LIFE CYCLE ASSESSMENT

sunhero

As the first European venture capital fund, Planet A relies on its own scientific team to assess the environmental and climate impact of an innovation. Prior to an investment, a life cycle assessment, like this one, is conducted and integral part of the investment decision. All assessments as well as the methodology is published for maximum transparency.

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Terminology, units and abbreviations

BEV	Battery electric vehicles
CED	Cumulative Energy Demand
CED_f	Cumulative fossil energy demand
CO_2-eq.	Carbon dioxide equivalents
EC	European Commission
EU	European Union
Functional unit	Quantified performance of a product system for use as a reference unit
g	gram
GHG	Greenhouse gas
GW	Gigawatt
IEA	International Energy Agency
INECP	Integrated National Energy and Climate Plan
kg	Kilogram
kWh	Kilowatt Hour
kW_p	Kilowatt peak power
LCA	Life Cycle Assessment
LCOE	Levelized Cost of Energy
MJ	Megajoule
MWh	Megawatt Hour
PV	Photovoltaic
PED	Primary Energy Demand
SA	Sensitivity Analysis
SLB	Second Life Battery

About Sunhero

Sunhero provides easy and affordable access to high quality residential rooftop solar, with a focus on Spain. Sunhero offers high-quality photovoltaic (PV) installations, making autonomous energy accessible to millions of households. The company also plans to expand its product portfolio to include electric vehicle (EV) chargers and other electrification solutions, providing a comprehensive suite of sustainable options for households.

Summary

Solar Photovoltaic (PV) capacity in Spain is set to increase to 39 GW by 2030, indicating the need for massive development of large-scale and residential solar. Sunhero will accelerate the installation of residential solar in Spain by adding additional solar PV and battery systems in households. Spain's electricity generation mix still relies on fossil fuels, with a 31% share of the total generation coming from natural gas, contributing to high overall electricity mix emissions. Adding residential solar PV results in a displacement of other means of electricity generation and it incentivises the electrification of other energy-consuming activities, e.g. transportation, heating and/or cooking.

In this study we assessed the environmental impact that a 1 kW$_p$ solar PV and battery system will have, by displacing electricity from a simulated marginal mix. Specifically, we derived the marginal electricity mix of Spain from present until 2062 and evaluated the effects of solar residential PV. In addition, we evaluated the impact of electrifying a Spanish household.

Our analysis indicated that additional solar PV and batteries will have a positive environmental impact, resulting in:

- Maximum of **134.4 g CO_2-eq./ kW$_p$** and **1.9 MJ/ kW$_p$** avoided by an additional 1kW$_p$ PV installed in 2023.
- Maximum of **65.7 g CO_2-eq/ kW$_p$** and **0.9 MJ/ kW$_p$** avoided by an additional 0.26 kW battery capacity installed in 2023.
- Electricity generation from a PV after 2050 leads to avoided emissions reaching a plateau of **2 kg CO_2-eq/ kW$_p$ per year**,
- Total lifetime 1 kW$_p$ PV avoided emissions of **2179 kg CO_2-eq/ kW$_p$** installed in 2023 and combined PV and Battery avoided emissions of **2493 kg CO_2-eq/ kW$_p$**.
- Total lifetime avoided emissions of **1.3 million Tons CO_2-eq/ 100,000 PV systems** installed in 2023.
- Electrifying Spanish households can save **5.3 - 7.6 tons CO_2-eq/ year per household** or reduce emissions by **83.1 - 87.6%** in 2023.
- Total lifetime avoided emissions after complete electrification of **15 - 22 million tons CO_2-eq/ 100,000 households** in 2023.

Overall, Sunhero's role in the residential solar market will have an immediate as well as long-term positive impact.

About this study

This study discussed the impact of adding residential solar PV to the Spanish energy system. First, current developments in the Spanish energy sector are discussed. Subsequently, we outline the methodology used in the study. This includes a detailed explanation of how the energy system was modeled and how the impact of adding residential solar PV is assessed. Lastly, the final results are presented, depicting the environmental impact of adding an additional PV and battery system.

Table of content

1. Introduction

Global primary energy consumption has seen a rapid exponential growth in the last century, which is anticipated to continue in the coming years. Studies show that the world's population is expected to increase by nearly 2 billion persons in the next 30 years (UN 2021), indicating a huge increase in energy demand. A large part of this demand is in electricity, which is positioned in the heart of modern economies, while the electrification of sectors such as transport and heat will only grow its demand. In addition, electricity production will need to be able to supply a constant load to ensure grid stability. At the same time, however, in order to mitigate climate change, fossil fuel production will need to fade out and be replaced with energy from renewable sources. The most promising green source is solar PV, which has seen a tremendous price reduction reaching a global Levelized Cost of Energy (LCOE) of 45 $/MWh in 2022 (BloombergNEF 2022), allowing for faster and more accessible deployment in many countries. Solar's irradiation abundance in various countries indicates the vast potential of solar generation to cover electricity demand and grow its share in the total mix. Moreover, as electricity prices are spiking around the world, users are searching for ways to reduce their consumption, with residential PV installations being a popular choice. Coupled with energy storage, households can cover their daily demand, while even injecting excess electricity into the grid to help balance it.

Spain's renewable resources are large and have not yet been fully utilized, especially regarding solar and wind availability across the country. Sunhero provides easy and affordable access to high quality residential rooftop solar by delivering custom-built solar panel solutions. The aim of this study is to assess the environmental impact that Sunhero is going to have while scaling in the market for residential solar PV. This is evaluated by assessing the environmental impact that an additional solar PV system installed will have on the electricity grid. The time frame of this assessment is to assess this impact in the next ten years 2023 - 2032.

Taking a look at the residential sector in Spain, in 2021 it was responsible for 18.2% of the final energy consumption of the country (Odysee mure 2021). While a large majority of the consumption is from electricity, fossil fuels capture a large share, with natural gas and oil still being used for heating and cooking. To reduce the emissions of households, the Spanish government is offering subsidies to help electrify and increase the efficiency of appliances that can result in a lower energy consumption. Adding residential solar PV incentivizes users to electrify other energy consuming appliances and activities. For instance, self-generated electricity can be used to charge battery electric vehicles or heating and cooking can be electrified. Sunhero aims to provide full electrification services in the future, ranging from electric vehicle chargers to electric appliances. Thus, this report also assesses the environmental impact of electrifying a household in the next ten years.

2. The Spanish energy system

Spain's energy system is still heavily dependent on fossil fuels in sectors such as transportation, industry and buildings (European Commission 2022). However, in the electricity sector, the country is positively progressing towards its 2030 climate targets. This is due to the massive development of renewables centered around wind and especially solar energy, which the country has an abundance of.

2.1. Today

Taking a closer look at today' Spanish electricity market, renewable installed capacity has significantly increased in the last few years. In 2022, renewables generated as much as 42% of electricity, with wind dominating at 22%, hydropower at 7%, solar at 10% and other renewables at 3% (Djunisic 2023). However, natural gas still captured a high share of production capacity around 31%. This is due to the base load it is able to provide around the clock that renewables like solar fail to do so due to their intermittency. In Spain, pumped and run-river hydropower plants are used to provide baseload from non-fossil energy sources. Table 1 below shows Spain's electricity generation by source in 2022.

Table 1 *Spain's electricity generation by source in 2022* (Djunisic 2023).

Source	Share
Wind	22.20%
Hydro	6.50%
Solar PV	10.10%
Solar CSP	1.50%
Other renewables	1.70%
Nuclear	20.20%
Cogeneration	6.40%
Combined cycle	24.70%
Coal	2.80%
Other	3.90%

Spain has made considerable progress towards its climate change goals, such as closing down existing coal mines. In 2019, the country adopted the Strategic Framework for Energy and Climate, focusing on how to better approach the energy transition. The framework comprised three components: The Integrated National Energy and Climate Plan (INECP), the Draft Bill on Climate Change and the Just Transition Strategy (World Resources Institute 2021). The framework raises Spain's commitments on its 2030 climate targets, ensuring an equal opportunity to all people from the upcoming transition.

2.2. Future

Spain has pledged to become climate neutral by 2050 with 100% renewable energy in the electricity mix. On a shorter time scale, its 2030 objectives include 160 GW of total installed renewable capacity and a 74% share in electricity generation (IEA 2021), which is 31% higher than currently. Wind and solar power are expected to supply 51% of total generation (50 GW and 39 GW respectively) due to their very low costs (BloombergNEF 2019). This indicates that a massive development of new solar PV capacity is required to meet political targets.

Spain's few interconnectors to neighboring countries indicate the need to build a self-sufficient flexible grid to meet the needs of a low carbon system. Energy storage will thus play an important role. The intermittent energy supply by solar and wind generation needs to be complemented by energy storage. At present, pumped hydro power is already used in Spain and experts expect a further increase in the storage capacity reaching a capacity of 20 GW by 2030 (GlobalData Energy 2022). Aside from pumped hydro power, battery storage is likely to play an important role. Batteries can displace fossil backup capacity and imports by absorbing excess renewable generation, providing flexibility and low system costs. As mentioned earlier, hydro-storage is set to double by 2030; however, its reliance on rainfall underlines the need for alternative batteries. The Spanish government targets the deployment of 400 MW of behind-the-meter battery storage by 2030 (Jules Scully 2021), as well as boost thermal deployment and hydrogen plants. Such efforts will add additional dispatchable technologies to the grid that will help better manage peak hour demand and balance the grid. Moreover, vehicle-to-grid technologies such as smart chargers are set to become advanced and will add flexibility to the grid and lower system costs. While solar PV is set to increase significantly in the upcoming years, it still faces the duck curve challenge, where excess solar energy is produced during low demand hours and vice versa. Thus, apart from energy storage solutions balancing that inefficiency, demand aggregation might come into play in a future smart grid. This involves shifting demand and peak load hours to non peak load hours, by integrating user behavior and smart devices. This way, users will consciously alter their consumption patterns, while searching for cheaper electricity bills and use of greener energy sources.

3. Methods

Adding solar PV to a household will reduce the demand for electricity provided by other technologies, such as incumbent (fossil) energy sources as well as other renewables. In addition, producing electricity on residential rooftops incentivizes residents to electrify their energy consumption, e.g. by using battery electric vehicles, electrifying heating etc. This study therefore assesses two major effects of adding more residential solar PV to the Spanish energy system: the displacement of conventional energy supply and the electrification of a household's energy consumption.

3.1. System description

The aim of this LCA study is to assess the potential systemic changes in environmental impacts of installing and using such systems in Spain. The approach evaluates marginal changes within the energy system as a consequence installing these residential solar PV and battery storage systems. This approach follows a consequential LCA approach, seeking to assess changes in environmental impact as a consequence of a change in the energy system (Ekvall et al. 2016). To account for marginal changes, marginal data is used wherever possible, e.g. marginal suppliers are identified and the change in their production output is considered (in contrast to using market averages).

3.1.1. Functional unit and assessed indicators

The LCA comprises two main elements: The displacement of conventional/incumbent electricity supply and the overall impact of electrifying the energy consumption of a household. To assess the first aspect, the functional unit is **one kWh of electricity supplied by a residential solar PV and battery system.**

The second aspect, the overall impact of electrifying a Spanish household, is assessed using one Spanish household as a reference.

The system is assessed using the indicators **climate change** (Masson-Delmotte et al. 2021) and **cumulative fossil energy demand** - CED$_f$ (Verein Deutscher Ingenieure (VDI) (ed.) 2012).

3.1.2. Temporal scope

The assessment evaluates the net benefit of installing residential solar PV and battery storage systems installed within the next ten years (2023 to 2032). These systems will be in operation for their whole life time (30 years in total). Therefore, the energy mix is projected into the future to cover the full lifetime of the installed systems.

3.2. Displacement of existing energy supply: the marginal and average impacts of energy supply

A country's electricity grid consists of several types of generating sources to cover the demand at every hour during the day. The average electricity mix depicts the total share of all generating technologies. However, not all sources are flexible and can respond to a change in demand or supply. The marginal electricity mix depicts only those sources that can provide additional or less electricity when requested. This has an important impact on the carbon intensity of the grid, as fossil fuels tend to be more flexible than renewables that are intermittent. Consequently, marginal mixes tend to have higher overall emissions than average mixes.

On the one hand, the emissions of an average electricity mix are calculated by using the total impact of each generation technology per kWh and multiplying the average share of those technologies for each time interval selected (e.g. annually, daily, monthly or hourly).

On the other hand, the emissions of a marginal electricity mix significantly differ. Here the relative change in the share of each generation technology due to a change in demand is taken into account. This means that intermittent sources like solar and wind cannot respond to an increase in demand unless a lot of overcapacity is installed. An increase in demand would be covered by controllable (fossil fuel) generation technologies. A decrease in demand would be answered by reducing the supply from adjustable sources, e.g. a natural gas power plant, or by curtailing wind and utility-scale solar PV. To calculate the short-term marginal mix, the emissions from the marginal mix are calculated by multiplying the change in the generation of the controllable mix from the previous hour to the current hour (one moment to the other), with the total carbon emissions per kWh of each technology for each hour. Similarly, to obtain an average monthly profile, the hourly generation mixes are averaged over each month for every hour of the day. In addition to hourly changes in supply, also long-term changes are taken into consideration by considering long-term projections of energy supply.

The marginal mix has several advantages over the average mix, as it considers which technologies would be used to cover an additional demand at a certain time point (Weidema, Frees, and Nielsen 1999). This provides a more accurate impact estimation especially for bidirectional loads, to align the hours of operation with hours of low or high marginal impact (Peters et al. 2022; Vandepaer et al. 2019). For a future mix with higher variability and renewables, the need for marginal mix simulations becomes more relevant. A future generation mix will likely consist of higher shares of renewables and lower fossil fuels, decreasing the Greenhouse Gas (GHG) intensity of the electricity mix. However, that increase underlines the importance of considering seasonal and daily variations, for systems with varying loads like solar PV and electric vehicle charging. Day charging vehicles can lead to ⅓ to ½ lower average emissions than night charging (Arvesen et al. 2021). This is due to high PV generation during daytime and more reliance on natural gas during late evenings. This effect is stronger during summer months than during winter months, when more sunlight is available. Thus, yearly averages don't accurately pinpoint emission intensities and hourly data should be used for a more transparent depiction.

Figure 1 below shows a schematic overview of the key methodological steps taken in this study. The **Inputs** column depicts the data that was collected and added to acquire the final results shown in the **Results** column. The **Insights** column contains the figures and tables corresponding to those results for a better understanding to the reader, which can be found later on in this study. Each result was acquired using the results from the previous steps, as indicated by the direction of the arrows.

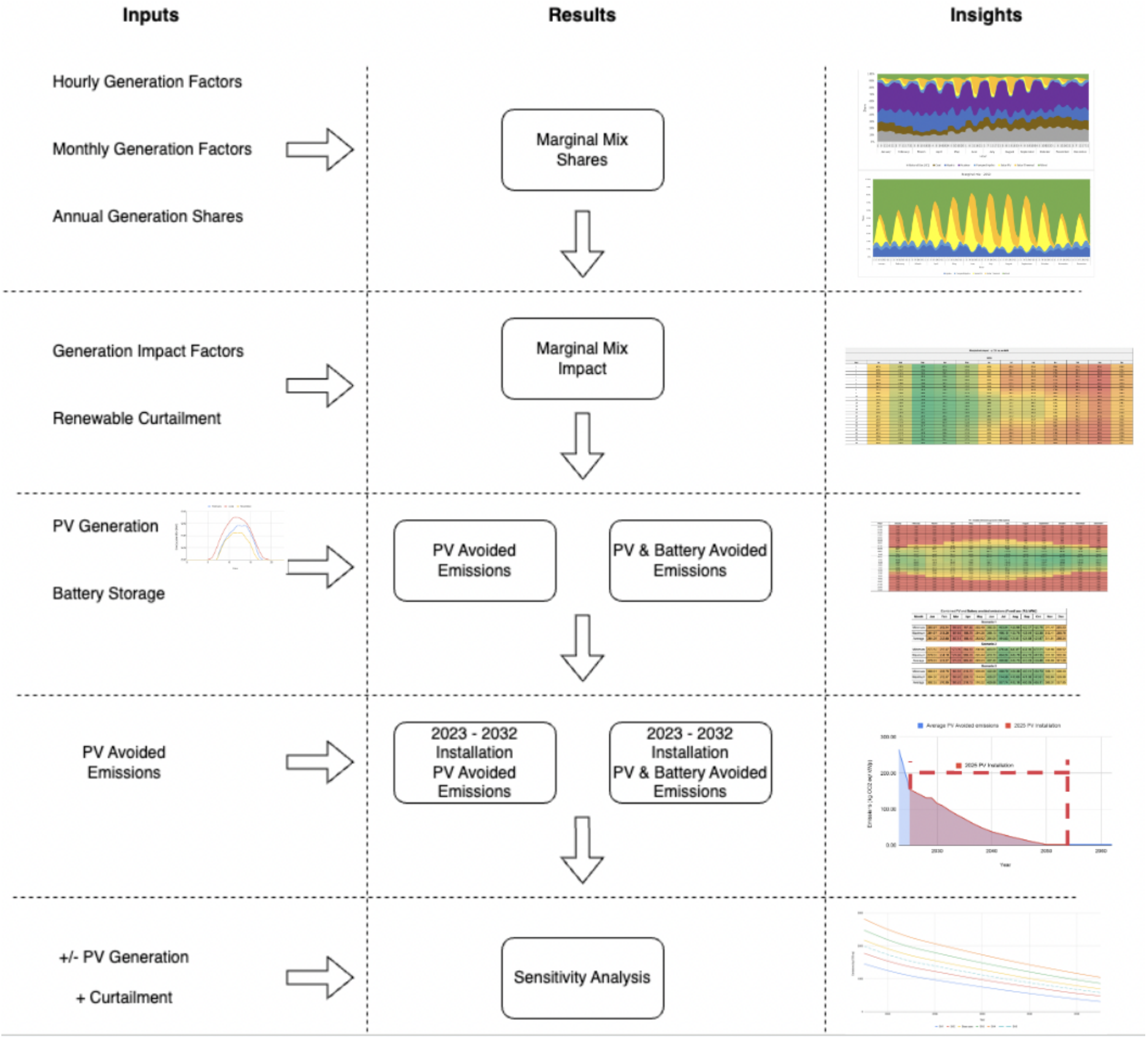


Figure 1 *Schematic depiction of methodology.*

3.2.1. Methodology to assess the marginal impact of energy supply

The first step to assess the marginal impact of energy supply is to simulate the average mix yearly until 2062. This year has been selected as this report studies the effect of installing additional PV and batteries until 2033. With a lifetime of 30 years the effects can be forecasted until 2062. To obtain an estimation of the possible daily and seasonal mix in the future, the seasonal hourly and monthly factors for each source of generation are extracted from Peters et al. 2022. Combining this with a long term annual forecast of generation technologies, we are able to forecast the cyclic behavior of the future **average** mix. This forecast is simulated under several assumptions:

- The generation system in the target scenario of the INECP was extracted from 2023 until 2030 (INECP 2020). For the remaining years until 2050, several assumptions were made for each generation source:
- Coal will be phased out in 2030.

- Spain's government targets to supply 100% of its electricity supply by renewable sources by 2050. Therefore, it was assumed that natural gas will be phased out by 2050. A linear decrease from the target scenario (INECP) in 2030 to 2050 was assumed.
- Nuclear is phased out in 2034, which is in line with Spain's political and legislative campaign against nuclear power (Reuters 2019).
- Run-of-the-river hydro and pumped-storage are assumed to reach full capacity in 2030. This is due to Spain's geographical constraints with no more available locations after 2030 for additional capacity.
- Solar PV and wind are expected to become the dominant electricity supply technologies after 2030. Spain's wind power has an ideal generation relationship ratio of 1.7:1 with solar PV (Mertens 2022). Since all other energy supplies are constrained by boundary conditions (already phased out, in the process of phasing out or limited capacity), it was assumed that wind and solar PV would complement these other constrained supplies.
- All energy supply technologies that contribute by less than 1% to the electricity supply by 2030 according to the INECP were excluded. This includes imports from France, Morocco and Portugal.
- One significant assumption taken in this study is that no efficiency improvements are considered.
    - As coal is expected to be phased-out by 2030 it will make no sense for new, more efficient coal plants to be installed.
    - Natural gas already exists on a large scale and will be phased out in 2050. Retrofitting existing plants with improvements or building new plants will have a significant cost and thus seems unlikely.
    - PV cell efficiency is likely going to increase, however, since PV's have already reached economies of scale, new designs might require different factories and supply chains that will increase overall costs. The scope of this assessment is to assess the impact of installing solar PV systems within the upcoming ten years (2023-2032). it seems unlikely that the efficiency of mass-produced solar PV cells will substantially increase during that time period. In the sensitivity analysis, we discuss the impact of a change in electricity output of a solar PV cell.

To get a more precise understanding of the actual emissions, the marginal mix was then simulated by taking into account only flexible generation sources. Several assumptions were made to decide which generation sources were to be included.

- Cogeneration that uses heat and gas is excluded, since it provides a base load where heat is used and cannot be stored for another hour.
- Energy supply from waste from renewables and non-renewable residues is a waste treatment process. The process is used to treat wastes and will take place regardless of the demand in order to treat wastes (that cannot be/are not treated by other means, e.g. recycling).
- For pumped hydro, it is assumed that 1.4 kWh are needed to store 1 kWh of energy (Jasper et al. 2022).

- Wind generation can be curtailed by shutting down the wind turbines in periods of excess supply. It is assumed that a future mix will have increased curtailment due to increased installed capacities. A study predicts a PV and wind curtailment of 40% until 2050. In this report we assume that this curtailment will stay constant at 40% until 2060, due to the increased flexibility improvements of the grid (Acciona 2019).
- Solar PV generation curtailment is also possible but only in utility-scale plants. This is because solar production has to undergo a series of voltage transformations to reduce its output, which is only a viable option for operators of large solar parks. On the other hand, residential solar PV cannot be controlled and will have a 0% curtailment. Georg Lettner et al. 2018, calculated that Spain's residential solar PV (<10 kW) is less than 2% of the total installed capacity. Thus, we assume that 98% of the solar generation can be curtailed. In the future, both residential and utility scale will increase so we assume that this ratio will approximately remain constant.

Based on these data sources and assumptions, the hourly marginal mix was constructed for each hour, month and year from 2023 to 2062. Figure 2 below shows exemplary the marginal Spanish electricity supply mix of 2023. Figure 3 shows the marginal mix in the future of 2050.

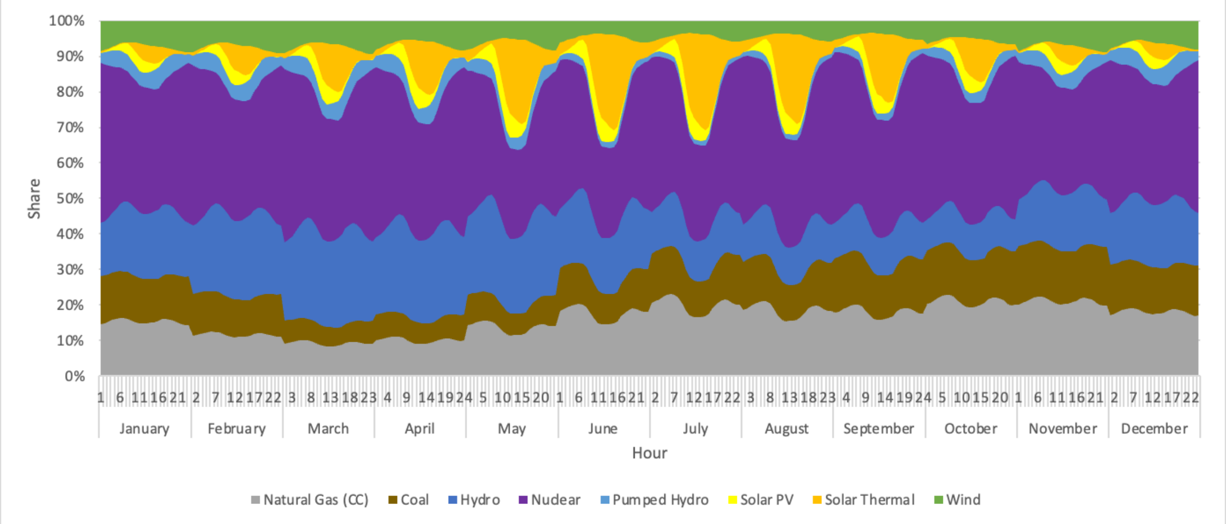


Figure 2 *Marginal electricity mix shares in 2023.*

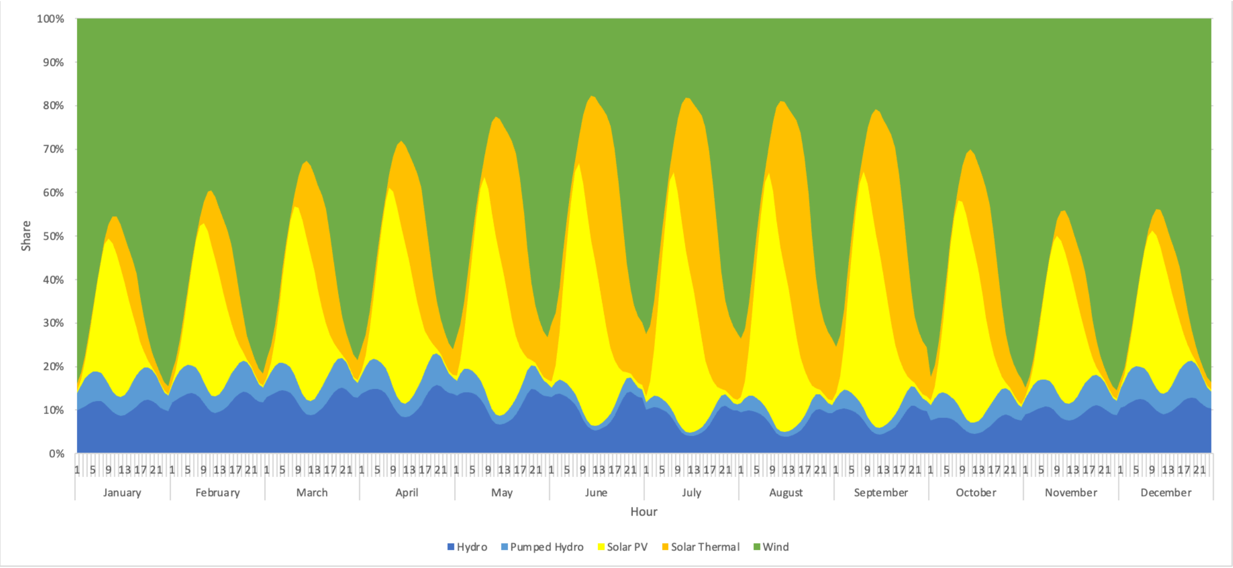


Figure 3 *Marginal electricity mix shares in 2050.*

To calculate the marginal mix impact, individual emission factors of all technologies except solar PV are used from Ecoinvent 3.8 (Wernet et al. 2016) and multiplied by the share of each generation source. The life cycle inventory data of residential solar PV was taken from (Krebs et al. 2020). The power produced per kW_p installed was adapted according to the selected location. Table 2 shows the environmental impact factors for each generation source.

Table 2 *Environmental impact factors per generation source.*

	NGCC	**Coal**	**Hydro**	**Nuclear**	**Solar PV**	**Solar thermal**	**Wind**	**Unit**
GHG emissions	0.471	1.140	0.005	0.007	0.035	0.051	0.027	kg CO_2-eq./kWh
Fossil energy demand	9.08	12.20	0.05	0.10	0.45	0.80	0.32	MJ/kWh

For pumped hydro, since it is unknown what energy is used to charge the plant at each time interval, the average annual marginal emissions per kWh are considered for each year separately. Even though a future mix will consist of a huge chunk of excess renewable energy being fed into pumped hydro, it might still be beneficial or required to feed in other energy sources due to seasonal storage.

3.2.2. Methodology to assess the impact of adding solar PV and energy storage

The photovoltaic geographical information system (PVGIS) online tool was used to simulate the generation of a hypothetical PV residential system installed in Madrid, Spain, with the following specifications.

- Installed Power: 1 kW_p (Crystalline Silicon)
- System Loss: 14%
- Optimized slope and azimuth position
- Fixed mounting

We assume an hourly generation for each hour of the year on a monthly basis with a total PV generation of **1562 kWh** per year and a system lifetime of 30 years. Figure 4 below shows the average hourly generation of the selected PV system for the months of February, June and November.

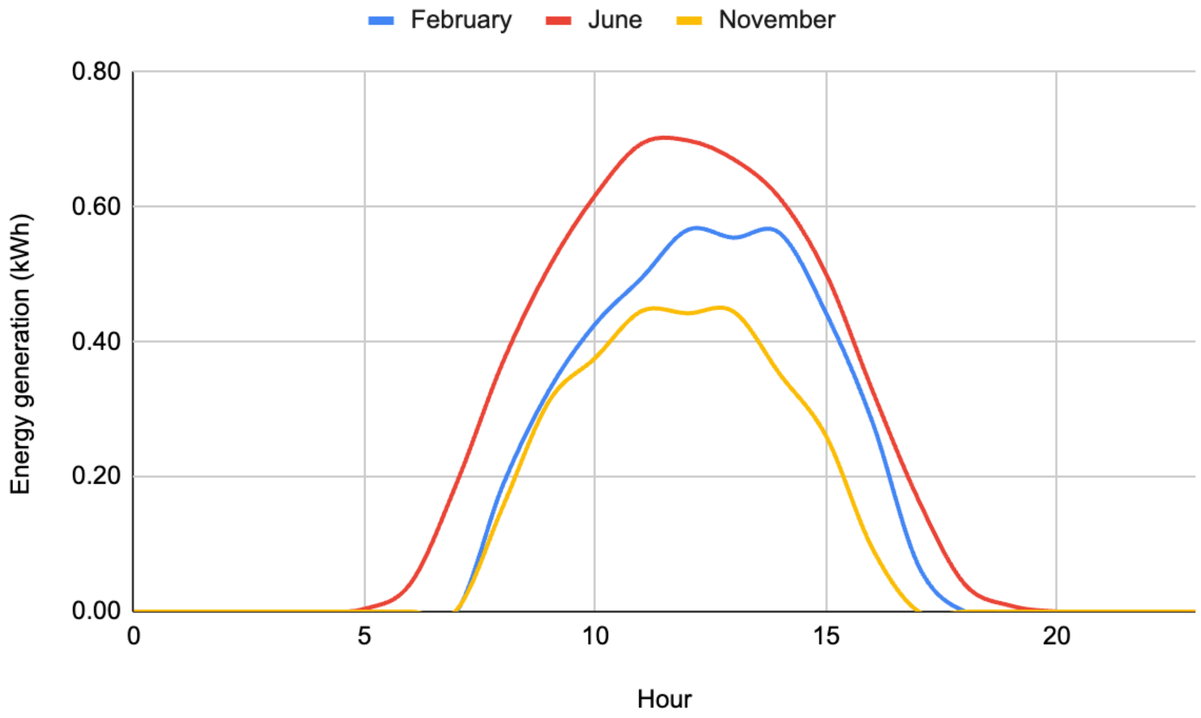


Figure 4 *Average monthly PV generation.*

The marginal impact of a solar PV system that generates electricity consumed by a household (or fed into the grid, if a surplus is available), displaces the marginal mix of electricity that would otherwise be consumed. Specifically, to calculate the impact ($PV_{Avoided\ impact}$), the PV electricity generated each hour of each month ($PV_{Generation}$) is multiplied by the impact of the avoided generation that would come from the marginal electricity mix for each corresponding hour ($Marginal\ mix_{impact}$). The impacts associated with the production of the PV system are then subtracted (PV_{impact}). Equation 1 below depicts the detailed equation used.

$$PV_{Avoided\ impact} = (Marginal\ mix_{impact} - PV_{impact}) \times PV_{Generation} \quad \text{(Eq. 1)}$$

The current growth in the battery electric vehicle (BEV) segment will lead to a supply of used batteries that can still be employed in stationary storage applications (Faessler 2021; Zhao et al. 2021). We assume that second life batteries (SLB) will be used in the future with a certain percentage of total batteries. Table 3 shows the share of SLB of batteries installed.

Table 3 *Share of SLB of batteries installed*

Year	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033 - 2062
Share SLB	0%	0%	2%	4%	6%	10%	25%	40%	60%	80%	80%

Used batteries from BEV can either be directly used as stationary batteries (if characteristics permit) or reassembled using battery modules. The use of lithium batteries in BEV will lead to a high amount of batteries that can either be used in a second life or that need to be recycled/treated. The decision to use BEV batteries as SLB therefore results in additional processes required to dismantle, characterize, sort and reassemble used batteries. Following the consequential LCA approach, these additional emissions are attributed to the SLB, whereas all other processes, i.e. the manufacture of the battery before its use in a BEV as well as its recycling are attributed to its primary purpose (the use in a BEV). The key parameters and impact of new batteries and SLB are presented in Table 4. The battery has a round-trip efficiency of 96% (Vandepaer et al. 2019; Vandepaer, Cloutier, and Amor 2017).

Table 4 *Share of SLB of batteries installed (Braco et al. 2020; Wrålsen and O'Born 2023).*

	SLB	New battery	Unit
Capacity	280	280	kWh
Cycles	2,033	4,066	kWh
Usable share of capacity	70%	70%	
Total dispatchable energy	398,468	796,936	kWh
GHG emissions	4.04	24.60	kg CO_2-eq./kWh capacity
	2.84	8.64	kg CO_2-eq./kWh dispatched
Fossil energy demand	49.04	377.65	
	0.03	0.13	

Three scenarios are used to assess the avoided impact of using energy from a battery, dependent on the excess electricity available by the PV system.

- **Scenario 1:** 20% of battery capacity charged - Excess electricity: 0.12 kWh/ kW_p system
- **Scenario 2:** 50% of battery capacity charged - Excess electricity: 0.30 kWh/ kW_p system
- **Scenario 3:** 100% of battery capacity charged - Excess electricity: 0.59 kWh/ kW_p system

It is assumed that the surplus renewable electricity from PV is used to power the battery and that after optimization, it will never exceed the total installed capacity of the battery. Moreover, the electricity discharged by the storage is supplied to the grid or is self consumed and displaces the marginal electricity mix that would be provided by alternative sources like fossil fuels. Thus, changes in demand from alternative power sources only occur when renewables are not producing. Batteries are integrated with their production causing solar power units to not be part of the displaced marginal mix, since they cannot be curtailed.

The avoided GHG emissions due to a battery is calculated in the following way. The lifecycle emissions of the battery system ($Battery_{impact}$) and of the PV system (PV_{impact}), multiplied by the lost energy due to the roundtrip efficiency ($n_{roundtrip}$), are subtracted from the marginal electricity mix ($Marginal\ mix_{impact}$) emissions that will be displaced by the battery using renewable energy. Different scenarios are considered with different shares of the total battery capacity that is charged by the solar

PV system ($Battery_{Capacity} \times Charged_{Capacity}$) that is used. Then the battery energy capacity is multiplied for each of the three scenarios, to get the total emissions avoided by the battery, as depicted in equation 2 below.

$$Battery_{Avoided\ Impact} = (Marginal\ mix_{impact} - Battery_{impact} - PV_{impact} \times (1 + (1 - n_{roundtrip})) \times Battery_{Capacity} \times Charged_{Capacity}$$

(Eq. 2)

3.3. Household electrification

In this section, the methodology used to calculate the environmental impact of electrifying a household is outlined. The Final Energy Consumption of the residential sector in Spain was identified by the share of each fuel and its percentage share on different usages such as heating, cooking and electricity ($Final\ Energy\ Consumption_{Fuel,\ Usage}$). An efficiency of the usage appliance was then assumed based on literature review ($Efficiency_{Fuel,\ Usage}$) and the Primary Energy Demand (PED) was estimated ($Primary\ Energy\ Demand_{Fuel,\ Usage}$) as shown in equation 3 below.

$$Primary\ Energy\ Demand_{Fuel,\ Usage} = \frac{Final\ Energy\ Consumption_{Fuel,\ Usage}}{Efficiency_{Fuel,\ Usage}} \quad \text{(Eq. 3)}$$

The efficiencies outlined in Table 5 below were used.

Table 5 *Efficiencies of different appliances* (Thirumalaikumaran 2022; Vakkilainen 2017).

Final Usage Source	Efficiency (%)
Wood stove	75
NG Boiler	94.50
Oil boiler	93
Electric boiler	100
Heat pump	300
Charcoal cooking	20
Induction cooking	90
Electric stove cooking	74
NG Cooking	40
LPG Cooking	63

Equation 4 was used to calculate the the emissions of each household ($Emissions_{Household}$). The PED for each fuel and usage ($Primary\ Energy\ Demand_{Fuel,\ Usage}$) was multiplied by the emission factors of each type of fuel ($Emission\ factor_{Fuel}$). For electricity consumption, the Spanish average electricity mix intensity was used.

$$Emissions_{Household} = Primary\ Energy\ Demand_{Fuel,\ Usage} \times Emission\ factor_{Fuel} \quad \text{(Eq. 4)}$$

Table 6 below shows the emission factors used for the different fuels/ electricity.

Table 6 *Efficiencies of different appliances (Stoves 2019)*.

Fuel	Emission factor (kg CO_2-eq./kWh)
Biomass	0.059
Natural Gas	0.233
Oil	0.331
LPG	0.2388
Spain’s electricity mix	0.206
Solar PV	0.035

If all appliances were electrified, then the PED changes as the efficiencies for electric appliances differ, shown in Table 5 previously. Equation 3 was used to calculate the new PED under the hypothesis that all appliances have been electrified. Equation 4 was used to calculate the new emissions assuming that all appliances are electric and electricity from a solar installation is being consumed to cover all the energy demand.

For electrifying vehicles, a lower medium sized vehicle with an internal combustion engine (ICE) using petrol (E5) was assumed to be replaced with a BEV. Given that the average household has 1.4 cars in Spain (INE 2020) and that the average distance traveled by each car in Spain is 10,591 km per year (Odysee mure 2019), the emissions reduced per household when electrifying cars is measured. The life cycle emissions of both manufacturing and fuel consumption has been taken into account (Table 7). Finally, the total avoided emissions per household were then calculated for the next 10 years assuming the same lifetime of a solar installation as indicated previously.

Two scenarios were used for the ICE vehicle emissions:

- Scenario 1 assumes that residents would have bought a new ICE vehicle. The decision to add residential solar PV offering an opportunity to electrify transportation thus results in a displacement of the ICE vehicle manufacturing and use of an ICE vehicle.
- Scenario 2 assumes that an existing ICE vehicle would still be in use if no residential solar was installed. In this case, incentivizing residents to electrify their transportation results in a net reduction stemming from conventional fuel combustion only.

In both cases, the manufacturing of a BEV as well as the emissions associated with the electricity production are considered.

Table 7 *Main parameters and values used to assess the impact of using conventional ICE vehicles and BEV* (Bieker 2021; Safarian 2023; Wernet et al. 2016).

Parameter	**Vehicle/Fuel**	**Indicator**	**Unit**	**Value**
Vehicle production	BEV	GWP	kg CO_2-eq./vehicle	13026
		CEDf	MJ/vehicle	99,105.3
	ICE	GWP	kg CO_2-eq./vehicle	11061
		CEDf	MJ/vehicle	129,231
Lifetime			km	240,000
Fuel consumption	BEV	Electricity	kWh/km	0.21
(Lower medium sized vehicle)	ICE	Petrol	L/km	0.07
Fuel production	Petrol (E5)	GWP	kg CO_2-eq./kg	0.03
		CEDf	MJ/kg	52.10
	Electricity		see other calculations in this report	
Fuel combustion	Petrol (E5)	GWP	kg CO_2-eq./kg	1.82

4. Results

Here we present a detailed discussion of the environmental impacts. Specifically, two impact factors have been evaluated, Global Warming Potential (CO_2-eq.) and fossil energy use (MJ). More detailed results for fossil energy use can be found in the Annex.

4.1. Impact of displacing conventional electricity supply

4.1.1. Impact of the marginal energy supply - Present

The current hourly marginal energy mix simulated still contains a significant amount of fossil fuels and less renewables. Table 8 below depicts the hourly marginal energy supply for each month of the year in Spain for 2023.

Table 8 *Marginal hourly energy mix in Spain 2023.*

Marginal mix impact - g CO_2-eq. per kWh												
hour	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	234.2	200.6	130.3	144.3	178.2	233.2	263.0	250.3	266.9	276.1	291.7	252.9
2	238.2	204.2	133.5	147.6	181.6	237.3	267.9	255.2	271.7	280.8	295.7	256.7
3	238.8	204.5	134.5	148.5	182.2	238.0	269.1	256.7	272.9	282.1	295.9	257.3
4	240.8	205.6	135.8	149.6	183.0	239.2	271.3	259.2	275.3	284.9	297.7	259.1
5	242.0	206.0	136.2	149.8	182.6	239.3	272.6	260.9	277.0	287.0	298.7	260.3
6	242.8	206.0	136.0	149.5	181.7	238.8	273.2	261.9	278.1	288.6	299.3	261.0
7	242.5	205.1	135.3	148.5	179.7	236.8	271.8	261.0	277.4	288.3	298.5	260.6
8	241.3	203.5	133.8	146.5	175.7	230.8	265.3	255.5	272.9	285.3	296.8	259.4
9	238.4	199.9	130.3	142.1	167.3	217.9	250.2	242.1	262.0	277.8	292.7	256.3
10	234.9	195.7	126.4	137.3	158.2	203.7	233.2	226.8	249.2	268.7	288.0	252.8
11	232.0	192.4	123.6	133.8	151.6	193.1	220.4	215.1	239.1	261.3	284.1	249.9
12	230.2	190.5	122.3	132.2	148.6	188.3	214.4	209.7	234.2	257.6	281.7	248.1
13	229.7	190.2	122.3	132.2	148.4	187.7	213.6	209.0	233.6	257.3	281.2	247.7
14	229.1	189.6	122.5	132.3	148.1	186.8	212.5	208.1	233.0	257.2	280.3	247.0
15	228.9	189.4	123.1	132.9	148.4	187.0	212.8	208.6	233.5	258.0	279.9	246.8
16	227.2	188.1	123.2	133.2	149.5	188.7	214.9	210.4	234.6	258.5	278.1	245.0
17	232.5	193.5	127.1	138.0	157.4	200.6	228.9	223.4	246.8	268.3	285.0	250.6
18	235.5	197.2	130.0	141.9	164.8	212.2	242.5	235.6	257.3	275.6	289.2	253.6
19	236.7	199.4	131.7	144.3	170.6	221.6	253.3	244.9	264.9	279.9	291.5	254.9
20	237.7	201.3	132.7	146.0	175.2	229.1	261.6	251.7	270.3	282.6	293.3	255.9
21	237.4	201.9	132.8	146.4	177.4	232.6	264.8	253.9	271.6	282.2	293.7	255.8
22	236.4	201.7	131.6	145.5	177.6	232.9	264.2	252.6	270.1	279.9	293.2	254.8
23	234.9	200.8	130.1	144.1	177.1	232.3	262.7	250.6	267.8	277.2	292.1	253.4
24	234.0	200.2	129.5	143.6	177.2	232.3	262.2	249.7	266.6	275.9	291.5	252.7

Highest environmental impacts are found in late autumn and summer due to lower wind and hydro resources available that in turn increase natural gas use. Lower emissions are found in early spring due to the availability of more renewables. A noticeable difference is also found regarding the hourly consumption, following high demand hours during early mornings and late afternoons, with summer peak demand shifting to later hours. Emissions follow hours of peak electricity prices, indicating the need for implementing a seasonal differentiation in the tariff scheme. Overall, the marginal mix shows substantial negative environmental effects due to high use of low efficiency hydropower, heavy polluting fossil fuels. As renewables increase and fossils decrease in the future, the marginal mix impacts are lowered every year.

4.1.2. Impact of additional solar PV - Present

Adding a hypothetical additional solar PV installation will have a positive effect on the total marginal mix impact. Specifically, solar generation displaces generation from short-term sources like fossil fuels, resulting in a reduction in GHG emissions. However, as solar PV is only available during sunlight hours, an hourly electricity mix is used to obtain accurate environmental benefits. The results for the avoided emissions of installing an additional PV installation of 1 kW$_p$ are presented below, for the year 2023. Table 9 shows the benefits of PV.

Table 9 *Benefits of PV in marginal mix.*

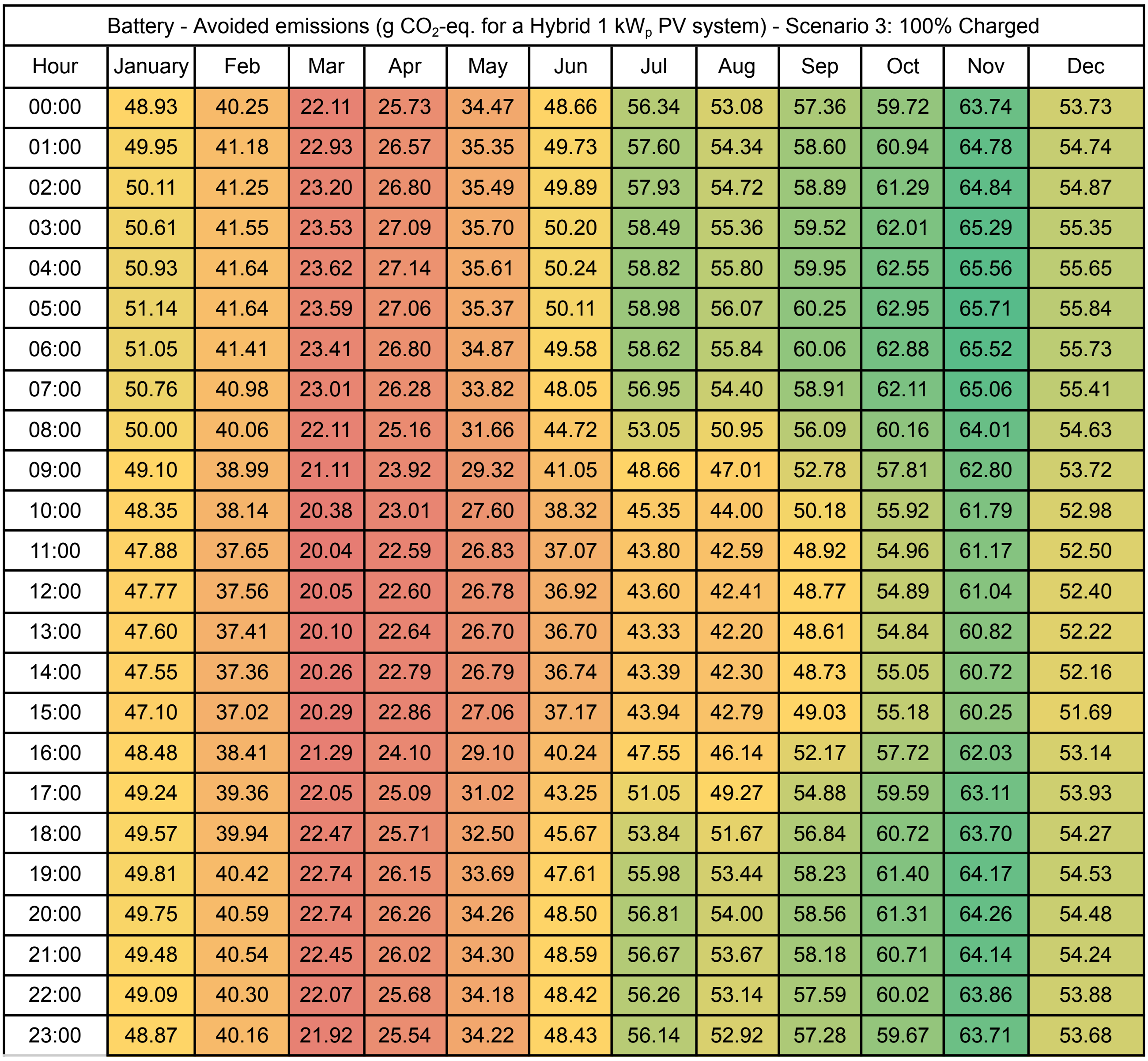
PV - Avoided emissions (g CO_2-eq. for 1kW$_p$ system)												
Hour	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
01:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
02:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
03:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
04:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
05:00	0.00	0.00	0.00	0.00	0.04	0.81	0.09	0.00	0.00	0.00	0.00	0.00
06:00	0.00	0.00	0.00	1.56	5.43	8.48	7.06	3.98	0.55	0.00	0.00	0.00
07:00	0.00	0.08	5.35	14.46	25.65	37.50	41.00	34.21	33.54	22.04	0.71	0.00
08:00	22.31	31.08	20.61	31.78	43.91	67.93	79.80	70.58	74.03	69.24	40.29	22.30
09:00	53.74	52.93	33.70	43.96	62.67	86.43	101.63	94.67	100.20	96.58	79.15	64.04
10:00	75.31	67.37	43.45	52.31	69.25	97.91	115.59	109.20	116.76	121.69	93.88	89.64
11:00	85.92	77.10	49.63	59.82	74.32	106.67	122.25	115.50	126.56	133.22	110.13	105.51
12:00	94.96	88.12	46.08	64.71	75.84	107.01	122.37	119.22	134.38	129.86	109.08	106.53
13:00	89.27	85.96	45.19	52.35	70.36	102.14	115.33	112.61	119.77	127.25	109.30	99.24
14:00	76.67	86.89	44.07	47.21	64.30	93.44	105.20	103.50	115.63	105.42	86.32	80.80
15:00	64.48	67.92	36.15	35.50	49.93	77.19	88.11	83.55	88.90	76.88	63.41	47.60
16:00	36.72	44.79	25.83	27.73	36.16	54.52	64.55	64.84	58.37	44.93	23.53	19.86
17:00	0.03	11.08	10.95	12.77	18.26	29.42	37.09	30.46	21.76	4.28	0.00	0.00
18:00	0.00	0.00	0.13	2.05	4.15	7.61	8.64	4.88	0.78	0.00	0.00	0.00
19:00	0.00	0.00	0.00	0.00	0.11	1.68	1.71	0.03	0.00	0.00	0.00	0.00
20:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

It is evident that there is a significant emission reduction during those hours when PV generates the most energy. However, PV is incapable of lowering emissions during early morning and late afternoon peak hours, when sunlight is minimal. The largest emission reduction is **134.38 g CO_{2}-eq. per kWp**, achieved at 12:00 in September, with an average reduction during sunlight hours of **58.99 g CO_{2}- eq. per kWp.**

4.1.3. Impact of additional solar PV and energy storage - Present

Adding an additional storage technology further improves the environmental impact of Spain's marginal mix. Storage will be able to absorb excess energy produced by solar PV's and later displace the marginal mix energy. Table 10 below depicts the hourly theoretical avoided GHG emissions each month, assuming that the battery discharged its full capacity each hour of the day.

Table 10 *Battery avoided GHG emissions (2023).*



Battery - Avoided emissions (g CO_2-eq. for a Hybrid 1 kW_p PV system) - Scenario 3: 100% Charged												
Hour	January	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
00:00	48.93	40.25	22.11	25.73	34.47	48.66	56.34	53.08	57.36	59.72	63.74	53.73
01:00	49.95	41.18	22.93	26.57	35.35	49.73	57.60	54.34	58.60	60.94	64.78	54.74
02:00	50.11	41.25	23.20	26.80	35.49	49.89	57.93	54.72	58.89	61.29	64.84	54.87
03:00	50.61	41.55	23.53	27.09	35.70	50.20	58.49	55.36	59.52	62.01	65.29	55.35
04:00	50.93	41.64	23.62	27.14	35.61	50.24	58.82	55.80	59.95	62.55	65.56	55.65
05:00	51.14	41.64	23.59	27.06	35.37	50.11	58.98	56.07	60.25	62.95	65.71	55.84
06:00	51.05	41.41	23.41	26.80	34.87	49.58	58.62	55.84	60.06	62.88	65.52	55.73
07:00	50.76	40.98	23.01	26.28	33.82	48.05	56.95	54.40	58.91	62.11	65.06	55.41
08:00	50.00	40.06	22.11	25.16	31.66	44.72	53.05	50.95	56.09	60.16	64.01	54.63
09:00	49.10	38.99	21.11	23.92	29.32	41.05	48.66	47.01	52.78	57.81	62.80	53.72
10:00	48.35	38.14	20.38	23.01	27.60	38.32	45.35	44.00	50.18	55.92	61.79	52.98
11:00	47.88	37.65	20.04	22.59	26.83	37.07	43.80	42.59	48.92	54.96	61.17	52.50
12:00	47.77	37.56	20.05	22.60	26.78	36.92	43.60	42.41	48.77	54.89	61.04	52.40
13:00	47.60	37.41	20.10	22.64	26.70	36.70	43.33	42.20	48.61	54.84	60.82	52.22
14:00	47.55	37.36	20.26	22.79	26.79	36.74	43.39	42.30	48.73	55.05	60.72	52.16
15:00	47.10	37.02	20.29	22.86	27.06	37.17	43.94	42.79	49.03	55.18	60.25	51.69
16:00	48.48	38.41	21.29	24.10	29.10	40.24	47.55	46.14	52.17	57.72	62.03	53.14
17:00	49.24	39.36	22.05	25.09	31.02	43.25	51.05	49.27	54.88	59.59	63.11	53.93
18:00	49.57	39.94	22.47	25.71	32.50	45.67	53.84	51.67	56.84	60.72	63.70	54.27
19:00	49.81	40.42	22.74	26.15	33.69	47.61	55.98	53.44	58.23	61.40	64.17	54.53
20:00	49.75	40.59	22.74	26.26	34.26	48.50	56.81	54.00	58.56	61.31	64.26	54.48
21:00	49.48	40.54	22.45	26.02	34.30	48.59	56.67	53.67	58.18	60.71	64.14	54.24
22:00	49.09	40.30	22.07	25.68	34.18	48.42	56.26	53.14	57.59	60.02	63.86	53.88
23:00	48.87	40.16	21.92	25.54	34.22	48.43	56.14	52.92	57.28	59.67	63.71	53.68

It is clear that the avoided emissions are driven mainly by the marginal mix emissions displaced. Even though batteries are usually discharged during night hours, in some cases it is more beneficial to discharge them during the day, especially during winter. It is clear that as summer months approach, it is more beneficial to discharge batteries during later hours, as there is enough solar PV production. The maximum and minimum emissions vary by month, with the highest reduction of **65.71 g CO_2-eq/kWp.**, achieved in November and the minimum of **20.04 g CO_2-eq/Kwp.** in March. Economic factors should also be considered when optimizing charging and discharging of a battery. Table 11 below shows the combined average PV and minimum, maximum and average battery avoided emissions in every month of the year.

__Table 11__ Combined solar PV and Battery avoided GHG emissions (2023).

Combined PV and Battery avoided emissions (GWP - kg CO_2-eq. / kWp)												
Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Scenario 1												
Minimum	18.87	17.69	11.32	13.52	18.78	26.58	31.59	29.63	30.03	29.21	21.84	20.02
Maximum	18.90	17.72	11.34	13.55	18.83	26.66	31.69	29.71	30.10	29.26	21.87	20.05
Average	18.89	17.71	11.33	13.54	18.81	26.63	31.65	29.68	30.07	29.24	21.85	20.04
Scenario 2												
Minimum	19.31	18.01	11.51	13.73	19.03	26.91	31.99	30.02	30.47	29.72	22.38	20.50
Maximum	19.37	18.07	11.56	13.79	19.17	27.12	32.24	30.23	30.64	29.85	22.46	20.57
Average	19.35	18.05	11.54	13.76	19.11	27.03	32.14	30.14	30.57	29.79	22.43	20.54
Scenario 3												
Minimum	20.04	18.54	11.82	14.06	19.44	27.46	32.67	30.67	31.20	30.57	23.28	21.30
Maximum	20.17	18.67	11.93	14.20	19.72	27.87	33.15	31.10	31.54	30.82	23.45	21.43
Average	20.11	18.61	11.88	14.14	19.60	27.71	32.95	30.92	31.40	30.71	23.38	21.38

The combined avoided emissions from PV and Battery use, are highest during summer where PV generation is the highest. Table 12 below depicts the avoided fossil energy.

__Table 12__ Combined PV and Battery avoided fossil use (2023).

Combined PV and Battery avoided impact (Fossil use MJ/ kWp)												
Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Scenario 1												
Minimum	258.77	238.84	164.61	195.40	279.30	388.36	457.99	425.11	418.13	414.49	304.89	279.21
Maximum	259.07	239.16	164.93	195.79	280.08	389.49	459.35	426.30	419.07	415.21	305.30	279.53
Average	258.89	239.00	164.78	195.61	279.75	389.02	458.77	425.78	418.66	414.87	305.08	279.34
Scenario 2												
Minimum	264.80	243.13	167.30	198.32	283.00	393.19	463.84	430.74	424.20	421.68	312.51	285.96
Maximum	265.56	243.92	168.08	199.27	284.95	396.02	467.24	433.71	426.56	423.49	313.54	286.76
Average	265.11	243.52	167.71	198.84	284.11	394.84	465.79	432.42	425.52	422.64	312.99	286.29
Scenario 3												
Minimum	274.87	250.27	171.77	203.17	289.15	401.24	473.58	440.12	434.32	433.68	325.22	297.21
Maximum	276.37	251.85	173.34	205.08	293.06	406.90	480.38	446.07	439.05	437.29	327.28	298.80
Average	275.48	251.06	172.59	204.22	291.39	404.55	477.48	443.48	436.97	435.59	326.18	297.88

4.1.4. Impact of solar PV installations and storage in a future mix

As coal and natural gas are phased out of the marginal mix, avoided emissions are lowered until 2050. After 2050, emissions reach a plateau as we assume that the share for each generation source will remain constant due to the fact that the 100% target for renewable energy has been achieved. Figure 5 below depicts how adding solar PV in the future has a gradually reduced impact on the grid.

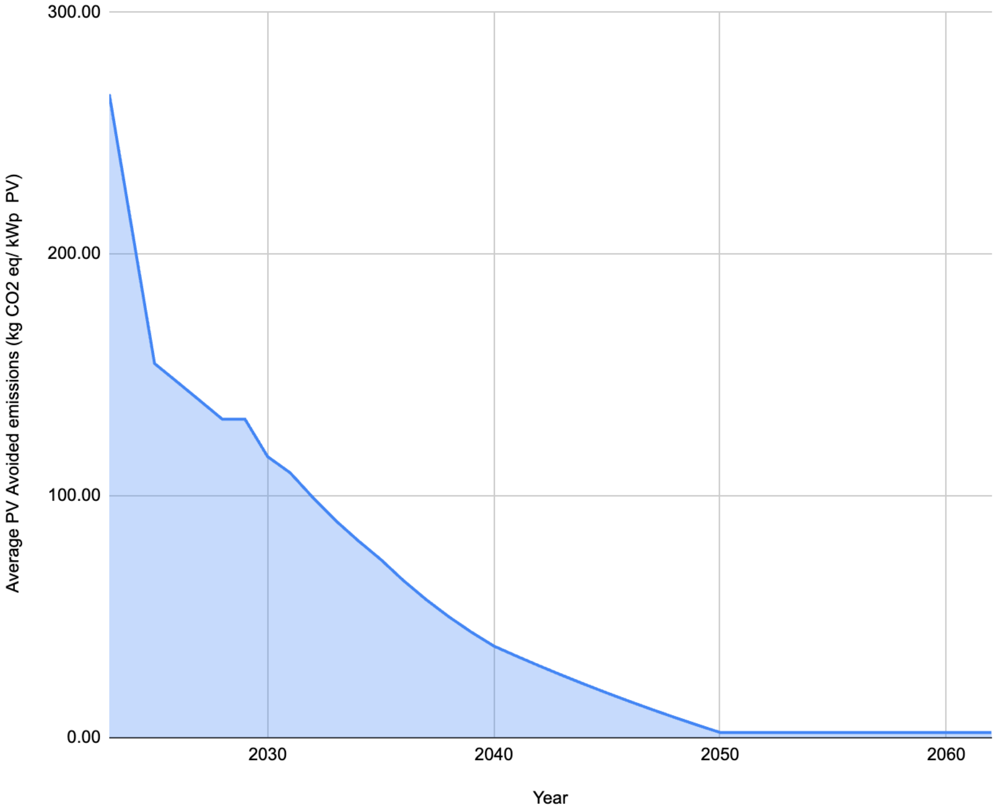


Figure 5 *PV average total avoided emissions yearly in kg* CO_2*-eq. per* kW_p*.*

Detailed yearly avoided emissions can be found in Annex A. After the year 2048, displacing marginal mix energy from the grid with a battery starts having a negative environmental impact. This is because the GHG emissions from the battery per kWh are higher than the marginal mix.

Finally, we calculate the total avoided GHG emissions that a PV system will be able to save during its lifetime. We assume that an additional 1 kW_p PV system will be added each year from the present until 2032. Assuming a PV lifetime of 30 years, the avoided PV emissions from the 1 kW_p system each year are added up. Tables 13 and 14 below show the total avoided emissions for the installation of a hypothetical 1 kW_p system installed from 2023 - 2032. The avoided emissions are lower each year as the marginal mix becomes “cleaner” in a hypothetical future.

Table 13 *Total avoided emissions PV and PV plus battery systems installed between 2023 and 2032 in kg CO_2-eq. per kW_p.*

Year	PV	PV & Battery - Scenario 3
2023	2178.38	2455.78
2024	1914.30	2173.35
2025	1705.94	1945.46
2026	1553.27	1772.27
2027	1408.21	1604.38
2028	1270.85	1444.98
2029	1141.25	1294.13
2030	1011.65	1143.29
2031	897.52	1009.36
2032	790.09	883.14

Table 14 *Total avoided emissions PV and PV plus battery systems installed between 2023 and 2032 in MJ per kW_p.*

Year	PV	PV & Battery - Scenario 3
2023	40.06	15661
2024	36.35	10848
2025	33.28	7730
2026	30.85	5687
2027	28.44	3833
2028	26.04	1969
2029	23.67	75
2030	21.33	-1983
2031	19.02	-4200
2032	16.85	-6502

Figure 6 below shows the total avoided GHG emissions of a 1 kW_p system installed in 2025 and lasting until the year of 2054. The area highlighted in red under the graph equals the PV avoided emissions in Table 10 above, of 1705.94 kg CO2 eq/ $kW_{p.}$

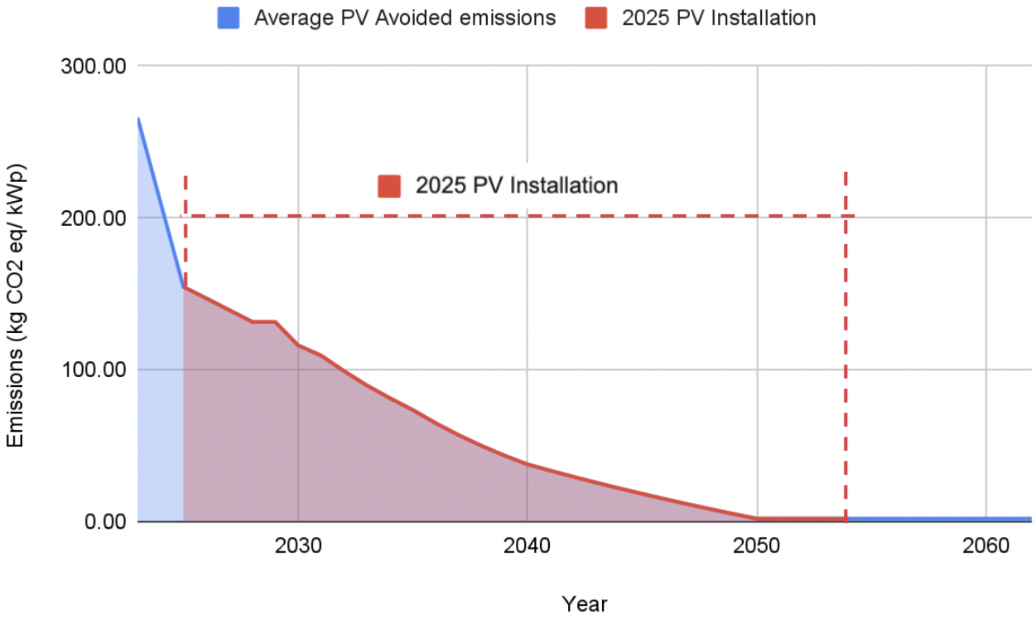


Figure 6 *PV average total avoided emissions yearly in kg* CO_2*-eq. per* kW_p*.*

The rooftop PV market in Spain is developing at a fast pace. With a market growth of 102% YoY, total capacity has reached 1.44 GW in 2021, while 32% of total additional PV capacity was residential. To put our results into more context, we can assume that an average residential PV system size is 6 kW in 2023-2025, growing at 7 kW in 2026 and remaining at 8kW after 2027. Thus, Tables 15 and 16 below estimate the total impact of adding 100,000 systems yearly (Solar Power Europe 2022):

Table 15 *PV average total avoided emissions yearly in kg* CO_2*-eq. per 100,000 solar systems.*

Year	PV system size (kW_p)	Total avoided emissions (10^6 t CO_2-eq./ 100,000 PV Systems)
2023	6	1.31
2024	6	1.15
2025	6	1.02
2026	7	1.09
2027	8	1.13
2028	8	1.02
2029	8	0.91
2030	8	0.81
2031	8	0.72
2032	8	0.63
2033	8	0.55

Table 16 *PV average total avoided emissions yearly in MJ per 100,000 solar systems.*

Year	PV system size (kW$_p$)	Total avoided emissions (10^{10} MJ/ 100,000 PV Systems)
2023	6	2.40
2024	6	2.18
2025	6	2.00
2026	7	2.16
2027	8	2.27
2028	8	2.08
2029	8	1.89
2030	8	1.71
2031	8	1.52
2032	8	1.35
2033	8	1.19

4.2. Household Electrification

At present, natural gas is the most used energy source after electricity in Spanish households (Figure 7). It is predominantly used to heat water, for heating and cooking purposes.

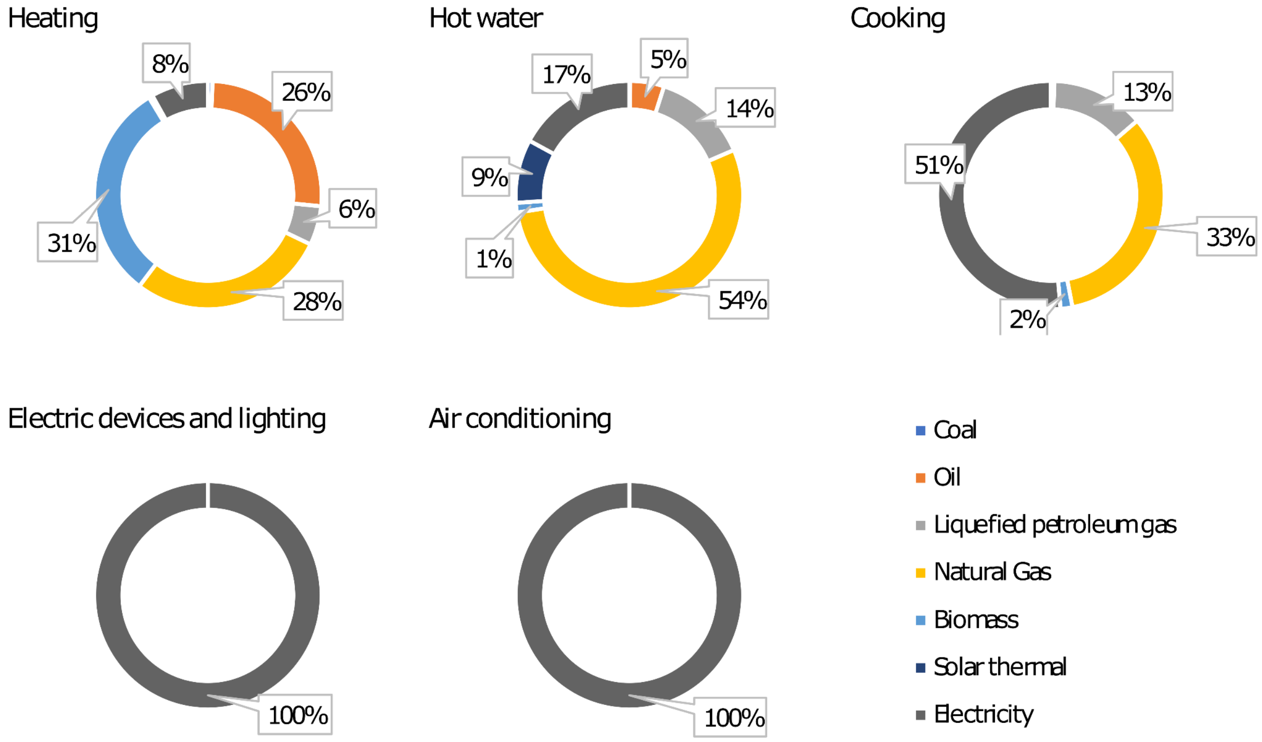


Figure 7 *Final energy consumption of households in Spain 2020 (excluding driving) (IDAE 2022).*

All applications shown in Figure 7 could be electrified. In addition, ICE cars can be replaced by BEV. The total emissions of a household amount to 6.4 t CO_2-eq per year per household. After electrifying all appliances in a household including heating & cooling and cooking, 1.3 t CO_2-eq. per year can be saved per household.

Under the assumption that residents would have bought a new ICE vehicle if they had not made the decision to electrify their transportation (Scenario 1), after electrifying vehicles, 4.0 t CO_2-eq. per year can be saved per household, with a total combined saving of 5.3 t CO_2-eq per year per household. This is an emission reduction of 83.12% after electrifying everything in a household. The PV system needed to cover this demand would be 7.74 kW.

Under the assumption that users would have kept on using their existing ICE vehicle (Scenario 2), when taking into account vehicle electrification as well, an extra 6.3 t CO_2-eq. per year can be saved per household, with a total combined saving of 7.6 t CO_2-eq per year per household. This is an emission reduction of 87.6% after electrifying everything in a household. Table A8 in the Annex provides detailed calculations for the emission reduction after electrification.

However, it should be noted that this demand is a yearly average and hourly demand may be higher than and would require more PV capacity or a battery to rely on 100% self consumption. Projecting into a future electricity mix, Table 17 below shows the emissions saved after electrifying a house, over the lifetime of a solar PV in the next 10 years of installations.

Table 17 *Total avoided emissions per household electrification.*

Year	Scenario 1 - Avoided emissions t CO_2-eq)	Scenario 2 - Avoided emissions (t CO_2-eq)
2023	218.35	149.86
2024	218.01	149.51
2025	217.77	149.28
2026	217.64	149.14
2027	217.52	149.02
2028	217.42	148.92
2029	217.33	148.83
2030	217.26	148.76
2031	217.20	148.70
2032	217.17	148.67
2033	217.15	148.65

Table 18 below expresses the avoided emissions per 100,000 systems installed or 100,000 households electrified.

Table 18 *Total avoided emissions per 100,000 household electrifications.*

Year	Scenario 1 - Avoided emissions (10^6 t CO_2-eq)	Scenario 2 - Avoided emissions (10^6 t CO_2-eq)
2023	21.84	14.99
2024	21.80	14.95
2025	21.78	14.93
2026	21.76	14.91
2027	21.75	14.90
2028	21.74	14.89
2029	21.73	14.88
2030	21.73	14.88
2031	21.72	14.87
2032	21.72	14.87
2033	21.71	14.87

4.3. Sensitivity analysis

The results derived from this study are based on certain assumptions, as mentioned previously. For this reason, a sensitivity analysis was conducted to evaluate the significance of those assumptions on final results. Detailed results for the sensitivity analysis can be found in the Annex (Tables A.1 to A.7).

- **Base case:** All assumptions considered previously.
- **SA1:** Energy generation from the 1 kW_p PV system considered is 20% lower than the base case generation. Spain's solar insolation varies by location with Madrid representing the average of the total. Thus, we simulate a more realistic representation of how much energy a PV system would generate if placed in the North of the country with less sunlight.
- **SA2:** Energy generation from the 1 kW_p PV system considered is 10% lower than the base case generation.
- **SA3:** Energy generation from the 1 kW_p PV system considered is 10% higher than the base case generation. The South of Spain has more insolation than central Spain.
- **SA4:** Energy generation from the 1 kW_p PV system considered is 20% higher than the base case generation.
- **SA5:** Curtailment reaches 50% instead of 40% in 2050. The future grid might not be as optimized as assumed in the base case and there will be an excess of renewables that will have to be curtailed.

Figure 8 below depicts the sensitivity analysis results against the base case scenario, for total avoided emissions.

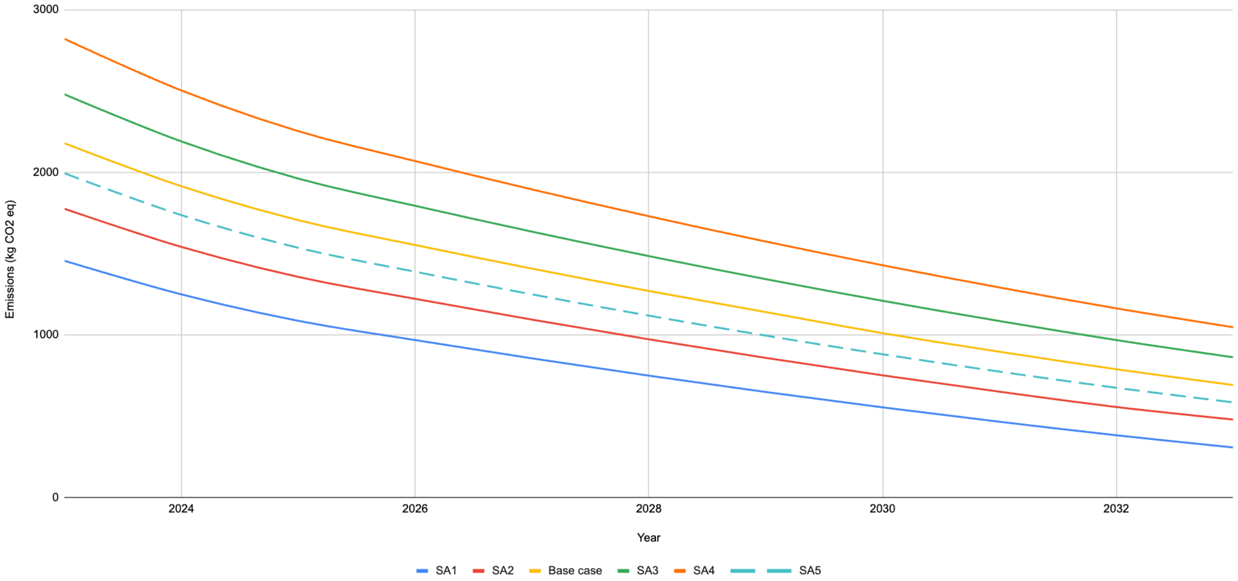


Figure 8 *Sensitivity analysis.*

For SA1 and SA2, total avoided emissions are lower than in the base case, as there is less energy generated by the 1 kW_p PV system. For SA3 and SA4, total avoided emissions are higher than in the base case, as there is more energy generated by the 1 kW_p PV. Thus, a larger amount of the marginal mix will be displaced by cleaner energy. Reduced generation from the PV system seems to have a larger effect on total avoided emissions than increased generation when comparing the base case with SA2 and SA3. For SA5, total avoided emissions are lower than in the base, as there is more curtailment of renewables. This leads to more renewables being able to respond to a change in demand and thus the marginal mix becomes cleaner. Displacing energy from a cleaner mix will result in lower avoided emissions.

4.4. Limitations

There are several limitations found in this study that havent been addressed but influence the final results:

- Pumped hydro is fed with electricity from the total marginal mix. Thus, the impact factor of pumped hydro equals the impact factor of the total marginal mix. However, in reality pumped hydro uses electricity from a single source and thus the impact associated with that electricity differs from our assumption. This can lead to higher or lower overall impacts along its generation, depending on the type of generation source. Acquiring the exact data to match sources is very hard and requires further insights from the grid operators.

- Efficiency improvements for different technologies are not considered. As discussed in section 3.2.1 substantial improvements in efficiencies are not expected in Spanish fossil power plants. Thus, the impact of each generation source remains constant rather than improving. This leads to higher impacts being considered for each type of generation. However, major efficiency breakthroughs seem unlikely and impacts are unlikely to differ by a large magnitude.

- Demand aggregation is not taken into account. This involves consumers to actively participate in the reduction of their demand by incentives from utility companies. This leads to the ability of reducing peak hour demands and in turn eliminating the need for short term flexible fossil fuel use. Not taking this into account might lead to higher shares of fossil fuels being considered and thus higher avoided impacts coming from PV electricity displacement.

- We assumed the future optimisation of the electricity grid to avoid bottlenecks and supply/ demand mismatches. Renewable curtailment is set to remain constant from 2050 to 2062. This means that excess electricity from renewables will increase in the future as their total capacity also increases. It is likely that new solutions will come into play that will lower curtailment and would thus lead to a lower share of "flexible" renewables being part of the marginal mix. In that case marginal mix impacts would be higher than considered in this study.
- There is large uncertainty around future developments of energy demand and supply, as well as the market structure. We assumed a future demand and supply predicted in several scientific studies. It is likely that demand and supply will differ in the future with new breakthroughs in technology coming into play such as nuclear fusion that could change the share of the marginal mix and make it greener.
- Seasonality factors are used to simulate the future marginal mix of Spain. This study assumes that Spain will achieve its net zero target (e.g. fully renewable by 100%). If this goal is not being reached, the marginal mix shares might differ leading to higher or lower impacts.
- Country-wide data has been used and there is no consideration of other bottlenecks. Grid capacity limitations at different locations are not considered, which could alter how the real marginal mix looks like for different consumers across the country. However, this could not be differentiated by location as data is not available. In a more accurate representation, mixes at different locations will be cleaner or more polluting.
- The number of cars in Spain is assumed to be the same today and in the future and thus the average cars per household too. Even though there has been a growth in total cars used, it is likely that this growth will reach a plateau as internal combustion vehicles will be replaced by electric vehicles.
- The efficiency of the selected electric appliances is assumed to remain constant in the future. It is likely that efficiencies will increase over the years as more research and development is spent on each appliance. However, given the complexity to predict this increase over the years, a constant value was assumed.

5. Conclusion

In conclusion, Sunhero has a positive environmental impact as they will accelerate the energy transition. This study found that adding PV and battery systems will be able to displace current marginal mix electricity, in turn reducing GHG emissions. A maximum of **134.4 g CO_2-eq./ kW_p** and **1.9 MJ/ kW_p** is being avoided by an additional 1kW_p PV installed in 2023. Also a maximum of **65.7 g CO_2-eq./ kW_p** and **0.9 MJ/ kW_p** is avoided by an additional 0.26 kW battery installed in 2023. The total lifetime 1 kW_p PV avoided emissions are **2179 kg CO_2-eq./ kW_p** installed in 2023 and combined PV and battery avoided emissions are **2456 kg CO_2-eq./ kW_p** installed in 2023. As Sunhero scales, their presence in the market still has a positive impact in 2032. We conclude that for every installation of an additional 1 kW_p PV system each year until 2032, total avoided emissions throughout the lifetime of the system are positive and the marginal mix emissions are never lower than PV emissions. However, PV generation avoided emissions after 2050 reach a plateau of **2 kg CO_2-eq./ kW_p per year**, as we assume that the marginal mix grid shares, curtailment and efficiencies remain constant. Taking into account the annual growth of residential solar in the future we can consider system sizes with an average size of 6,7 and 8 kW_p in 2023-2025, 2026 and 2027 to 2062. If 100,000 systems are then installed yearly, the total lifetime avoided emissions are **1.3 million tons CO_2-eq./ 100,000 PV systems** installed in 2023. Electrifying Spanish households can save between **5.3 - 7.6 tons CO_2-eq/ year per household** or reduce emissions by **83.1 - 87.6%** in 2023. If 100,000 households are electrified, the total avoided emissions over the lifetime are **15 - 22 million tons CO_2-eq/ 100,000 households** in 2023. These values show the enormous potential of electrifying the energy use of Spanish households. Adding residential solar PV as offered by Sunhero offers a decentralized way to support this transition.

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Annex

A.1 Base case - GWP

Table A.1 *Combined PV and Battery total avoided GHG emissions yearly.*

Year	Average PV Avoided emissions (kg CO_2-eq)	Average Combined PV & Battery Avoided emissions (kg CO_2-eq)		
		Scenario 1	Scenario 2	Scenario 3
2023	266.09	273.75	285.25	304.41
2024	210.36	216.41	225.49	240.62
2025	154.68	159.06	165.63	176.59
2026	147.07	151.30	157.66	168.25
2027	139.36	143.44	149.56	159.76
2028	131.61	135.53	141.41	151.21
2029	131.61	135.53	141.41	151.21
2030	116.13	119.76	125.21	134.29
2031	109.43	112.86	118.01	126.59
2032	99.22	102.43	107.26	115.30
2033	89.74	92.70	97.14	104.53
2034	81.38	84.10	88.17	94.96
2035	73.60	76.08	79.80	85.99
2036	64.89	67.05	70.28	75.67
2037	57.04	58.90	61.69	66.33
2038	49.96	51.54	53.92	57.89
2039	43.56	44.90	46.90	50.25
2040	37.77	38.88	40.55	43.32
2041	33.62	34.56	35.98	38.34
2042	29.60	30.39	31.56	33.52
2043	25.72	26.35	27.30	28.87
2044	21.98	22.46	23.17	24.37
2045	18.36	18.69	19.19	20.02
2046	14.86	15.05	15.34	15.82
2047	11.48	11.53	11.62	11.75
2048	8.21	8.13	8.02	7.83
2049	5.05	4.85	4.54	4.03
2050	2.00	1.68	1.18	0.36
2051	2.00	1.68	1.18	0.36
2052	2.00	1.68	1.18	0.36
2053	2.00	1.68	1.18	0.36
2054	2.00	1.68	1.18	0.36
2055	2.00	1.68	1.18	0.36
2056	2.00	1.68	1.18	0.36
2057	2.00	1.68	1.18	0.36
2058	2.00	1.68	1.18	0.36
2059	2.00	1.68	1.18	0.36
2060	2.00	1.68	1.18	0.36
2061	2.00	1.68	1.18	0.36
2062	2.00	1.68	1.18	0.36

A.2 Base case - Fossil use

Table A.2 *Combined PV and Battery total avoided fossil energy use.*

Year	Average PV Avoided Impact (10^3MJ)	Average Combined PV & Battery Avoided Impact (10^3MJ)		
		Scenario 1	**Scenario 2**	**Scenario 3**
2023	3.78	3.89	4.05	4.32
2024	3.14	2.87	2.45	1.75
2025	2.51	2.21	1.78	1.04
2026	2.49	2.20	1.77	1.06
2027	2.47	2.19	1.77	1.07
2028	2.45	2.18	1.77	1.10
2029	2.42	2.19	1.84	1.26
2030	2.39	2.19	1.90	1.42
2031	2.24	2.10	1.87	1.50
2032	2.03	1.93	1.77	1.52
2033	1.84	1.73	1.56	1.29
2034	1.66	1.55	1.38	1.09
2035	1.50	1.38	1.21	0.91
2036	1.33	1.20	1.02	0.70
2037	1.17	1.04	0.84	0.52
2038	1.03	0.89	0.69	0.35
2039	0.90	0.76	0.55	0.20
2040	0.79	0.64	0.42	0.06
2041	0.70	0.56	0.33	-0.04
2042	0.62	0.47	0.24	-0.14
2043	0.55	0.39	0.16	-0.23
2044	0.47	0.31	0.08	-0.32
2045	0.40	0.24	0.00	-0.41
2046	0.33	0.17	-0.08	-0.49
2047	0.26	0.10	-0.15	-0.57
2048	0.20	0.03	-0.22	-0.65
2049	0.14	-0.04	-0.29	-0.72
2050	0.08	-0.10	-0.36	-0.80
2051	0.08	-0.10	-0.36	-0.80
2052	0.08	-0.10	-0.36	-0.80
2053	0.08	-0.10	-0.36	-0.80
2054	0.08	-0.10	-0.36	-0.80
2055	0.08	-0.10	-0.36	-0.80
2056	0.08	-0.10	-0.36	-0.80
2057	0.08	-0.10	-0.36	-0.80
2058	0.08	-0.10	-0.36	-0.80
2059	0.08	-0.10	-0.36	-0.80
2060	0.08	-0.10	-0.36	-0.80
2061	0.08	-0.10	-0.36	-0.80
2062	0.08	-0.10	-0.36	-0.80

A.3 SA1

Table A.3 *Sensitivity Analysis 1.*

Year	Average PV Avoided emissions (kg CO_2-eq)	Average Combined PV & Battery Avoided emissions (kg CO_2-eq)		
		Scenario 1	**Scenario 2**	**Scenario 3**
2023	200.7	207.92	218.76	236.83
2024	156.48	162.1	170.54	184.6
2025	112.38	116.35	122.3	132.22
2026	106.43	110.26	115.99	125.55
2027	100.44	104.11	109.61	118.78
2028	94.42	97.93	103.2	111.98
2029	88.43	91.8	96.86	105.3
2030	82.48	85.71	90.56	98.63
2031	77.06	80.08	84.62	92.18
2032	69.1	71.92	76.14	83.17
2033	61.76	64.31	68.15	74.54
2034	55.29	57.61	61.09	66.89
2035	49.29	51.37	54.5	59.72
2036	42.54	44.31	46.96	51.39
2037	36.46	37.94	40.17	43.87
2038	30.99	32.2	34.03	37.07
2039	26.04	27.02	28.48	30.91
2040	21.58	22.33	23.46	25.34
2041	18.38	18.97	19.86	21.33
2042	15.29	15.72	16.38	17.46
2043	12.3	12.58	13.01	13.72
2044	9.41	9.55	9.76	10.1
2045	6.62	6.62	6.61	6.6
2046	3.92	3.78	3.57	3.22
2047	1.31	1.04	0.63	-0.06
2048	-1.21	-1.61	-2.21	-3.22
2049	-3.65	-4.17	-4.96	-6.28
2050	-5.93	-6.58	-7.55	-9.16
2051	-5.93	-6.58	-7.55	-9.16
2052	-5.93	-6.58	-7.55	-9.16
2053	-5.93	-6.58	-7.55	-9.16
2054	-5.93	-6.58	-7.55	-9.16
2055	-5.93	-6.58	-7.55	-9.16
2056	-5.93	-6.58	-7.55	-9.16
2057	-5.93	-6.58	-7.55	-9.16
2058	-5.93	-6.58	-7.55	-9.16
2059	-5.93	-6.58	-7.55	-9.16
2060	-5.93	-6.58	-7.55	-9.16
2061	-5.93	-6.58	-7.55	-9.16
2062	-5.93	-6.58	-7.55	-9.16

A.4 SA2

Table A.4 *Sensitivity Analysis 2.*

Year	Average PV Avoided emissions (kg CO_2-eq)	Average Combined PV & Battery Avoided emissions (kg CO_2-eq)		
		Scenario 1	Scenario 2	Scenario 3
2023	232.2	239.63	250.79	269.38
2024	182.37	188.21	196.95	211.54
2025	132.69	136.86	143.12	153.56
2026	125.89	129.91	135.96	146.02
2027	119.02	122.9	128.7	138.38
2028	112.14	115.85	121.42	130.7
2029	105.27	108.84	114.2	123.13
2030	98.46	101.88	107.02	115.58
2031	92.35	95.57	100.4	108.45
2032	74.91	77.66	81.78	88.64
2033	61.76	64.31	68.15	74.54
2034	67.54	70.04	73.8	80.07
2035	60.69	62.96	66.37	72.05
2036	53.04	54.99	57.93	62.81
2037	46.15	47.81	50.31	54.47
2038	39.94	41.34	43.43	46.93
2039	34.33	35.48	37.22	40.11
2040	29.26	30.19	31.59	33.93
2041	25.63	26.4	27.56	29.48
2042	22.12	22.73	23.65	25.19
2043	18.72	19.19	19.88	21.04
2044	15.45	15.76	16.24	17.03
2045	12.28	12.45	12.71	13.15
2046	9.21	9.25	9.3	9.39
2047	6.25	6.15	6.01	5.77
2048	3.38	3.16	2.82	2.26
2049	0.61	0.26	-0.26	-1.14
2050	-1.97	-2.43	-3.14	-4.31
2051	-1.97	-2.43	-3.14	-4.31
2052	-1.97	-2.43	-3.14	-4.31
2053	-1.97	-2.43	-3.14	-4.31
2054	-1.97	-2.43	-3.14	-4.31
2055	-1.97	-2.43	-3.14	-4.31
2056	-1.97	-2.43	-3.14	-4.31
2057	-1.97	-2.43	-3.14	-4.31
2058	-1.97	-2.43	-3.14	-4.31
2059	-1.97	-2.43	-3.14	-4.31
2060	-1.97	-2.43	-3.14	-4.31
2061	-1.97	-2.43	-3.14	-4.31
2062	-1.97	-2.43	-3.14	-4.31

A.5 SA3

Table A.5 *Sensitivity Analysis 3.*

Year	Average PV Avoided emissions (kg CO_2-eq)	Average Combined PV & Battery Avoided emissions (kg CO_2-eq)		
		Scenario 1	**Scenario 2**	**Scenario 3**
2023	295.19	302.94	314.55	333.91
2024	234.17	240.3	249.51	264.85
2025	173.3	177.77	184.49	195.67
2026	164.79	169.12	175.61	186.42
2027	156.2	160.37	166.61	177.03
2028	147.57	151.57	157.58	167.59
2029	138.96	142.82	148.61	158.26
2030	130.41	134.12	139.68	148.95
2031	122.95	126.45	131.7	140.46
2032	111.66	114.94	119.87	128.08
2033	101.22	104.25	108.78	116.33
2034	92.03	94.81	98.98	105.93
2035	83.49	86.03	89.85	96.2
2036	74.04	76.26	79.6	85.16
2037	65.52	67.45	70.35	75.18
2038	57.84	59.5	62	66.16
2039	50.9	52.32	54.45	58
2040	44.62	45.82	47.61	50.6
2041	40.12	41.16	42.71	45.29
2042	35.78	36.65	37.97	40.16
2043	31.57	32.3	33.38	35.19
2044	27.51	28.09	28.95	30.39
2045	23.58	24.02	24.67	25.75
2046	19.79	20.08	20.53	21.26
2047	16.12	16.28	16.52	16.92
2048	12.57	12.6	12.65	12.73
2049	9.14	9.04	8.9	8.67
2050	5.97	5.75	5.43	4.9
2051	5.97	5.75	5.43	4.9
2052	5.97	5.75	5.43	4.9
2053	5.97	5.75	5.43	4.9
2054	5.97	5.75	5.43	4.9
2055	5.97	5.75	5.43	4.9
2056	5.97	5.75	5.43	4.9
2057	5.97	5.75	5.43	4.9
2058	5.97	5.75	5.43	4.9
2059	5.97	5.75	5.43	4.9
2060	5.97	5.75	5.43	4.9
2061	5.97	5.75	5.43	4.9
2062	5.97	5.75	5.43	4.9

A.6 SA4

Table A.6 *Sensitivity Analysis 4.*

Year	Average PV Avoided emissions (kg CO_2-eq)	Average Combined PV & Battery Avoided emissions (kg CO_2-eq)		
		Scenario 1	**Scenario 2**	**Scenario 3**
2023	326.69	334.55	346.34	365.98
2024	260.06	266.31	275.69	291.31
2025	193.6	198.19	205.07	216.54
2026	184.24	188.68	195.34	206.43
2027	174.79	179.06	185.48	196.17
2028	165.29	169.4	175.57	185.85
2029	155.81	159.77	165.72	175.64
2030	146.39	150.2	155.92	165.46
2031	138.24	141.85	147.27	156.29
2032	125.84	129.23	134.32	142.79
2033	114.38	117.5	122.19	130.01
2034	104.28	107.16	111.48	118.69
2035	94.89	97.53	101.5	108.11
2036	84.53	86.86	90.35	96.16
2037	75.2	77.24	80.28	85.37
2038	66.79	68.55	71.2	75.61
2039	59.18	60.7	62.98	66.78
2040	52.3	53.6	55.54	58.78
2041	47.37	48.5	50.2	53.03
2042	42.6	43.58	45.04	47.48
2043	38	38.82	40.05	42.11
2044	33.54	34.22	35.23	36.92
2045	29.24	29.77	30.57	31.89
2046	25.08	25.47	26.06	27.04
2047	21.05	21.31	21.7	22.34
2048	17.16	17.29	17.48	17.8
2049	13.4	13.4	13.41	13.41
2050	9.93	9.82	9.64	9.35
2051	9.93	9.82	9.64	9.35
2052	9.93	9.82	9.64	9.35
2053	9.93	9.82	9.64	9.35
2054	9.93	9.82	9.64	9.35
2055	9.93	9.82	9.64	9.35
2056	9.93	9.82	9.64	9.35
2057	9.93	9.82	9.64	9.35
2058	9.93	9.82	9.64	9.35
2059	9.93	9.82	9.64	9.35
2060	9.93	9.82	9.64	9.35
2061	9.93	9.82	9.64	9.35
2062	9.93	9.82	9.64	9.35

A.7 SA5

Table A.7 *Sensitivity Analysis 5.*

Year	Average PV Avoided emissions (kg CO_2-eq)	Average Combined PV & Battery Avoided emissions (kg CO_2-eq)		
		Scenario 1	**Scenario 2**	**Scenario 3**
2023	258.00	265.44	276.61	295.22
2024	202.79	208.64	217.40	232.01
2025	148.18	152.38	158.68	169.18
2026	140.00	144.03	150.09	160.17
2027	131.81	135.67	141.46	151.10
2028	123.66	127.34	132.86	142.06
2029	115.60	119.13	124.41	133.22
2030	107.69	111.05	116.09	124.49
2031	100.19	103.31	107.99	115.79
2032	89.83	92.71	97.04	104.25
2033	80.38	82.99	86.91	93.43
2034	72.14	74.50	78.04	83.94
2035	64.59	66.71	69.89	75.18
2036	56.56	58.38	61.10	65.65
2037	49.38	50.93	53.25	57.12
2038	42.95	44.25	46.21	49.47
2039	37.19	38.27	39.89	42.59
2040	32.01	32.89	34.21	36.41
2041	28.33	29.07	30.17	32.00
2042	24.79	25.39	26.28	27.77
2043	21.38	21.85	22.54	23.69
2044	18.11	18.44	18.94	19.77
2045	14.96	15.16	15.48	16.00
2046	11.92	12.01	12.14	12.36
2047	9.00	8.97	8.93	8.87
2048	6.19	6.05	5.84	5.50
2049	3.48	3.24	2.87	2.26
2050	0.99	0.64	0.13	-0.74
2051	0.99	0.64	0.13	-0.74
2052	0.99	0.64	0.13	-0.74
2053	0.99	0.64	0.13	-0.74
2054	0.99	0.64	0.13	-0.74
2055	0.99	0.64	0.13	-0.74
2056	0.99	0.64	0.13	-0.74
2057	0.99	0.64	0.13	-0.74
2058	0.99	0.64	0.13	-0.74
2059	0.99	0.64	0.13	-0.74
2060	0.99	0.64	0.13	-0.74
2061	0.99	0.64	0.13	-0.74
2062	0.99	0.64	0.13	-0.74

A.8 Household electrification emissions

Table A.8 *Household electrification emissions.*

		Current		Electrification	
Fuel	**Application**	**Energy demand (kWh)**	**Emissions (kg CO_2-eq)**	**Energy demand (kWh)**	**New Emissions (kg CO_2-eq)**
Natural gas	Total	4.91E+10	1.14E+10	2.34E+10	8.08E+08
	Heating	3.81E+10		1.80E+10	
	Cooking	1.10E+10		5.37E+09	
Oil	Total	3.18E+10	1.02E+10	1.57E+10	5.44E+08
	Heating	2.85E+10	9.43E+09	1.32E+10	
	Cooking	3.27E+09	7.82E+08	2.50E+09	
Biomass	Total	2.94E+10	1.73E+09	1.09E+10	3.75E+08
	Heating	2.82E+10	1.67E+09	1.06E+10	
	Cooking				
Electricity	Total	7.47E+10	1.54E+10	7.47E+10	2.58E+09
	Heating, lighting, appliances	6.64E+10			
	Cooking	8.30E+09			
Total		1.85E+11	3.87E+10	1.25E+11	4.31E+09

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