EuroSun2026

ENVIRONMENTAL ASSESSMENT OF SOLAR-INTEGRATED RESIDENTIAL HEATING AND DOMESTIC HOT WATER: A CASE STUDY

Summary

This study evaluates the Global Warming Potential (GWP) of solar-integrated residential heating and domestic hot water (DHW) systems through a case study in France, framed under an Energy-as-a-Service perspective. The functional unit corresponds to the provision of space heating and DHW over the contracted service horizon. Two base systems, an air-to-water heat pump (AWHP) and a wood pellet boiler (WPB), are coupled with photovoltaic (PV) panels, a solar water heater (SWH), or both. Non-operational emissions are derived from Product Environmental Profiles (PEP), while operational emissions are computed from building energy simulation (BES) outputs using two electricity accounting approaches. Three PV compensation mechanisms available in France are analyzed. The results show that solar integration reduces operational GWP, although the magnitude depends on the PV valorization mechanism and the interaction with the grid. However, at the service level, non-operational emissions become relevant and should be considered alongside operational gains.

Keywords: EaaS, solar energy, residential heating, Global Warming Potential, PV compensation mechanism

Field of application for the findings: The findings complement existing environmental assessment methodologies by incorporating a service-oriented perspective into the evaluation of solar residential energy systems.

Addressed audience: ***researchers, energy engineers, policy makers***

1. Introduction

The Energy-as-a-Service (EaaS) model offers a framework in which space heating and domestic hot water (DHW) are delivered as a contracted service, integrating system design, financing, and operation (IRENA, 2020). Evaluating these models from an environmental perspective demands an assessment that goes beyond the equipment and considers the performance of the entire service. When solar technologies are added, the evaluation becomes more complex. The addition of photovoltaic (PV) panels or solar water heaters (SWH) modifies both the operational and non-operational emission profiles. The emission factor used for electricity, the PV configuration and the service boundary all influence the result.

This work presents the environmental assessment of eight EaaS configurations with solar integration for a French residential case study. The Global Warming Potential (GWP) is quantified covering both non-operational and operational emissions, and examining the sensitivity to the electricity emission accounting approach and the PV valorization mechanism.

2. Methodology

The case study is a single-family house in France. The functional unit is defined as the provision of space heating and DHW over the contracted service duration of 17 years, corresponding to the expected lifetime of the base system. Two base systems are analyzed: an air-to-water heat pump (AWHP) and a wood pellet boiler (WPB). Each is combined with a 3 kWp PV installation, a solar water heater (SWH), or both.

2.1. Non-operational emissions

Non-operational emissions are derived from the Product Environmental Profiles (PEP) of each component, covering manufacturing, transport, installation and end-of-life stages. Values are aggregated per configuration and annualized over the service duration (17 years).

2.2. Operational emissions

Annual energy consumption is obtained from a building energy simulation in the software Pleiades. Two electricity emission accounting approaches are compared: a detailed approach using differentiated factors by end use (heating, DHW, other uses) as defined in the French standards (République française, 2021), and a grid-average factor based on the French electricity mix (RTE, 2024). The grid-average factor is also used to compute the "environmental credit" of injected PV electricity. Tab. 1 presents the emission factors used in this study.

Tab. 1: Energy emissions factors by energy source

Energy Type / Energy Use	Emission Factor [kg CO2-eq./kWh (EF)]			
	Space Heating	**DHW**	**Other Uses**	**Grid Average**
Electricity	0.079	0.065	0.064	0.032
Wood Pellets (LHV)	0.03		-	-

2.3 PV compensation configurations

Three compensation mechanisms available in France are considered: (a) self-consumption with surplus injection, (b) self-consumption without injection, and (c) total injection. Each defines how PV electricity is credited in the GWP calculation.

3. Results and Discussion

Tab. 2 presents the non-operational GWP per variant. The addition of solar components increases non-operational emissions proportionally to the number of systems included in the service configuration.

Tab. 2: Non-Operational Global Warming Potential per technological variant

Base System / Solar Configuration	Non-Operational GWP [kg CO2-eq./year]			
	Without Solar System	**PV**	**SWH**	**SWH+PV**
AWHP	129	297	186	354
WPB	75	243	108	276

Tab. 3 shows the net operational GWP under both emission accounting approaches. For AWHP-based configurations, the difference between the detailed and the grid-average approaches ranges from 205 to 231 kg CO_2-eq./year, since the AWHP relies entirely on electricity and the French grid-average factor is particularly low due to the nuclear share in the mix. For WPB-based configurations, this difference is less pronounced (65-66 kg CO_2-eq./year) as wood pellet combustion dominates operational emissions.

Tab. 3: Net operational GWP per technological variant, emissions approach and PV compensation configuration

	Net Operational GWP [kg CO2-eq./year]					
Accounting Approach	Detailed			Average		
Compensation Configuration	a	b	c	a	b	c
Air-to-Water Heat Pump Variants						
AWHP	417			186		
AWHP+SWH	368			163		
AWHP+PV	308	376	308	77	145	77
AWHP+SWH+PV	259	334	259	54	128	54
Wood Pellet Boiler Variants						
WPB	593			528		
WPB+SWH	553			488		
WPB+PV	484	567	483	418	501	418
WPB+SWH+PV	444	527	443	378	461	378

Fig. 1 illustrates the influence of the PV compensation mechanism on the net operational GWP for AWHP configurations. The SWH reduces operational emissions by directly lowering DHW energy demand. For PV-integrated variants, mechanisms that include grid injection (a and c) yield lower net operational emissions due to the “environmental credit” associated with exported electricity. Notably, under a static annual analysis, the difference between mechanisms (a) and (c) is minimal. A dynamic evaluation accounting for temporal self-consumption patterns could provide further insight into differentiating their actual environmental performance.

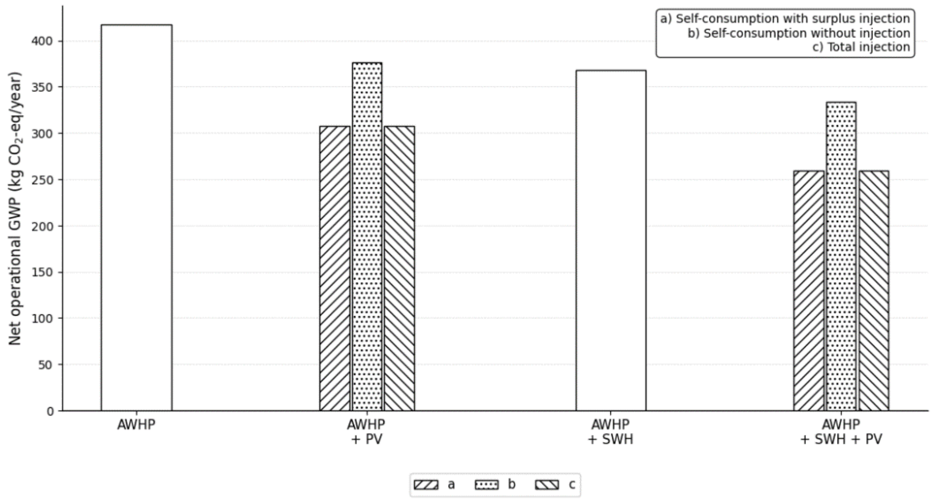

Fig. 1: Net operational GWP for AWHP-based configuration under different PV compensation configurations

When combining non-operational and operational contributions, configurations including only the SWH show the lowest total GWP. This result illustrates how the proposed framework captures the trade-off between operational reductions and non-operational additions, and how assumptions on service duration and PEP reference values directly influence the environmental ranking of configurations. These findings are consistent with Turk et al. (2025), who reported that solar integration reduced GWP by 36% but increased non-operational impacts due to additional equipment, and with Pinto et al. (2023), who found that equipment-related emissions represented up to 10% of total emissions in an EaaS configuration in France.

The net environmental benefit therefore depends on the combined effect of the PV compensation mechanism, the emission accounting approach, and the weight of embodied and end-of-life emissions within the full-service scope.

4. References

IRENA, 2020. Innovation landscape brief: Energy as a Service. International Renewable Energy Agency, Abu Dhabi. Available at: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jul/IRENA_Energy-as-a-Service_2020.pdf (accessed 30 March 2026).

Pinto, E.S., Gronier, T., Franquet, E., Serra, L.M., 2023. Opportunities and economic assessment for a third-party delivering electricity, heat and cold to residential buildings. Energy 272, 127019.

République française, 2021. Arrêté du 4 août 2021 relatif aux exigences de performance énergétique et environnementale des constructions de bâtiments en France métropolitaine. Journal officiel de la République française, JORF n°0189, NOR: LOGL2107359A. Available at: https://www.legifrance.gouv.fr/eli/arrete/2021/8/4/LOGL2107359A/jo/texte (accessed 30 March 2026).

RTE – Réseau de Transport d'Électricité, 2024. Bilan électrique 2023: Émissions associées à la production d'électricité en France. Available at: https://analysesetdonnees.rte-france.com/bilan-electrique-2023/emissions (accessed 30 March 2026).

Turk, J., Oarga Mulec, A., Ostruh, P., Ceket, A., 2025. Environmental Evaluation of Residential Heating: Comparative Life Cycle Assessment of Two Heating Systems. Buildings 15(21), 3977