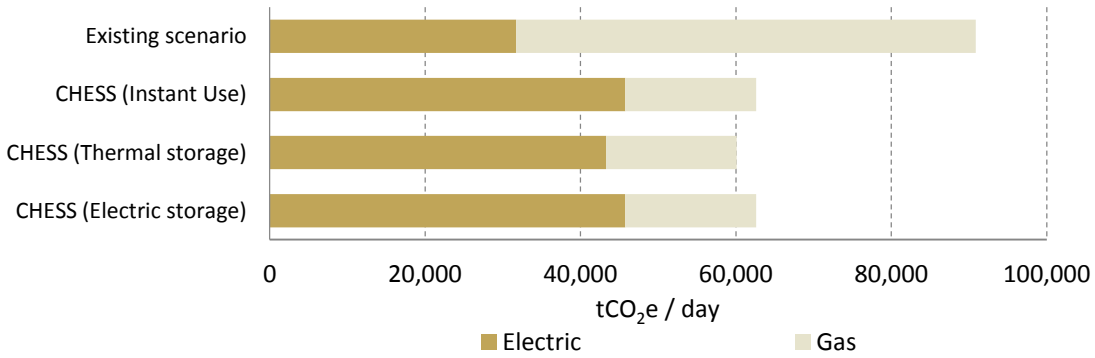

Figure 72. Dwellings totals equivalent CO2 emissions in the existing scenario and each CHESS Setup configurations

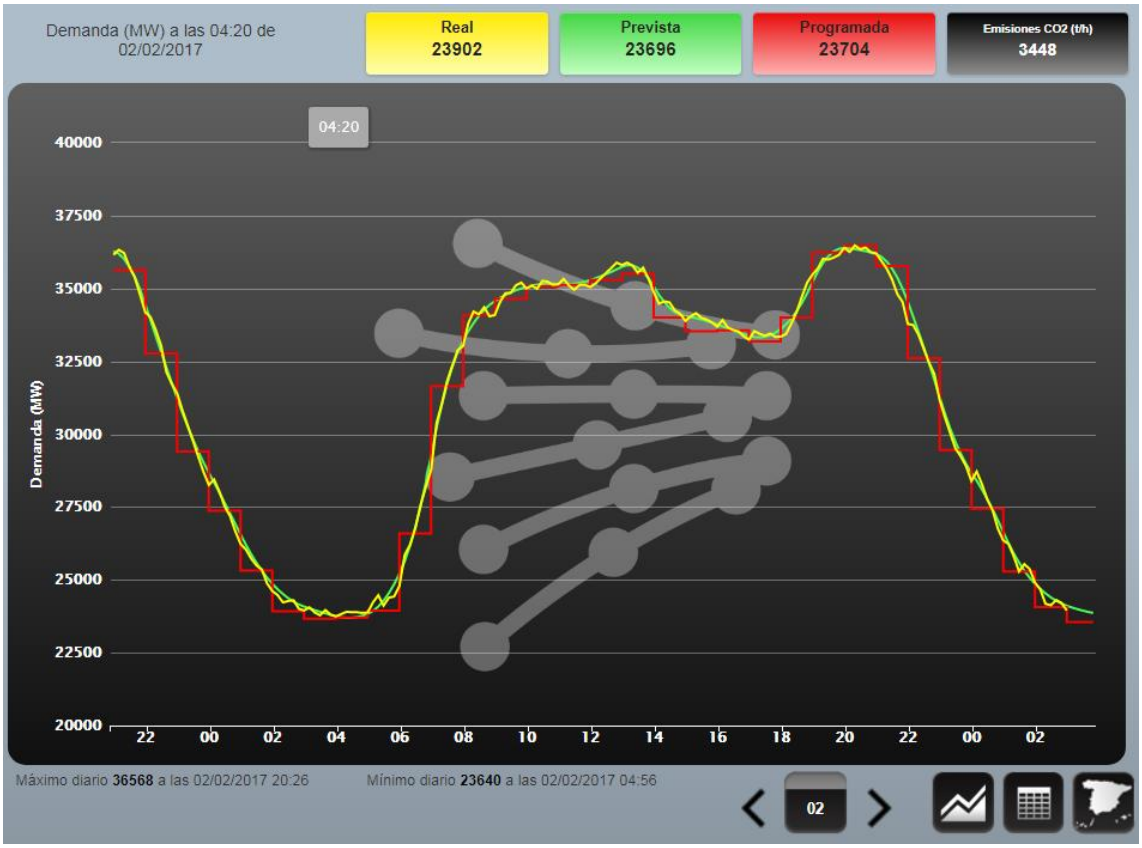

Figure 73. Hourly supply of Spain electricity. (Red Eléctrica de España S.A., 2017)

7.2. Typical summer day

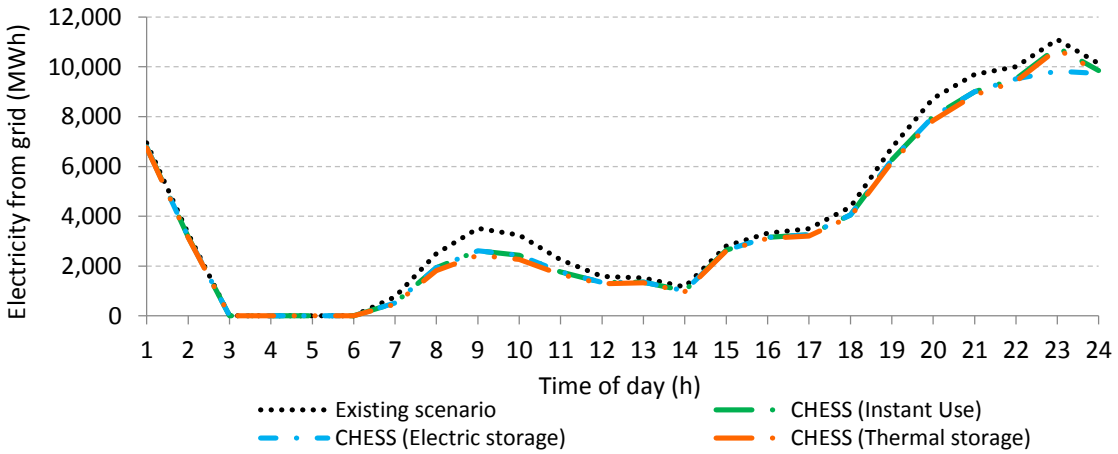

Figure 74. Dwellings existing scenario and CHESS Setup configurations hourly electric grid consumption

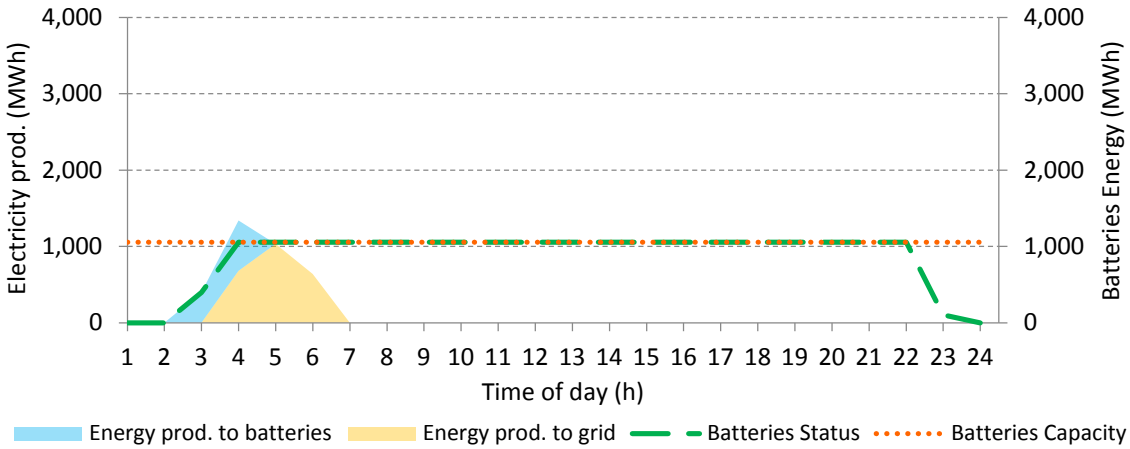

Figure 76. PVs electric production usage and batteries status.

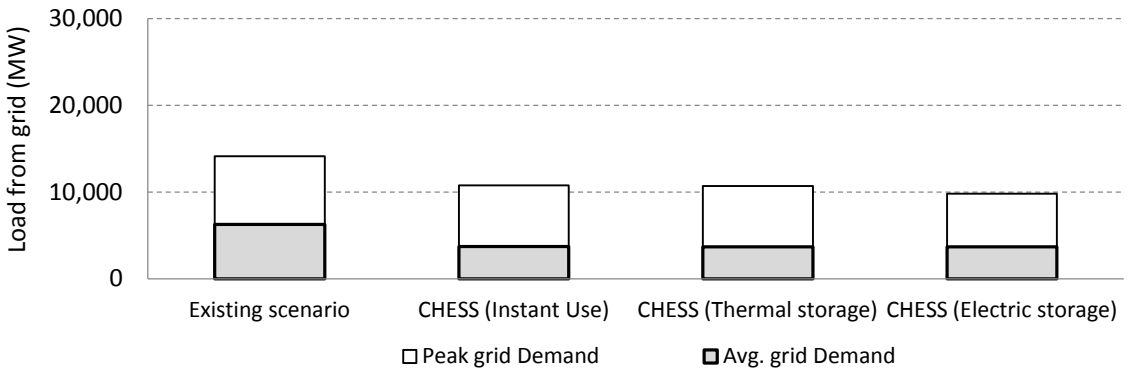

Figure 77. Peak and average electric grid demand

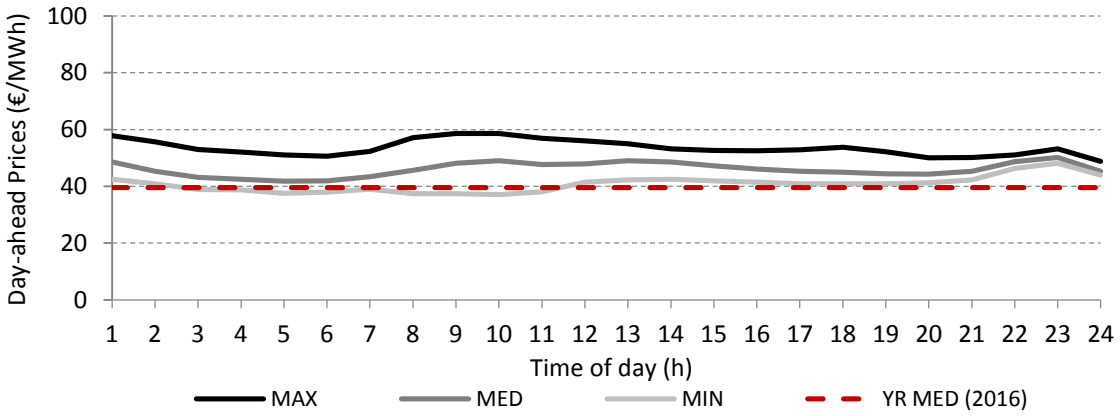

Figure 75. Hourly day-ahead electricity prices

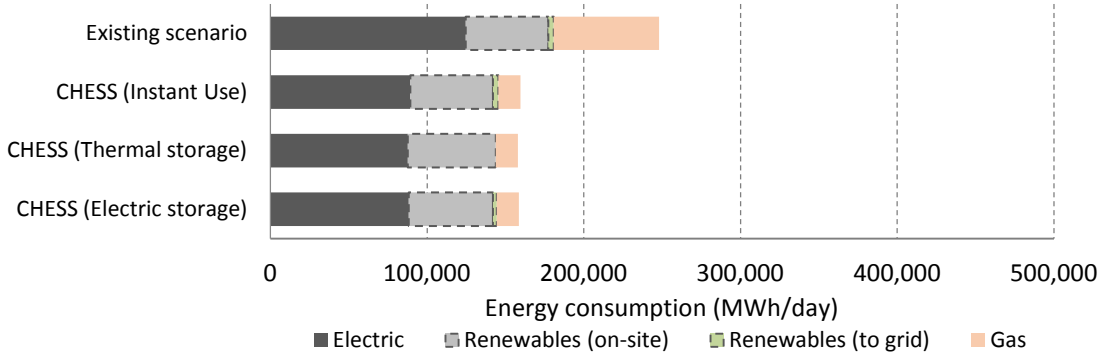

Figure 78. Dwellings totals energy uses/consumption in the existing scenario and each CHESS Setup configurations

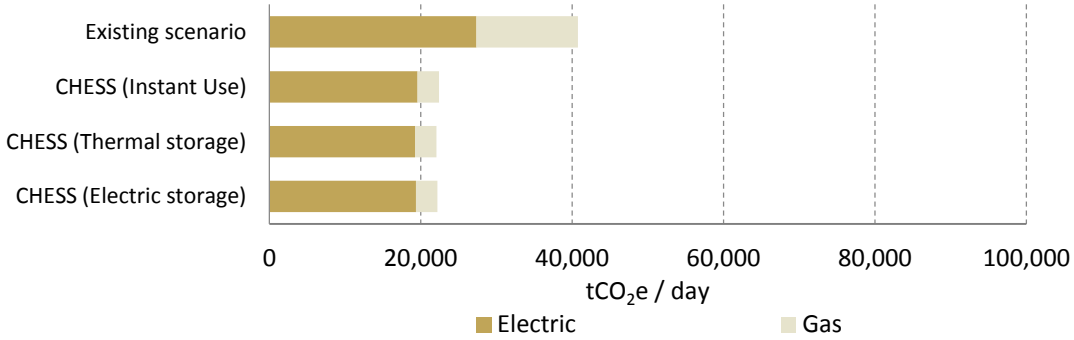

Figure 79. Dwellings totals equivalent CO2 emissions in the existing scenario and each CHESS Setup configurations

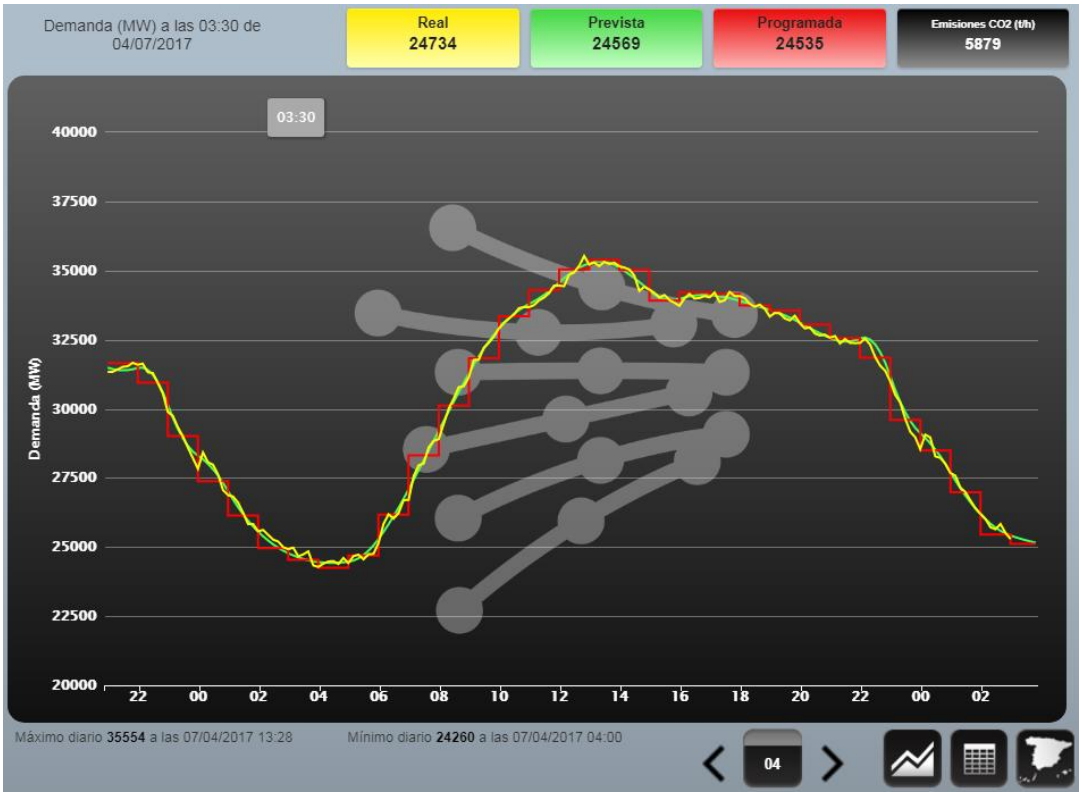

Figure 80. Hourly supply of Spain electricity. (Red Eléctrica de España S.A., 2017)

8. SPAIN (CHESS 42%/half implementation)

Location:	Madrid
Global horizontal radiation (kWh/m^2):	1,617
Number of houses	
Number of flats	
Total number of dwellings:	17,199,630

Electric consumption	**(kWh/dwelling)**
Current electric consumption	*2,648*
Current Htg consumption	4,661
Current DHW consumption	1,877
Current electric Htg+DHW cons.:	
CHESS electric Htg+DHW cons.:	
Total current electric consumption:	2,648
Total CHESS electric consumption:	*2,648*
Usable Battery Energy	2.46
Battery penetration	*2.45 %*

		Heating (HTG)		**Domestic Hot Water (DHW)**	
Type	**Eff.**	**Base Case**	**Test**	**Base Case**	**Test**
Gas boiler/other fuels	94%	49%	15%	71%	15%
Direct electric	99%	35%	1%	29%	1%
Heat pump	340%	16%	42%	0%	42%
CHESS Setup	450%	0%	42%	0%	42%

Share of renewable

Electric Grid	**PV**	**Wind power**
Spain	3.1 %	18.4 %

8.1. Typical winter day

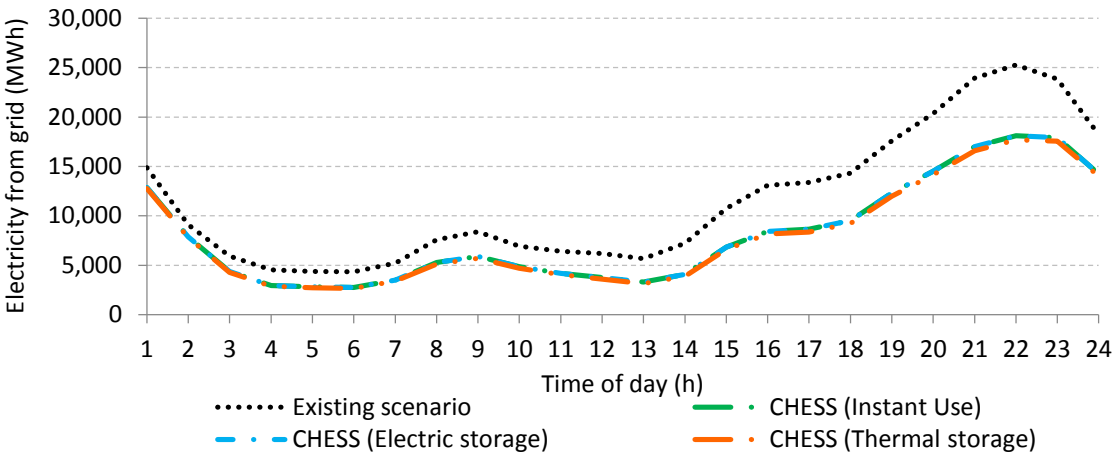

Figure 81. Dwellings existing scenario and CHESS Setup configurations hourly electric grid consumption

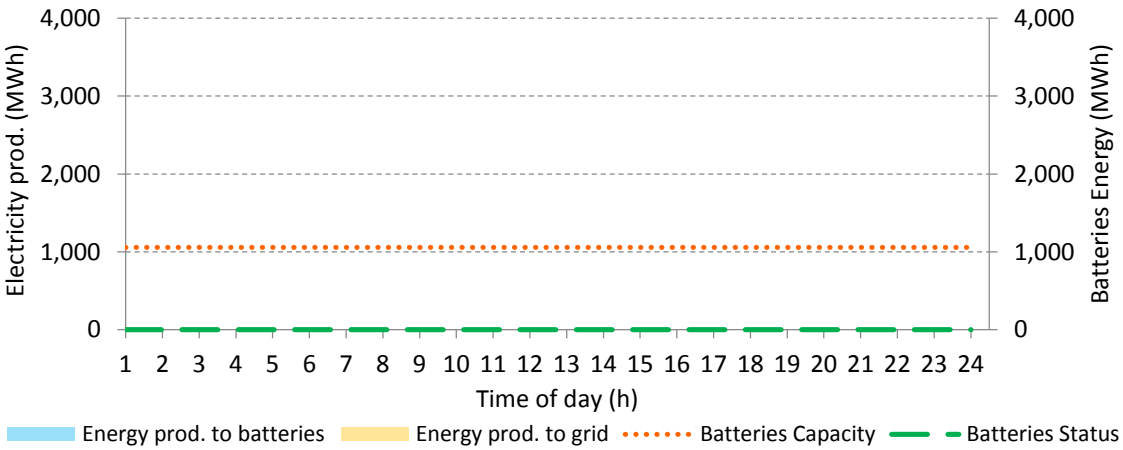

Figure 82. PVs electric production usage and batteries status.

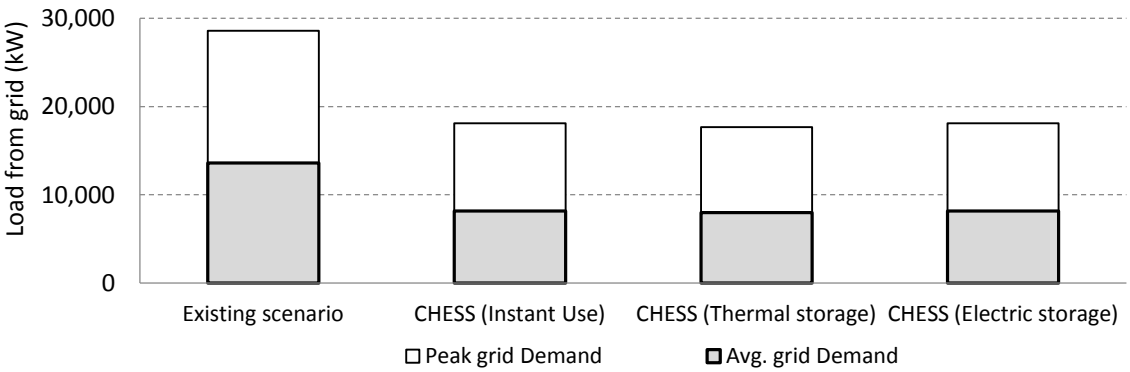

Figure 83. Peak and average electric grid demand

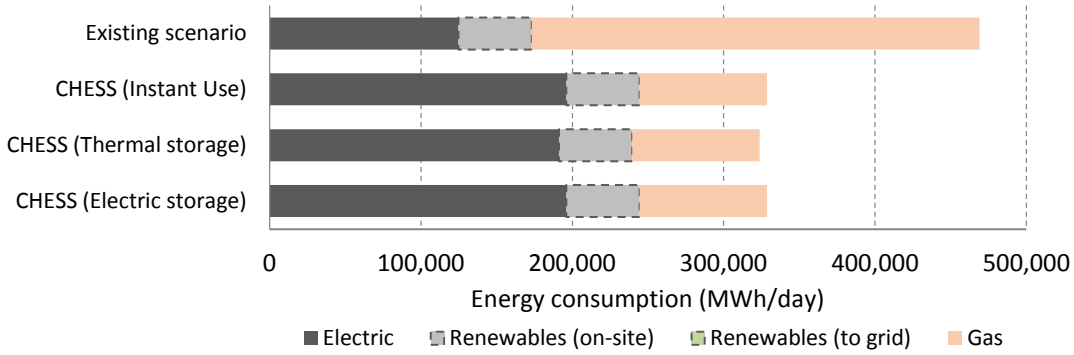

Figure 84. Dwellings totals energy uses/consumption in the existing scenario and each CHESS Setup configurations

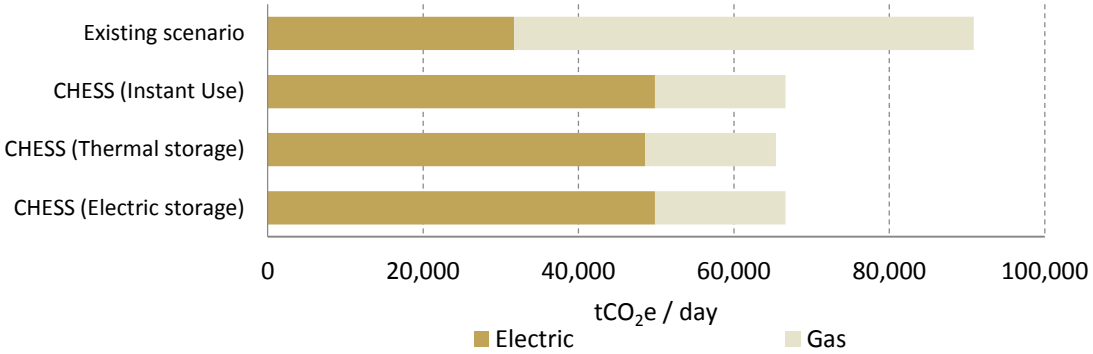

Figure 85. Dwellings totals equivalent CO2 emissions in the existing scenario and each CHESS Setup configurations

8.2. Typical summer day

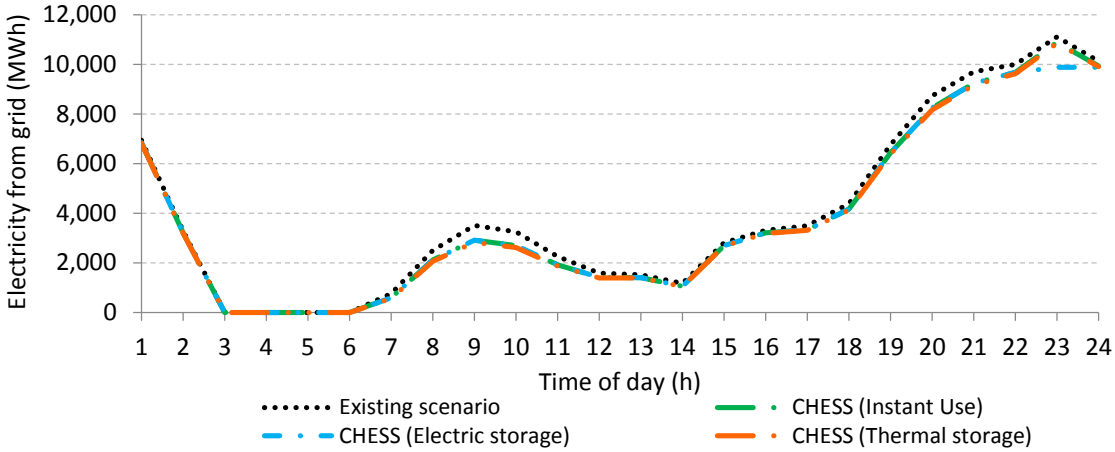

Figure 86. Dwellings existing scenario and CHESS Setup configurations hourly electric grid consumption

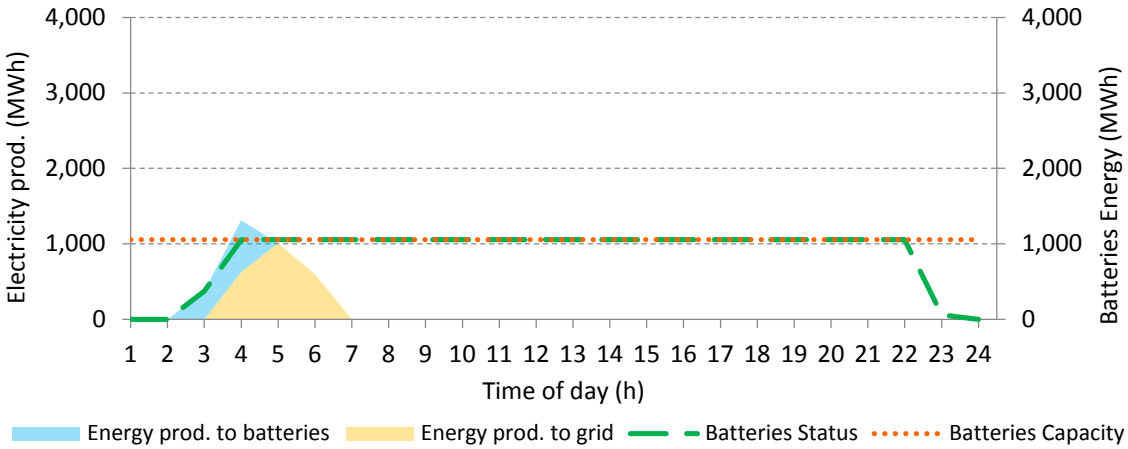

Figure 87. PVs electric production usage and batteries status.

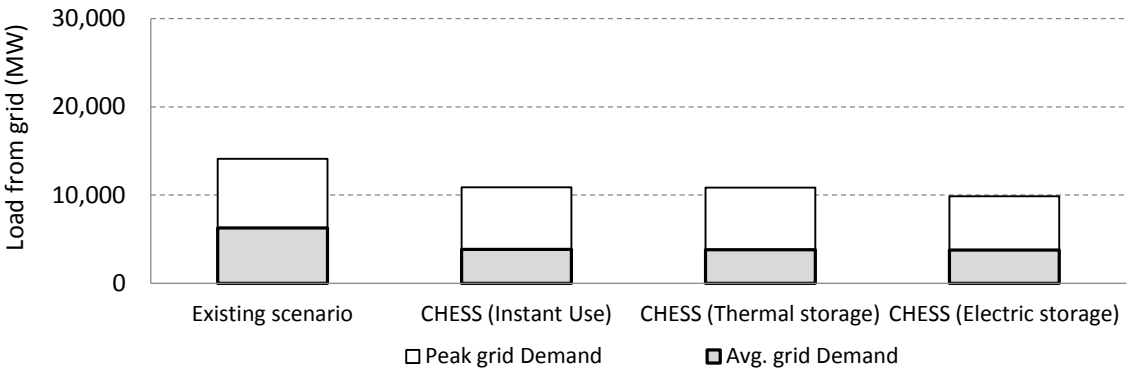

Figure 88. Peak and average electric grid demand

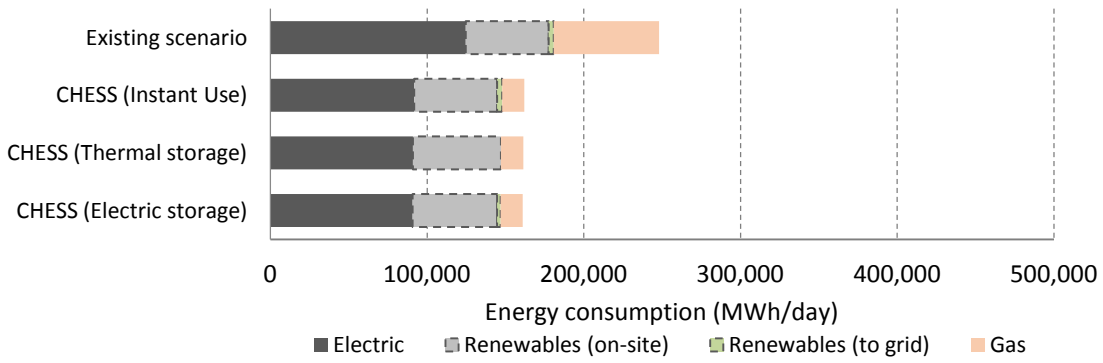

Figure 89. Dwellings totals energy uses/consumption in the existing scenario and each CHESS Setup configurations

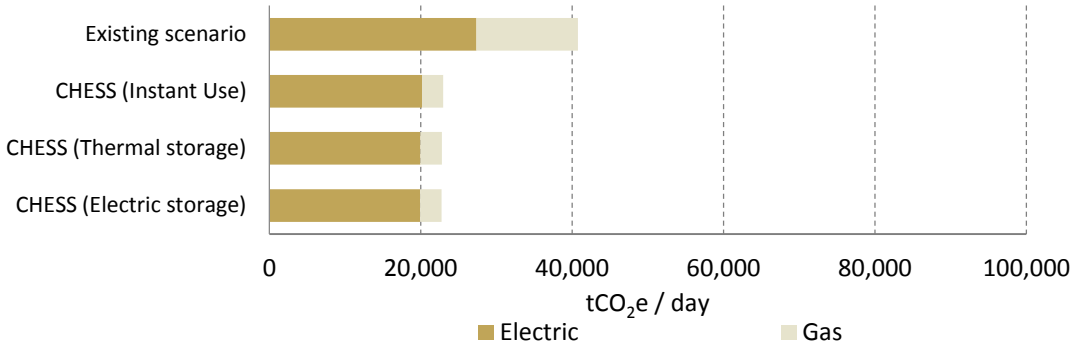

Figure 90. Dwellings totals equivalent CO2 emissions in the existing scenario and each CHESS Setup configurations

9. SPAIN 2050 Scenario (CHESS 84%/full implementation)

Location:	Madrid
Global horizontal radiation (kWh/m^2):	1,617
Number of houses	
Number of flats	
Total number of dwellings:	17,199,630

Electric consumption	**(kWh/dwelling)**
Current electric consumption	*2,648*
Current Htg consumption	4,661
Current DHW consumption	1,877
Current electric Htg+DHW cons.:	
CHESS electric Htg+DHW cons.:	
Total current electric consumption:	2,648
Total CHESS electric consumption:	*2,648*
Usable Battery Energy	2.46
Battery penetration	*5.00 %*

		Heating (HTG)		**Domestic Hot Water (DHW)**	
Type	**Eff.**	**Base Case**	**Test**	**Base Case**	**Test**
Gas boiler/other fuels	94%	49%	15%	71%	15%
Direct electric	99%	35%	1%	29%	1%
Heat pump	340%	16%	0%	0%	0%
CHESS Setup	450%	0%	84%	0%	84%

Share of renewable

Electric Grid	**PV**	**Wind power**
Spain	11.1 %	41.9 %

9.1. Typical winter day

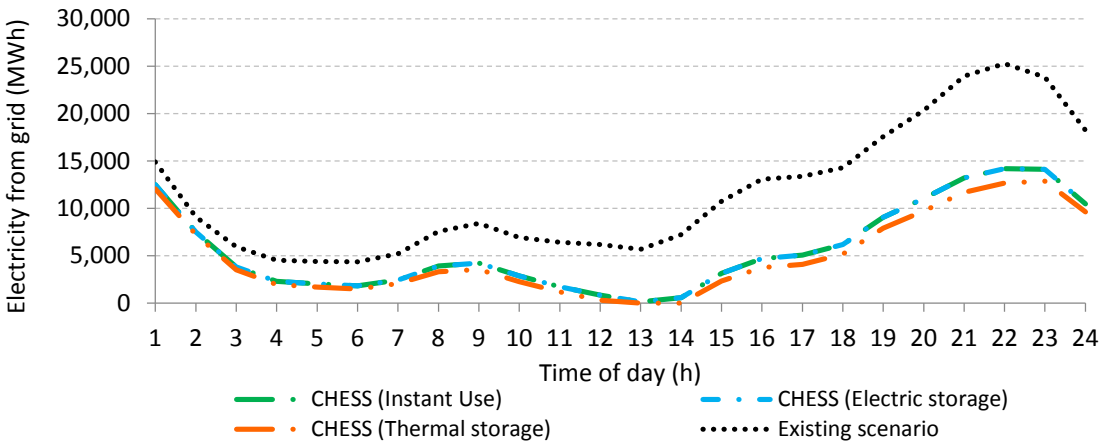

Figure 91. Dwellings existing scenario and CHESS Setup configurations hourly electric grid consumption

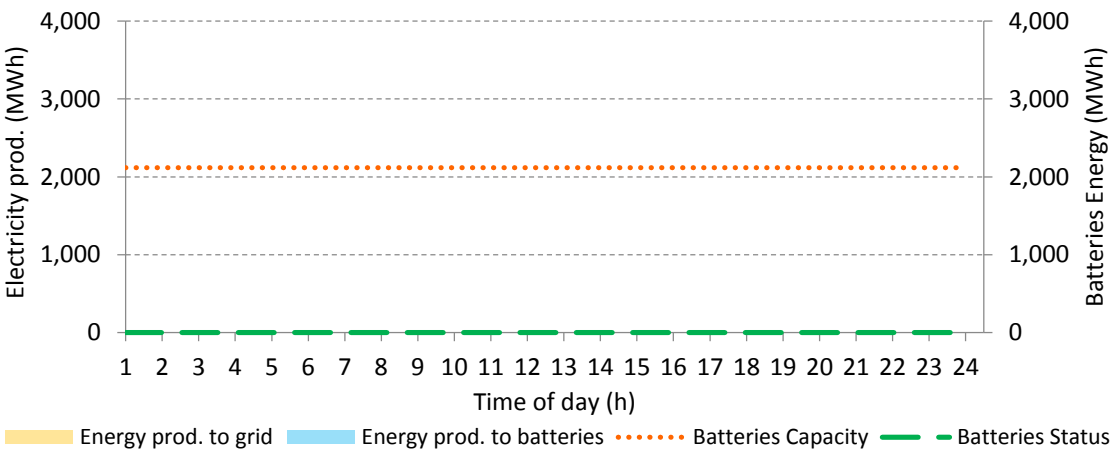

Figure 92. PVs electric production usage and batteries status.

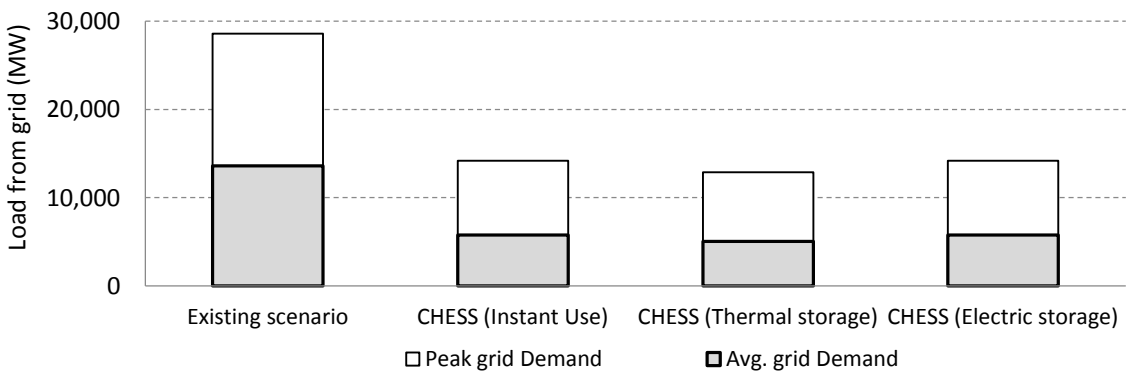

Figure 93. Peak and average electric grid demand

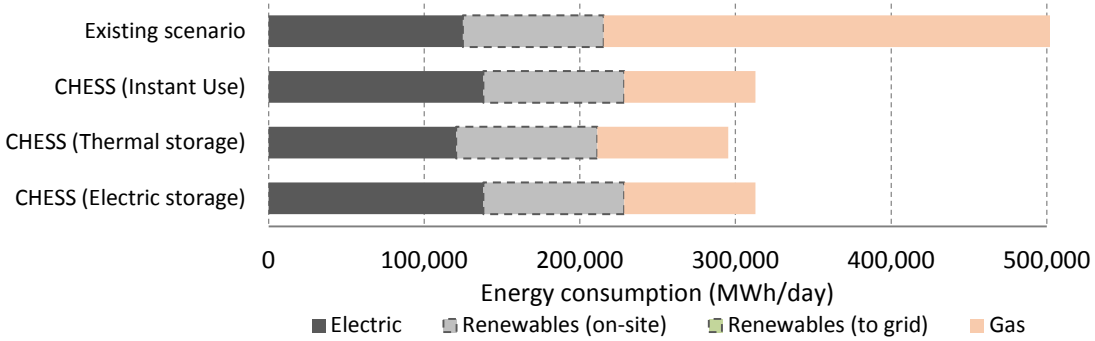

Figure 94. Dwellings totals energy uses/consumption in the existing scenario and each CHESS Setup configurations

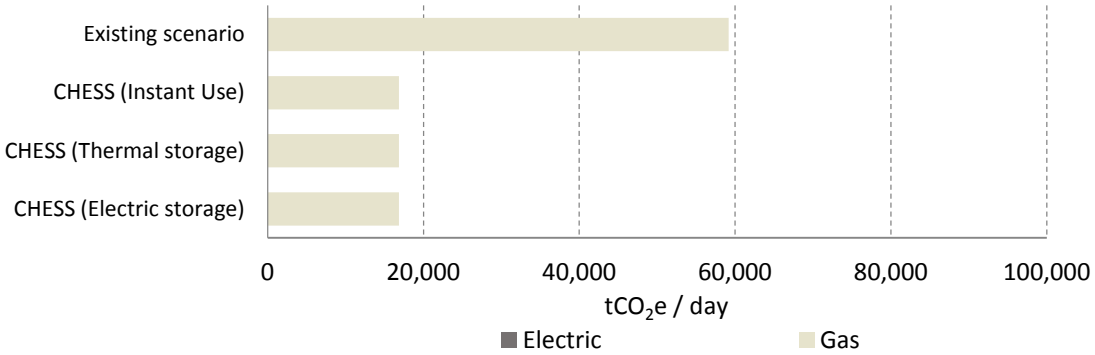

Figure 95. Dwellings totals equivalent CO2 emissions in the existing scenario and each CHESS Setup configurations

9.2. Typical summer day

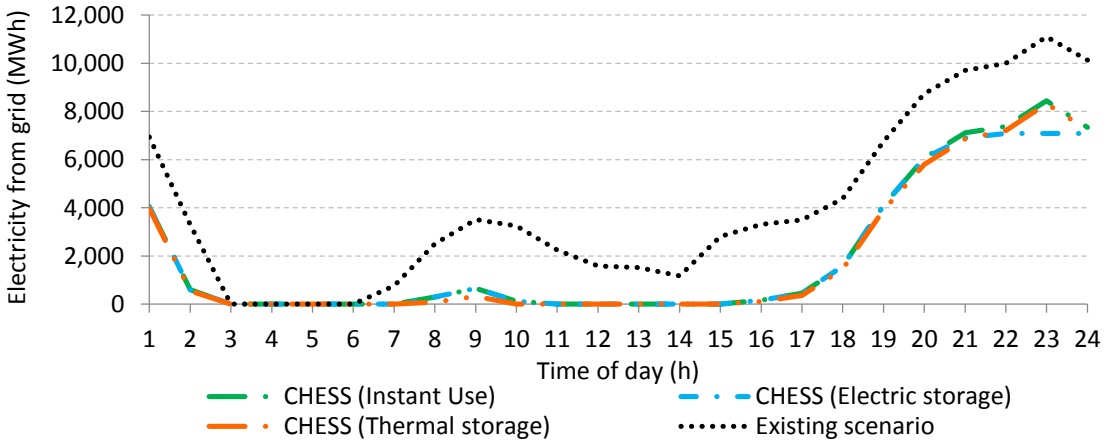

Figure 96. Dwellings existing scenario and CHESS Setup configurations hourly electric grid consumption

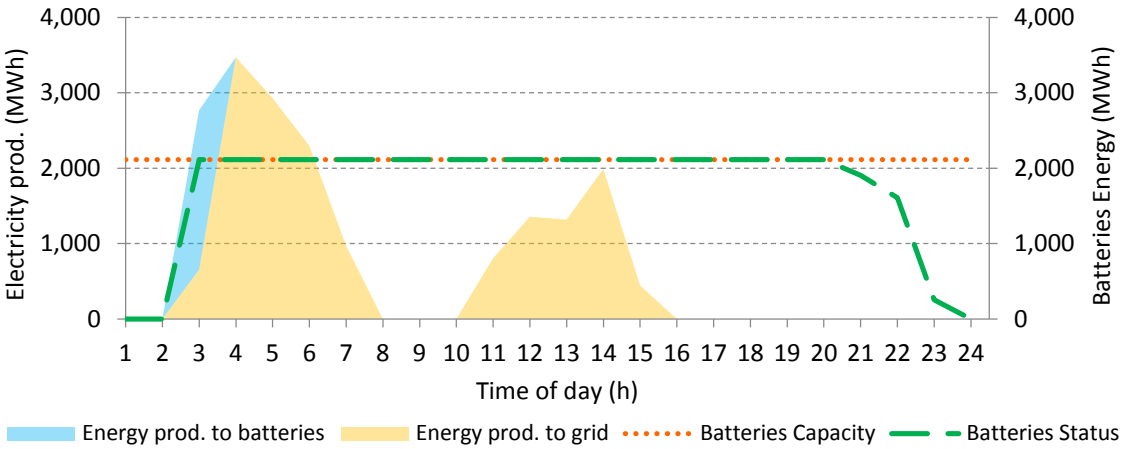

Figure 97. PVs electric production usage and batteries status.

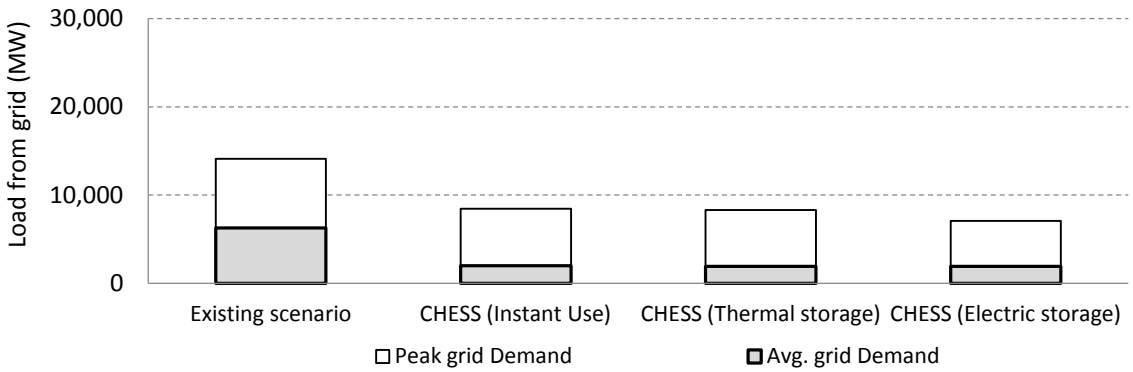

Figure 98. Peak and average electric grid demand

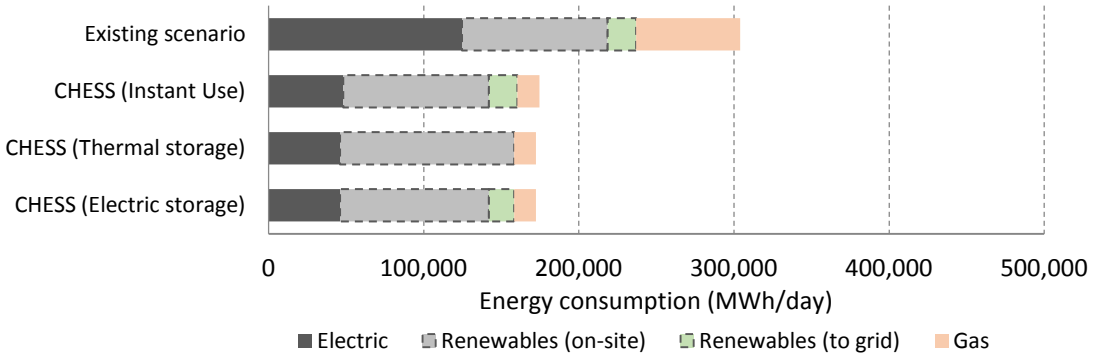

Figure 99. Dwellings totals energy uses/consumption in the existing scenario and each CHESS Setup configurations

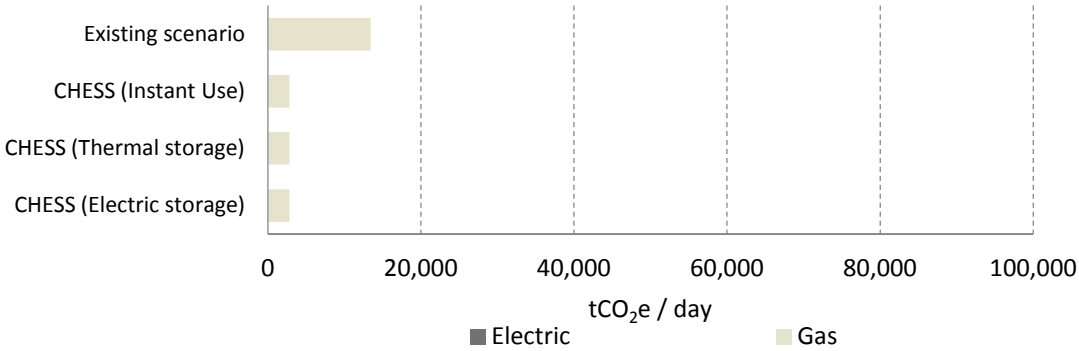

Figure 100. Dwellings totals equivalent CO2 emissions in the existing scenario and each CHESS Setup configurations

10. SPAIN 2050 Scenario (42%/half implementation)

Location:	Madrid
Global horizontal radiation (kWh/m^2):	1,617
Number of houses	
Number of flats	
Total number of dwellings:	17,199,630

Electric consumption	**(kWh/dwelling)**
Current electric consumption	*2,648*
Current Htg consumption	4,661
Current DHW consumption	1,877
Current electric Htg+DHW cons.:	
CHESS electric Htg+DHW cons.:	
Total current electric consumption:	2,648
Total CHESS electric consumption:	*2,648*
Usable Battery Energy	2.46
Battery penetration	*5.00 %*

		Heating (HTG)		**Domestic Hot Water (DHW)**	
Type	**Eff.**	**Base Case**	**Test**	**Base Case**	**Test**
Gas boiler/other fuels	94%	49%	15%	71%	15%
Direct electric	99%	35%	1%	29%	1%
Heat pump	340%	16%	42%	0%	42%
CHESS Setup	450%	0%	42%	0%	42%

Share of renewable

Electric Grid	**PV**	**Wind power**
Spain	11.1 %	41.9 %

10.1. Typical winter day

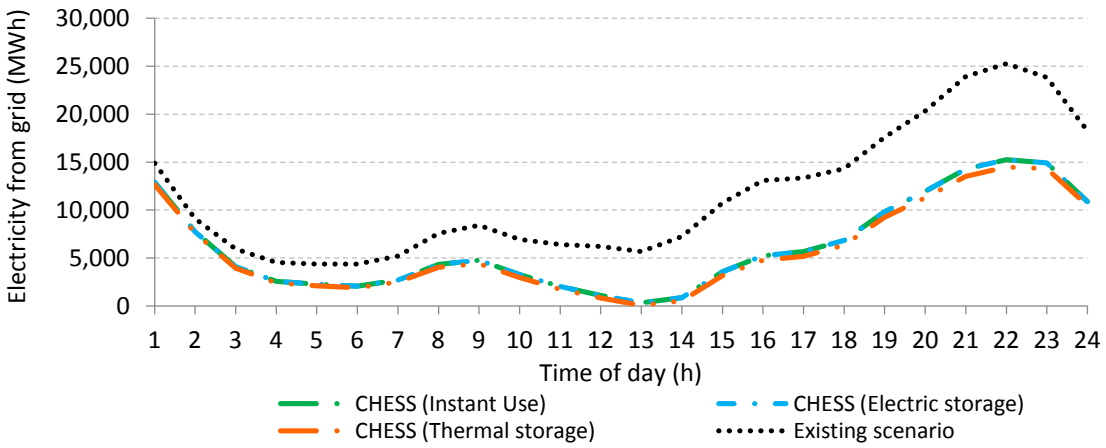

Figure 101. Dwellings existing scenario and CHESS Setup configurations hourly electric grid consumption

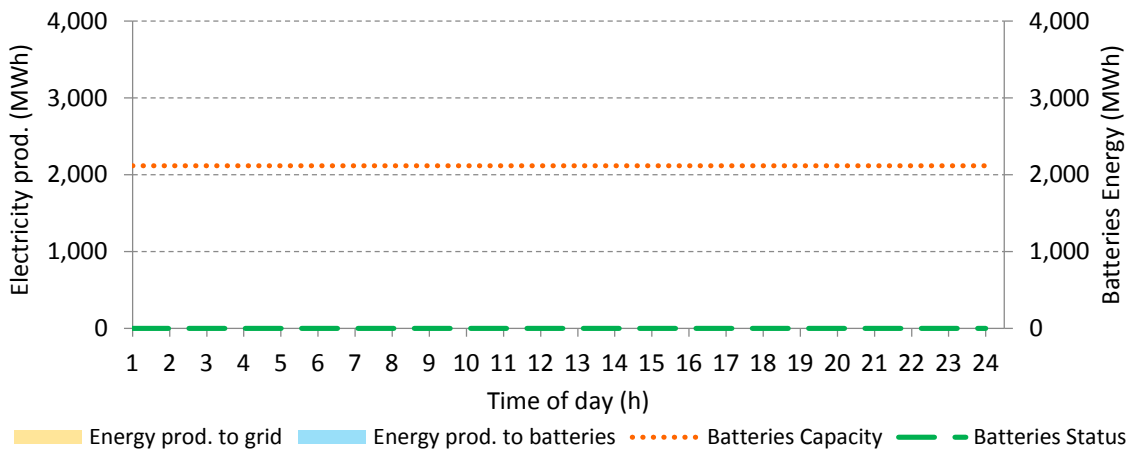

Figure 102. PVs electric production usage and batteries status.

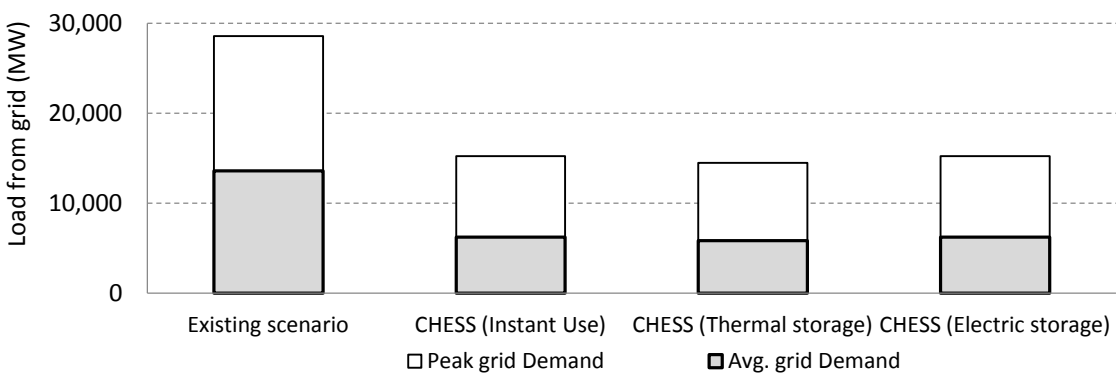

Figure 103. Peak and average electric grid demand

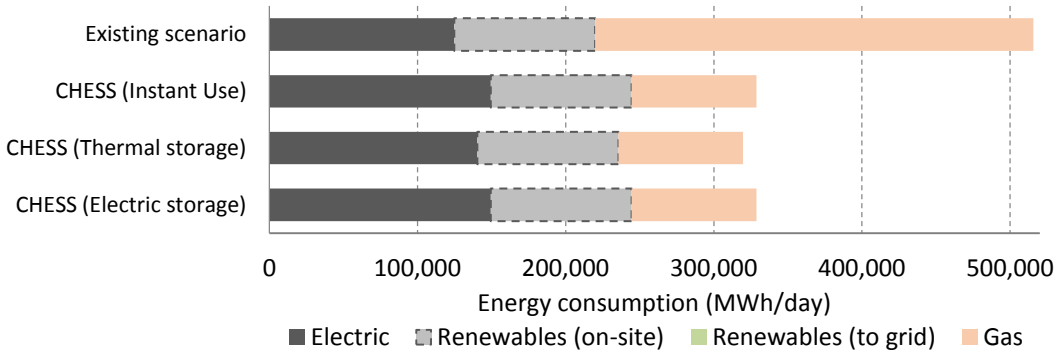

Figure 104. Dwellings totals energy uses/consumption in the existing scenario and each CHESS Setup configurations

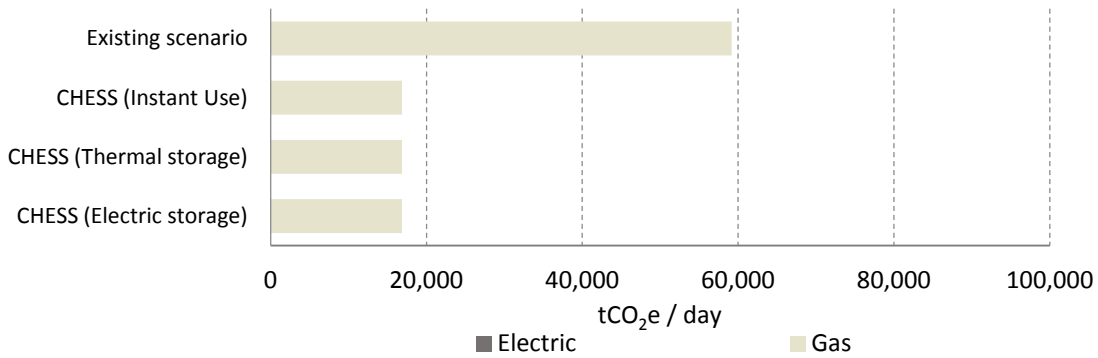

Figure 105. Dwellings totals equivalent CO2 emissions in the existing scenario and each CHESS Setup configurations

10.2. Typical summer day

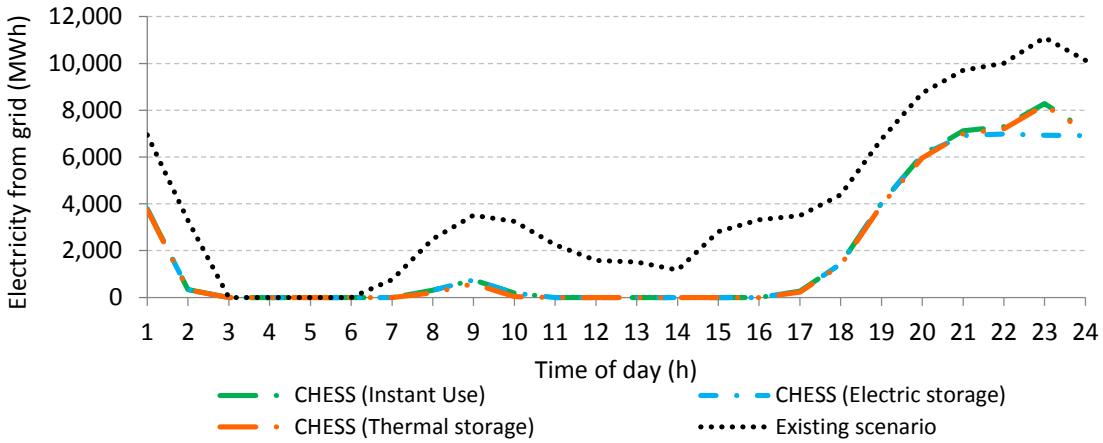

Figure 106. Dwellings existing scenario and CHESS Setup configurations hourly electric grid consumption

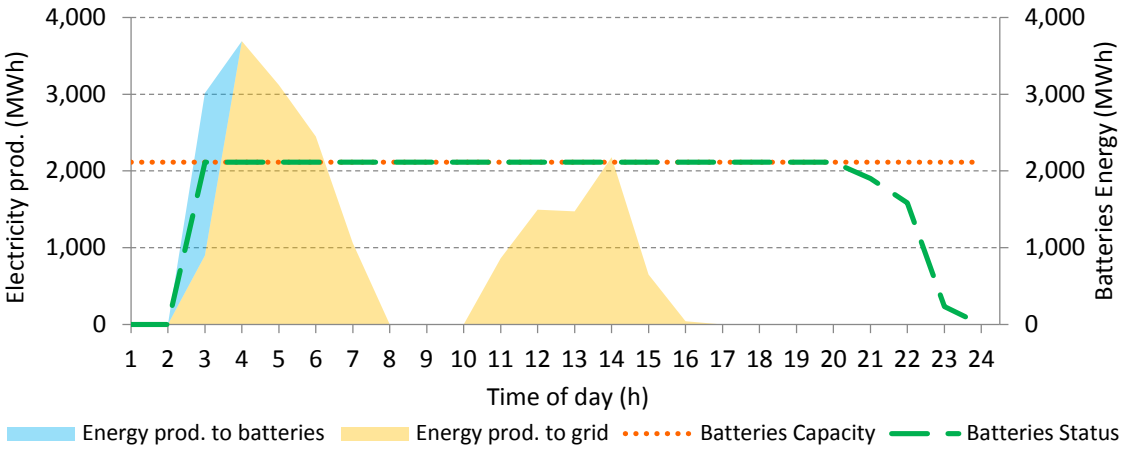

Figure 107. PVs electric production usage and batteries status.

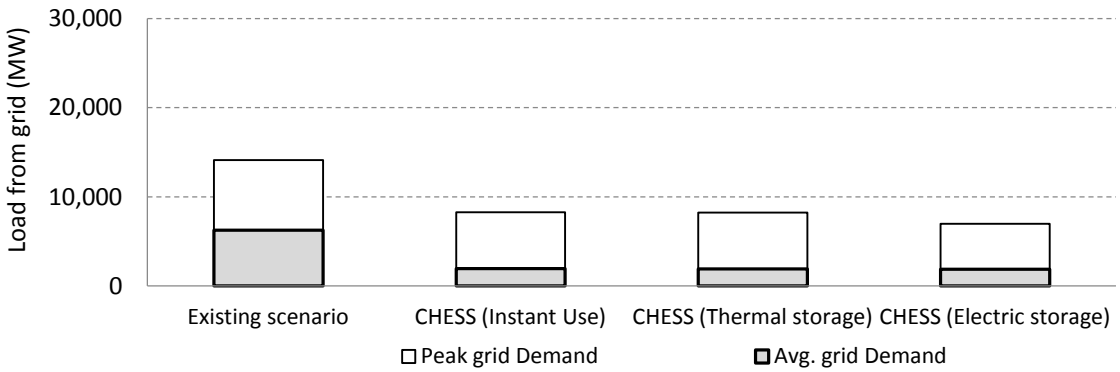

Figure 108. Peak and average electric grid demand

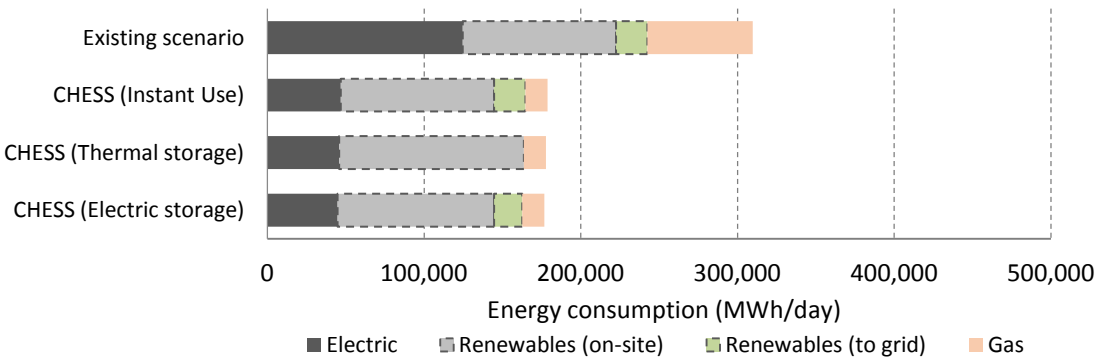

Figure 109. Dwellings totals energy uses/consumption in the existing scenario and each CHESS Setup configurations

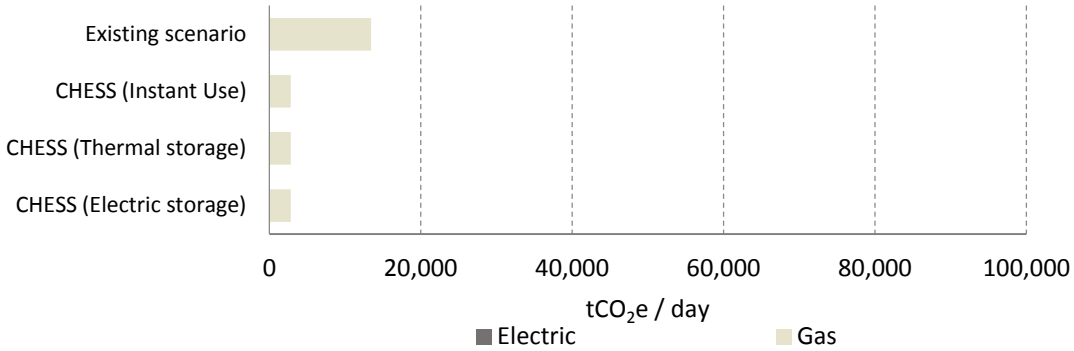

Figure 110. Dwellings totals equivalent CO2 emissions in the existing scenario and each CHESS Setup configurations