

LIFE CYCLE ASSESSMENT

FINANCING RESIDENTIAL RETROFITTING



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 are published for maximum transparency.

Terminology, units and abbreviations

ASHP	Air source heat pump
CED	Cumulative energy demand
CEDf	Cumulative fossil energy demand
CO ₂ -eq.	Carbon dioxide equivalents
COP	Coefficient of performance
EF	Emission factor
EU	European Union
Functional unit	Quantified performance of a product system for use as a reference unit
g	Gram
GHG	Greenhouse gas
GSHP	Ground source heat pump
GW	Gigawatt
IEA	International Energy Agency
kg	Kilogram
kWh	Kilowatt hour
kWp	Kilowatt peak power
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
MJ	Megajoule
MWh	Megawatt hour

About Eclair

[Eclair](#) is a European startup on a mission to accelerate the adoption of renewable energy technologies by providing financing and financial tools accelerating and promoting the adoption of residential solar PV, insulation and heat pumps.

Summary

Addressing climate change necessitates significant reductions in greenhouse gas emissions across all sectors, with residential heating and the adoption of renewable energies like solar PV playing a crucial role. This Life Cycle Assessment (LCA) report evaluates the environmental impact of Eclair's mission to accelerate residential energy renovations in France, focusing on the replacement of existing heating systems with heat pumps, improved insulation, and the installation of solar PV. The study employs a consequential LCA approach to assess net reductions in GHG emissions and fossil energy demand. These net reductions are computed until 2050. The results show slightly declining savings over the next decades, but substantial net reduction in GHG emissions and fossil fuel use if heat pumps are installed and buildings are renovated .

The report also highlights that accelerating these installations through Eclair's financial tools can lead to significant additional reductions in GHG emissions and fossil energy consumption.

About this study

This study discusses the impact of replacing existing heating systems with heat pumps and improving insulation in residential households in France. Additionally, the installation of residential solar PV is assessed. First, the current systems used in French dwellings are discussed. Subsequently, we outline the methodology used in the study. This includes a detailed explanation of how the French system was modelled and how the impact was assessed. Lastly, the final results are presented along with the limitations of this study.

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1. Introduction

Almost half of the European residential buildings were constructed before 1970 (European Investment Bank, 2020) when energy efficiency was not yet a priority in the EU energy policy agenda (Economidou et al. 2020), resulting in excessive energy needs. Over the years, these buildings have deteriorated, leading to even poorer energy performances. The EU Commission has set ambitious renovation targets, including a target of 150 million global retrofits by 2050 (with projected costs of \$5250 billion) doubling the renovation rate annually, which currently stands at just 1% (European Commission 2022). National governments have set their own renovation targets to renovate buildings in an effort to reach their net-zero targets.

At present, France’s building sector still accounts for around 24% of the country’s overall energy consumption. The final residential energy demand is supplied by electricity from all sources (40%), natural gas (27%), biofuels and wastes (18.7%), oil products (9.5%) and waste heat (4.0%) (International Energy Agency (IEA) 2025). Figure 1 below depicts the distribution of residential consumption of electricity in France in 2022.

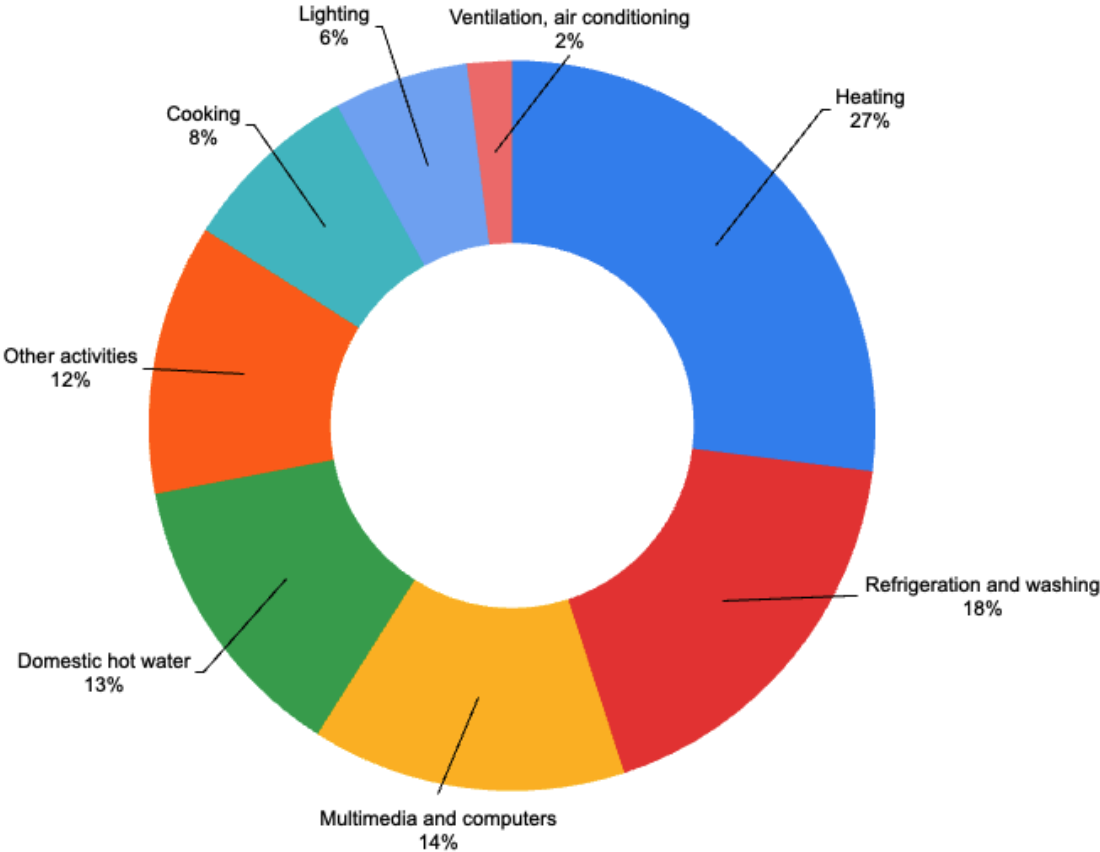


Figure 1 Residential consumption of electricity in France in 2020 (Statista 2022).

The French Government seeks to reduce the dependence on carbon-based fossil fuels associated with high GHG emissions. This can be achieved by reducing the residential energy consumption through better insulation, a switch in heating systems from boilers or electric heating to heat pumps and via the installation of residential solar PV installations. **France set a goal of 500,000 global energy retrofits¹ by 2027** (ECEEE 2021; Ministère Écologie Énergie Territoires n.d.) **and reaching 900,000 global**

¹ “Global energy retrofits” refers to the upgrading of all existing energy systems to improve their efficiency and reduce energy consumption.

energy retrofits by 2030 (Secrétariat général à la planification écologique 2023), supported by heavy subsidies and severe regulation. Despite these ambitious plans, more than 45,000 requests for funding for renovations and heat pumps remain unprocessed in France. Applications for funding of small projects are delayed by 2.5 months (+ another 1.5 months until payment is received (Pouliquen 2025; Eve 2025)). Funding of larger renovations is delayed by 3.5 months (+ 1 month delay in payment). Such delays slow down the market adoption of renewable energy (Pouyanne 2024; Patrier 2024). In addition, uncertain financing mechanisms and regulatory uncertainty are a key bottleneck hindering the ramp-up of heat pumps and renewable energies (European Heat Pump Association 2025; Talbot 2025; Finergreen 2022).

Ecair supports the energy transition and helps to address the aforementioned challenges by providing financing and financing tools to facilitate easy, accessible and fast financing of global renovation projects in France. The aim of this study is therefore to understand the potential environmental impacts of Ecair. To this end, our LCA evaluates the environmental impact of global renovation projects in France, including heat pumps, insulation and solar PV.

2. Methods and Inventory data

In the following section, we describe the assessed system, the functional unit, the temporal scope, assumptions and the life cycle inventory (LCI).

2.1. System description

This LCA study aims to assess the potential environmental impacts of deploying heat pumps, insulation, solar PV, and EV charging infrastructure in France—technologies financed through Eclair's financial vehicles. The study follows a consequential LCA approach, seeking to assess changes in environmental impact; i.e. the net reductions in GHG emissions (in CO₂-eq.) as a consequence of a change in the energy system resulting from these installations (Ekvall et al. 2016). To account for marginal changes, a domestic marginal electricity mix for France was calculated without considering the electricity import or exports over time and using consequential emission factors (Muñoz and Weidema 2021; Treyer and Bauer 2016). It is important to note that this study focuses solely on the operational emission savings resulting from the installation of heat pumps and insulation; the embodied emissions are not considered. This is due to three reasons: first, to align the study with scientific literature and publications (see IEA 2021), where embodied and operational emissions are reported separately, second, the impact of embodied emissions is negligible compared to the lifetime energy savings.

2.1.1. Functional unit and assessed indicators

This LCA comprises several elements: The displacement of conventional heating due to the installation of heat pumps and the displacement of primary energy used in heating due to the installation of insulation. Additionally, the marginal displacement of electricity production by accelerated and additional installations of solar PV, as well as EV chargers is assessed. Different functional units are chosen for each case:

- **Heat pumps and insulation:** The functional unit to assess both the aspects is one housing unit equipped with a heat pump and insulation, i.e. the net reductions in GHG emissions and fossil energy demand achieved per m² and year. We additionally calculate the annual net reductions using the average size of a housing in France (90 m²).
- **Solar PV:** The functional unit is the annual and lifetime reduction in GHG emissions and cumulative fossil energy demand of one residential solar PV installation.

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).

2.1.2. Temporal scope

The assessment evaluates the net benefit of installing heat pumps and insulation within the next five years (2023 to 2027). These systems will be in operation for their whole lifetime (20 years in total). Therefore, the energy mix is projected into the future to cover the full lifetime of the installed systems.

2.1.3. Assessment procedure

- **Heat pumps and insulation:** Figure 2 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 of 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.

- **Solar PV:** The impact of adding a solar PV system includes the first two steps shown in Figure. Based on the marginal energy mix, technologies displaced in the market are identified. GHG emissions and fossil energy demand of these technologies are then used to calculate the net reduction in GHG emissions and fossil energy demand.

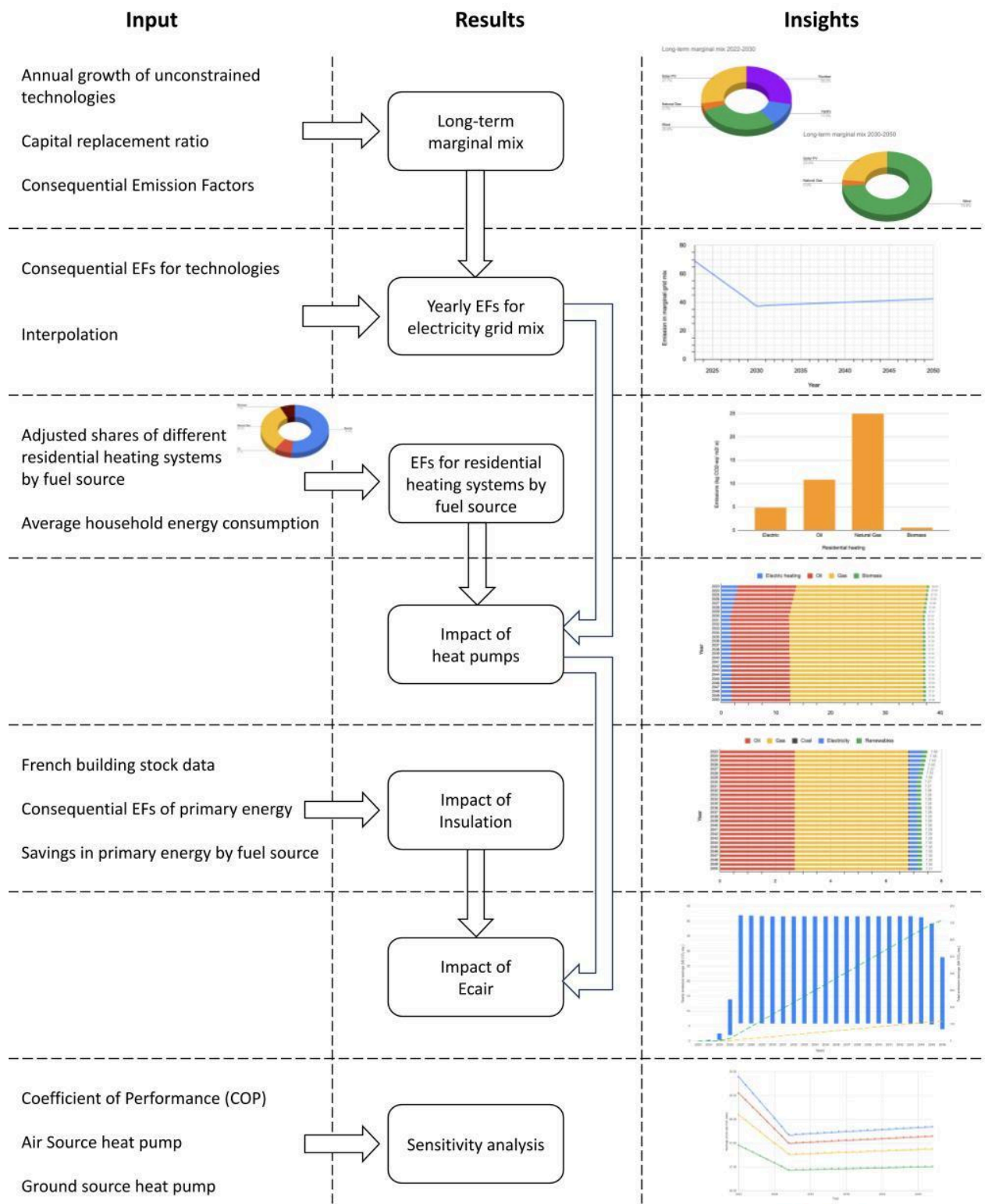


Figure 2 Schematic overview of the assessment to assess the impact of installing heat pumps and insulation.

2.2. Inventory and methodology

2.2.1. Marginal electricity supply

Electrical heating systems consume electricity from the local electricity grid. 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 respond to the change in demand and provide additional or less electricity as required. Consequently, marginal mixes tend to differ in comparison to the emissions of average mixes. 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 the selected time interval.

In contrast, the emissions of a marginal electricity mix significantly differ. Here the relative change in the share of each unconstrained generation of technology due to a change in demand is taken into account. This means that intermittent sources like solar and wind can only respond to an increase in demand if 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 long-term marginal mix, the emissions from the marginal mix are calculated by multiplying the change in the generation of the controllable and unconstrained technologies' mix (also accounting for the capital replacement) between two time periods (Muñoz and Weidema 2021), with the carbon emissions per kWh of each technology as depicted in Table 1.

Table 1 Emission factors and energy demand by electricity source.

Indicator	NGCC	Hydro	Nuclear	Solar PV	Wind	Unit
GHG Emissions	0.471	0.005	0.007	0.035	0.027	kg CO ₂ -eq./kWh
Fossil energy demand	9.08	0.05	0.10	0.45	0.32	MJ/kWh

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). The need for marginal mix simulations becomes more relevant for a future mix with higher variability and renewables. A future generation mix will likely consist of higher shares of renewables and lower fossil fuels, decreasing the greenhouse gas intensity of the electricity mix. When considering the effect of a change in heating systems (or any system dependent on electricity) the marginal mix accurately represents the change in emissions with the changing demand. Furthermore, it is also relevant when assessing the change in emissions from primary energy consumption when new insulation is installed, reducing the need for heating.

The following data sources and assumptions were used to determine the marginal energy mix:

- Nuclear energy: Nuclear power is the dominant source of electricity generation at the moment. Most plants in operation today were built in the 1980s and early 1990s (World Nuclear Association 2025). New power plants under construction face long delays and costs keep increasing (Renewable-Energy-Industry.com 2025). The first new reactors are not expected to be operational before 2038. By 2050, 75% of nuclear power plants in operation today will be decommissioned. To counter the decrease in nuclear capacity, the French government has decided to accelerate the construction of nuclear power and to extend the lifetime of existing power plants. By 2050, the French government projects a total of 39 GW (Scenario N2 - additional renewable energy and new nuclear reactors, (World Nuclear Association 2025;

Mouterde 2023)). The capacity factor of nuclear power plants in France reached 74% in 2024. Globally, capacity factors ranging from 85 to 95% are achieved (International Atomic Energy Agency 2025; World Nuclear Association 2024). We assumed that in future, a slight increase of the capacity factor (80%) can be achieved.

- All other energy sources: The current and future capacities of other energy sources was taken from French government statistics and most recent (2025) national energy plans (Ministère de la Transition écologique (France) 2025; RTE (Réseau de Transport d'Électricité) 2025, 2021). Again, we used scenario N2 of the French Government, reflecting additional capacities of renewable energy and nuclear power to model the future energy supply.

2.2.2. Heat pumps

The first step to assess the impact of using a heat pump is to calculate the marginal electricity mixes over different time periods from 2023 onwards; when the pump is being installed till 2046 - the time the pump will end its operating lifetime. Data was gathered from multiple sources including the IEA, the French government, and the EU to analyse electricity generation by source for the years 2022, 2030, and 2050. Interpolation between 2030 and 2050 was employed due to the unavailability of data for 2040. Subsequently, the average emissions ($Emissions_t$) resulting from installed heating systems were computed based on a final energy consumption of 131 kWh/m² (Odyssee 2015) (Odyssee 2015), proportions of different heating technologies utilised in French households and their respective efficiencies. Then, the emissions from heat pumps in a specific year with respect to the heated area were determined by multiplying the energy consumption of a heat pump technology per heated area ($Final\ Energy\ Consumption_t$) with the emission factor for heat pumps ($Emissions_{100\% \text{ heat pumps, } y}$) in that particular year. Finally, the emission savings ($Savings_{t,y}$) were calculated as the difference between the two sets of emissions mentioned above. The different values used in the calculation are given below in Table 2. Boiler efficiencies were assumed to be 90%.

$$Savings_{t,y} = Emissions_t - (Final\ Energy\ Consumption_t \times Emissions_{100\% \text{ heat pumps, } y} \div 1000)$$

t = Heating system technology by fuel source

y = Year

Table 2 Properties of different heating systems. GHG emissions and CED_f per m² include the adjusted shares.

Current residential heating	Adjusted share	Final energy consumption (kWh/ m ²)	Emissions (g CO ₂ / kwh)	Emissions (kg CO ₂ -eq./m ² /a)	CED_f (MJ/kWh)	CED_f (MJ/m ² /a)
Electric	51%	67.1	73.0	4.6	10.0	0.6
Oil	8%	10.9	996.1	10.9	13.1	0.1
Natural Gas	33%	43.7	571.7	25.0	11.1	0.5
Biomass	7%	9.4	58.8	0.5	0.6	<0.1

Additionally, the environmental impact associated with the production, maintenance and end-of-life of heat pumps was considered. The inventory data was taken from Naumann et al. (2022) and complemented with the consequential ecoinvent database (Treyer and Bauer 2016).

Emission factors of different heating systems were calculated using the adjusted share of different types of residential heating systems by fuel source, their efficiencies and the average household energy consumption of 131 kWh/m² for space heating in France (Odyssee 2015) as shown in Figure 3.

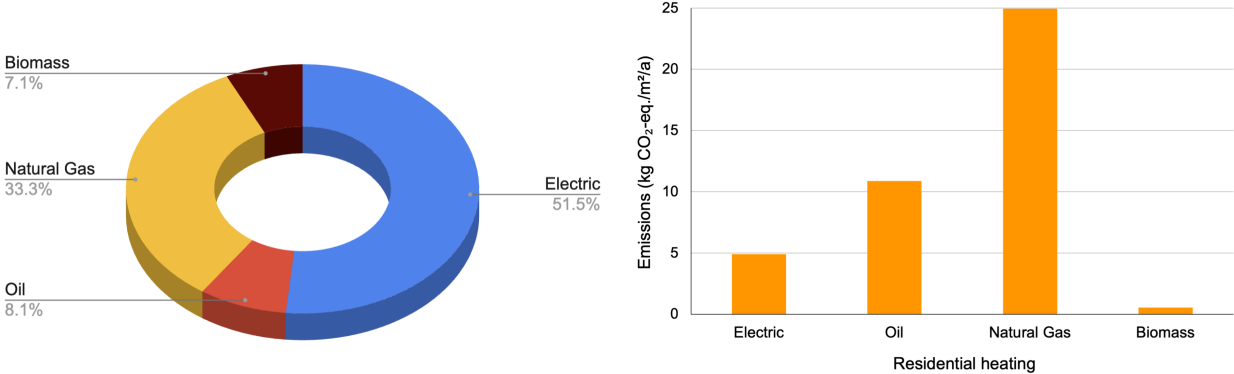


Figure 3 Adjusted shares and emission factors of residential heating systems in France by fuel source.

2.2.3. Insulation

The impact of insulation is related to the savings in the consumption of primary energy. To assess this change in energy consumption, an average energy demand of 122.12 kWh/m² was used for French dwellings (ODYSSEE-MURE 2021). The primary energy savings due to insulation for each heating system were extracted from the *Building Performance Institute Europe* (BPIE 2022) and (Foda, El-Hamalawi, and Le Dréau 2020), accounting for different French geographies.. The emission savings of insulation ($Emission Savings_{t,y}$) for each year and fuel source used were calculated by multiplying the primary energy savings ($PE Savings_t$) for each year with the emission factor of each heating fuel source ($Emission Factor_t$), as seen in the equation below. The total emissions over the operating lifetime of the insulation of 20 years were calculated for installations between the years 2023 and 2027. The different values used in the calculation are provided below in Table 3.

$$Emission Savings_{t,y} = PE Savings_t \times Emission Factor_t$$

t = Heating system technology by fuel source

y = Year

Ecair’s business reduces fossil energy demand by reducing the heating energy required in residential buildings as heat pumps are significantly more efficient than other heating systems ((Fitzgibbon 2021) and insulation reduces the demand to actively heat a space by preventing heat loss through the surfaces.

The change in cumulative fossil energy demand was calculated using fossil energy demand values (cumulative energy demand, non-renewable, fossil) from the consequential ecoinvent database (Treyer and Bauer 2016) for different heating technologies.

Table 3 Primary energy use and insulation.

Primary Energy Use in residential heating	Primary Energy Use (Ktoe)	Primary Energy Saving due to Insulation (TWh)
Oil	3400	18.3
Natural Gas	9000	34.8
Coal	200	0.1
Electricity	3000	16.1
Renewables	8000	38.4

2.2.4. Solar PV and battery storage

The installation of residential solar PV will accelerate the adoption of renewable energy and the phase out of fossil energy sources, as planned by the French government (section 2.2.1). We used the long term marginal energy mix to determine the net benefits of introducing solar PV to the French energy system. At present, The average capacity of new residential solar PV installation in France is 4.6 kW (calculated by dividing the total installed capacity by the number of installations, (France Territoire Solaire 2024)). From 2030 onwards, we additionally included a battery storage system. We assume that 50% of the electricity is stored in the battery (and dispatched whenever there is low solar radiation. The battery was modelled with LCA data published in (Wrålsen and O’Born 2023).

3. Results

Here we present a detailed discussion of the environmental impacts of two main impact factors: global warming potential and fossil energy demand.

3.1. Long-term marginal electricity and heat supply

To calculate the marginal electricity mixes we considered the electricity generation from unconstrained energy sources in France in 2022, 2030 and 2050 (Table 4). Note: Nuclear and hydro power are only unconstrained in the long-term. Scaling these technologies takes a long time (nuclear) or is constrained by geography (hydropower).

Table 4 Current and projected future electricity generation (in TWh) from unconstrained sources in France.

Generation Technology	Production in 2023	Production in 2030	Production in 2050
Nuclear	279	279	273
Hydropower	54	54	46
Wind, onshore	49	72	116
Wind, offshore	2	14	81
Conv. Natural gas	33	28	0
Coal	2.9	0	0
Fuel oil	2.2	0	0

Long-term marginal mixes between 2022-2030 and 2030-2050 were calculated considering the annual growth of unconstrained technologies, capital replacement ratio, and share of the long-term marginal mix is shown in Tables 5 and 6. Electricity imports were not considered due to potential inaccuracies in predicting those over such a long time frame.

Table 5 Long-term marginal mixes in France 2023 to 2030.

Generation	Annual growth 2023-2030 (%)	Plant lifetime (years)	Capital replacement (%)	Net annual growth 2023-2030 (%)	Net annual growth 2022-2030 (TWh/yr)	Long term marginal mix	Long term marginal decrease
Nuclear	0.00%	60	-1.67%	1.67%	4.65	20%	
Hydropower	-0.05%	100	-1.00%	0.95%	0.51	2%	
Wind, onshore	6.69%	20	-5.00%	11.69%	5.69	24%	
Wind, offshore	87.23%	20	-5.00%	92.23%	1.75	7%	
Conv. natural gas	-1.84%	30	-3.33%	1.49%	0.49	2%	
Solar	43.62%	30	-3.33%	46.95%	10.66	45%	
Coal	-14.29%	30	-3.33%	-10.95%	-1.16		-79%
Fuel oil	-14.29%	30	-3.33%	-10.95%	-0.32		-21%
Total						100%	-100%

Table 6 Long-term marginal mixes in France 2030 to 2050.

Generation	Annual growth 2030-2050 (%)	Plant lifetime (years)	Capital replacement (%)	Net annual growth 2030-2050 O (%)	Net annual growth 2030-2050 (TWh/yr)	Long term marginal mix	Long term marginal decrease
Nuclear	-0.10%	60	-3.33%	3.23%	9.02	40%	
Hydropower	-0.74%	100	-1.00%	0.26%	0.14	1%	
Wind, onshore	3.09%	20	-5.00%	8.09%	5.78	25%	
Wind, offshore	25.16%	20	-5.00%	30.16%	4.07	18%	
Conv. natural gas	-5.00%	30	-3.33%	-1.67%			-100%
Solar	0.75%	30	-3.33%	4.09%	3.76	17%	
Total						100%	-100%

Technologies reducing the electricity demand result in a displacement of certain technologies (i.e. coal and fuel oil until 2030 and conventional natural gas from 2031 to 2050). The associated reduction in GHG emissions and fossil energy demand are listed in Tables 7 and 8.

Table 7 GHG intensity (in kg CO₂-eq.) of long-term marginal mixes (increase and decrease in electricity demand)

Generation	GHG intensity	2023 - 2030			2031 - 2050		
		Marginal change	GHG emissions marginal increase	GHG emissions marginal decrease	Marginal change	GHG emissions marginal increase	GHG emissions marginal decrease
Nuclear	0.00703	20%	0.001		40%	0.0028	
Hydropower	0.00499	2%	0.000		1%	0.0000	
Wind, onshore	0.02770	24%	0.007		25%	0.0070	
Wind, offshore	0.01840	7%	0.001		18%	0.0033	
Conv. natural gas	0.47100	2%	0.010		-100%		0.4710
Solar PV	0.03460	45%	0.016		17%	0.0057	
Coal	1.14000	-79%		0.895			
Fuel oil	1.03000	-21%		0.221			
Total			0.035	1.116		0.0189	0.4710

Table 8 Cumulative fossil energy demand (CED_f in MJ) of long-term marginal mixes (increase and decrease in electricity demand).

Generation	CED _f	2023 - 2030			2031 - 2050		
		Marginal change	CED _f marginal increase	CED _f marginal decrease	Marginal change	CED _f marginal increase	CED _f marginal decrease
Nuclear	13.90	20%	2.72		40%	5.50	
Hydropower	0.06	2%	0.00		1%	0.00	
Wind, onshore	0.37	24%	0.09		25%	0.09	
Wind, offshore	0.22	7%	0.02		18%	0.04	
Conv. natural gas	14.10	2%	0.29		-100%		-14.10
Solar PV	1.30	45%	0.58		17%	0.21	
Coal	12.00	-79%		-9.42			
Fuel oil	13.10	-21%		-2.81			
Total			3.70	-12.24		5.85	-14.10

These emission factors of long-term marginal grid mixes were interpolated to get a yearly emission factor for the long-term marginal grid mix (increase in demand) in France, as shown in Figure 4. These yearly emission factors for the grid mix serve as a basis for calculating the savings of technologies increasing the electricity demand (heat pumps and EV charging).

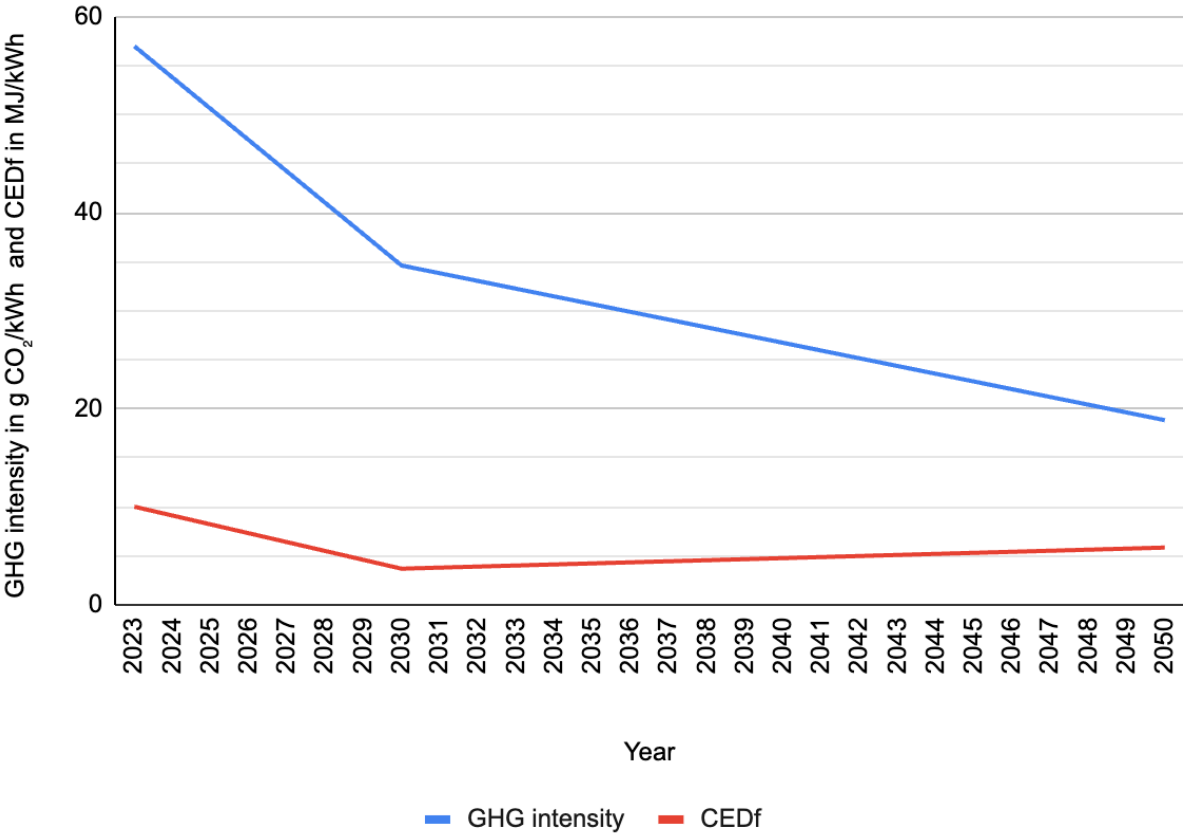


Figure 4 Year-wise marginal grid mix GHG emissions (g CO₂-eq./kWh) and fossil energy demand (MJ/kWh).

3.2. Heat pumps and insulation

Table 9 Net reductions in GHG emissions (in kg CO₂-eq./m²/a) and cumulative fossil energy demand (CED_f, in MJ/m²/a) achieved by switching from existing heating systems to heat pumps, by full renovations, partial insulations and a combination of heat pumps and renovation/insulation.

Year	Heat pump		Full renovation (-70%)		Partial insulation (-40%)		Heat pump + full renovation		Heat pump + partial insulation	
	GHG	CED _f	GHG	CED _f	GHG	CED _f	GHG	CED _f	GHG	CED _f
2023	34.81	969.05	27.97	1272.10	15.94	724.85	38.14	419.66	36.71	1303.15
2024	34.66	929.04	27.68	1190.93	15.77	678.59	37.81	382.22	36.46	1233.02
2025	34.52	889.02	27.39	1109.75	15.61	632.34	37.48	344.77	36.21	1162.88
2026	34.38	849.01	27.10	1028.57	15.44	586.08	37.16	307.33	35.96	1092.75
2027	34.24	808.99	26.82	947.40	15.28	539.83	36.83	269.88	35.71	1022.61
2028	34.10	768.98	26.53	866.22	15.12	493.57	36.50	232.44	35.47	952.48
2029	33.96	728.96	26.24	785.05	14.95	447.32	36.17	194.99	35.22	882.34
2030	33.82	688.94	25.96	703.87	14.79	401.06	35.84	157.55	34.97	812.21
2031	33.78	693.71	25.89	713.54	14.75	406.57	35.76	190.29	34.91	820.56
2032	33.75	698.48	25.81	723.21	14.71	412.08	35.68	223.03	34.85	828.92
2033	33.71	703.24	25.74	732.88	14.67	417.59	35.60	255.77	34.79	837.27
2034	33.68	708.01	25.67	742.55	14.63	423.10	35.52	288.51	34.72	845.63
2035	33.64	712.78	25.60	752.22	14.59	428.61	35.44	321.25	34.66	853.98
2036	33.61	717.54	25.53	761.89	14.55	434.12	35.35	353.99	34.60	862.34
2037	33.57	722.31	25.46	771.56	14.51	439.63	35.27	386.74	34.54	870.69
2038	33.54	727.08	25.39	781.23	14.47	445.14	35.19	419.48	34.48	879.04
2039	33.50	731.84	25.32	790.90	14.43	450.65	35.11	452.22	34.42	887.40
2040	33.47	736.61	25.25	800.57	14.39	456.16	35.03	484.96	34.36	895.75
2041	33.43	741.38	25.18	810.24	14.35	461.67	34.95	517.70	34.30	904.11
2042	33.40	746.14	25.10	819.90	14.30	467.18	34.87	550.44	34.23	912.46
2043	33.36	750.91	25.03	829.57	14.26	472.69	34.79	583.18	34.17	920.82
2044	33.33	755.68	24.96	839.24	14.22	478.20	34.71	615.92	34.11	929.17
2045	33.29	760.44	24.89	848.91	14.18	483.71	34.62	648.66	34.05	937.52
2046	33.26	765.21	24.82	858.58	14.14	489.22	34.54	681.41	33.99	945.88
2047	33.22	769.98	24.75	868.25	14.10	494.73	34.46	714.15	33.93	954.23
2048	33.19	774.74	24.68	877.92	14.06	500.24	34.38	746.89	33.87	962.59
2049	33.15	779.51	24.61	887.59	14.02	505.75	34.30	779.63	33.81	970.94
2050	33.12	784.28	24.54	897.26	13.98	511.26	34.22	812.37	33.74	979.30

3.3. Solar PV

Coal and fuel oil are the only two types of fuels of relevance that decrease in the long term marginal mix until 2030 (Table 6). From 2030 onwards, natural gas will be gradually replaced by other types of energy sources (Table 7). Hence, the addition of residential PV will contribute to these marginal long-term energy mixes in the same manner. Consequently, adding solar PV to the grid will result in

- A net decrease in GHG emissions of 4.9 t CO₂ and fossil energy demand of 77.2 GJ per residential solar PV installation per year between now and 2030.
- A net decrease in GHG emissions of 2.5 t CO₂ and fossil energy demand of 125.6 GJ per installation per year between 2031 and 2050.

3.4. Acceleration and lifetime impact of heat pumps, insulation and solar PV

At present, financing mechanisms and other systemic inefficiencies delay the installation of heat pumps, insulation and solar PV. Eclair offers financial tools that prevent such delays. Table 9 shows the impact of preventing a delay in the installation of heat pumps, installations, heat pumps and insulation, and solar PV.

Table 9 Net reduction in GHG emissions (in t CO₂-eq.) and cumulative fossil energy demand (CED_f in MJ) per installation of accelerating installations by 1 year.

Impact	Unit	Heating	Insulation	Heating + Insulation	Solar PV
GHG	t CO ₂ -eq.	1.75	0.75	1.84	4.91
CED _f	GJ	48.5	35.0	64.2	77.2

Table 10 shows the lifetime net reduction in GHG emissions and fossil energy demand, assuming a lifetime of 20 years and an average size of a residential housing unit of 90 m² as indicated in statistics of the French building stock. The assessment period ends in 2050. Therefore, the considered time span of installations installed less than 20 years before 2050 is lower than 20 years. Their lifetime expands beyond 2050, but this is beyond the temporal scope of this assessment.

Table 10 Net reduction in GHG emissions (in t CO₂-eq.) and cumulative fossil energy demand (CED_f in GJ) per installation achieved over its lifetime.

Year of installation	Heat pump		Full renovation (-70%)		Partial insulation (-40%)		Heat pump + full renovation		Heat pump + partial insulation	
	GHG	CED _f	GHG	CED _f	GHG	CED _f	GHG	CED _f	GHG	CED _f
2023	61	1374	47	1539	27	877	65	608	63	1697
2024	61	1355	47	1500	27	854	64	623	63	1663
2025	61	1339	46	1468	26	836	64	644	63	1636
2026	61	1328	46	1444	26	823	64	671	63	1615
2027	61	1320	46	1429	26	814	64	705	62	1602
2028	60	1317	46	1422	26	810	63	745	62	1596
2029	60	1317	46	1423	26	811	63	791	62	1597
2030	60	1322	46	1432	26	816	63	843	62	1605
2031	60	1330	45	1450	26	826	63	902	62	1620
2032	57	1268	43	1386	25	789	60	885	59	1546
2033	54	1205	41	1320	23	752	57	865	56	1471
2034	51	1142	38	1254	22	715	53	842	52	1396
2035	48	1078	36	1188	21	677	50	816	49	1320
2036	45	1014	34	1120	19	638	47	787	46	1243
2037	42	949	31	1051	18	599	44	755	43	1165
2038	39	884	29	982	17	559	41	721	40	1087
2039	36	819	27	912	15	519	37	683	37	1008
2040	33	753	25	840	14	479	34	642	34	928
2041	30	687	22	768	13	438	31	599	31	848
2042	27	620	20	695	11	396	28	552	28	766
2043	24	553	18	622	10	354	25	502	24	684
2044	21	485	16	547	9	312	22	450	21	601
2045	18	417	13	471	8	269	19	394	18	518
2046	15	349	11	395	6	225	15	336	15	433
2047	12	280	9	318	5	181	12	275	12	348
2048	9	210	7	240	4	137	9	210	9	262
2049	6	141	4	161	3	92	6	143	6	176
2050	3	71	2	81	1	46	3	73	3	88

3.6. Sensitivity analysis

The calculations performed in this report were based on several assumptions. A sensitivity analysis was performed to test the significance of those assumptions and how results differ when they are tweaked.

We assumed that Eclair will install heat pumps with a constant coefficient of performance (COP) of 3, which is in line with air source heat pumps. The COP shows the ratio of useful heating to work required, indicating an efficiency of 300% for the systems. However, as outdoor temperatures fall, the efficiency of an air source heat pump drops as well.

One way to tackle this limitation is by using ground source heat pumps that perform better as outdoor temperatures drop. However, in densely populated areas, ground source heat pumps are very restricted as they could deplete the heat stored in the ground. Therefore, in this sensitivity analysis, the COP of the heat pumps to be installed by Eclair is altered to between 2.5 - 4 (see Energy Transition Model 2023). This analysis takes into consideration that France experiences cold winters with temperatures dropping to -10°C and moderate summers with temperatures reaching 15°C, during the time when the heat pumps are operated. Figure 8 shows the emission savings for each scenario.

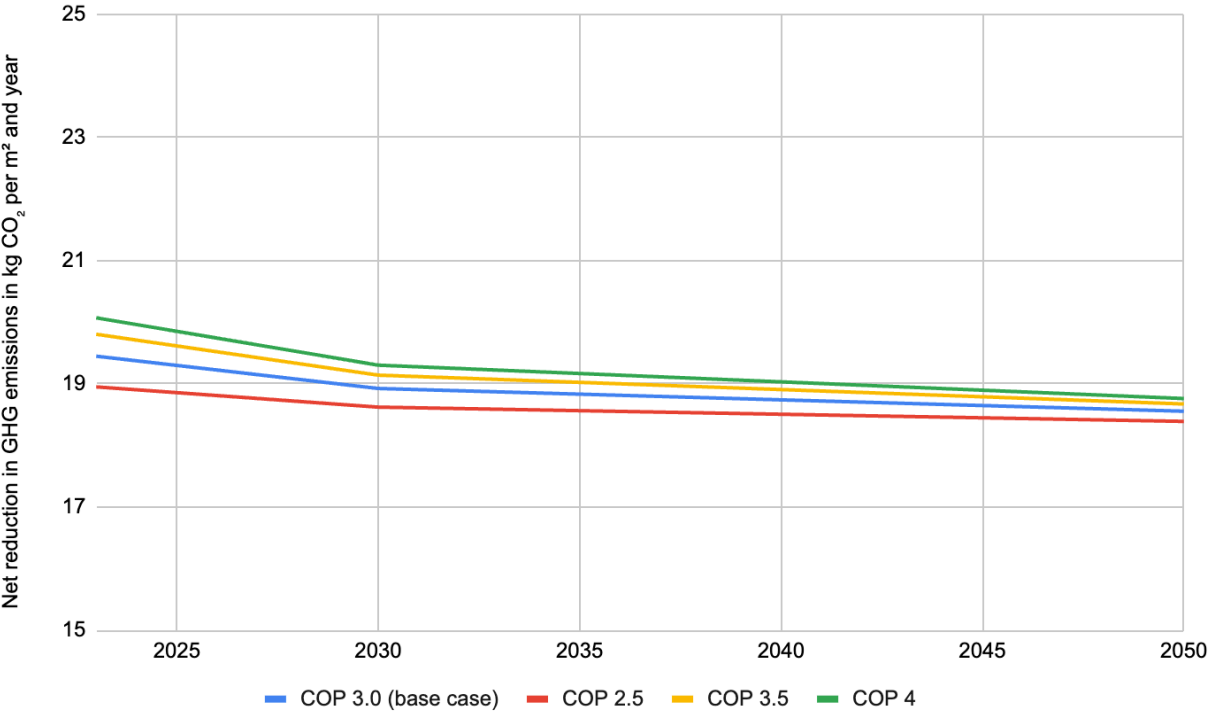


Figure 8 Sensitivity analysis: COP of heat pumps (heating without insulation).

Even at a lower COP of 2.5, the emission savings are still significant over the years. The slight increase in GHG emission savings after 2030 is due to the reduction of nuclear energy compared to current shares, which have low emissions and will be displaced by higher-emitting sources.

3.6. Limitations

There are several limitations in this study that were not addressed but may influence the final results:

- The electricity grid emission intensity was sourced for only three points in time: the present, 2030, and 2050. For the intervening years, a linear interpolation was applied. In reality, emissions are unlikely to evolve linearly, as different energy sources will change at varying rates.
- Insulation savings were calculated using an average thermal conductivity requirement for French households. In practice, customers will choose their preferred insulation type and may opt for less efficient, lower-cost materials.
- We did not assess the impact of insulation on cooling energy demand.
- We assumed the shares of different heating systems in France remain constant over time. In reality, heating systems will gradually electrify, which would reduce energy savings from replacing them with heat pumps.
- The replacement of heating systems was calculated using an adjusted share of “residential heating systems by fuel source” (electricity, oil, gas, biomass). However, Eclair intends to prioritize fossil-based systems such as oil and gas boilers. In that case, emission savings would be higher than those calculated in this report.
- The quality of heat delivered by heat pumps versus other systems was not considered; only the efficiency of the systems was assessed.
- The study accounted for emission savings from installed insulation over a 20-year period; however, insulation typically lasts longer and would continue reducing heating emissions beyond this timeframe.
- Future energy demand was modeled using the most recent studies and projections, but energy policies evolve over time. New policies and innovations may change the technologies used to deliver energy.
- An average COP for heat pumps was assumed across all years. Actual efficiencies vary depending on the heat pump type (GSHP vs. ASHP) and seasonal temperature conditions.
- Technical parameters, fossil energy demand, and GHG intensities of technologies were held constant. Yet significant improvements are expected by 2050—including higher COPs, lower impacts from renewable electricity generation, and reduced impacts from manufacturing appliances and insulation materials. Ignoring these improvements is a conservative assumption: accounting for them would lead to even higher net savings in GHG emissions and fossil energy demand.

4. Conclusion

In conclusion, Eclair has the potential to accelerate the rate of energy renovations in France and will have a significant positive environmental impact. This study found that improving the heating systems and insulation of French dwellings as well as the installation of residential solar PV will result in net reduction in GHG emissions and fossil energy demand. Specifically, heat pumps deliver the largest net reduction in GHG emissions and fossil energy demand if single measures are considered. The combination of heat pumps and a full renovation delivers the highest benefits. On a systemic level, a swift replacement of heating systems or full renovation can be effective measures to reduce GHG emissions from the residential sector, adding both maximises savings.

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