Long term impact of hybrid heat pumps (HHP) on electricity supply security case study with French energy system

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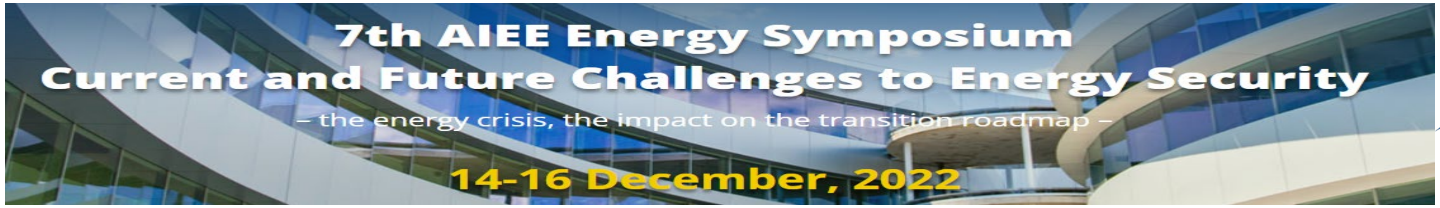
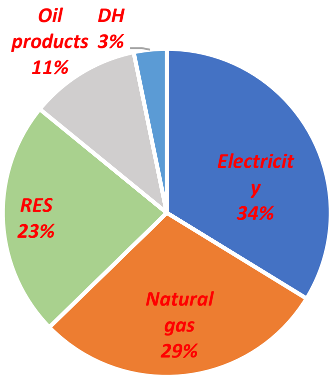


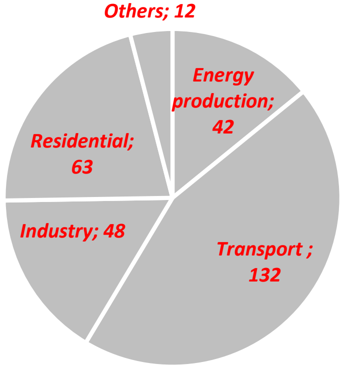
Necessity to decarbonize residential buildings in France and important to consider entire energy system

French commitment to reduce carbon emission of energy usage and aim to achieve carbon neutrality in 2050

Regulatory framework and energy policies in France for carbon mitigation
LTECV: carbon mitigation as a national goal
SNBC: precise emission goal, by 2030 40% of carbon emission reduce compared to 1990 and "zero net emission" by 2050
For residential-tertiary sector: 49% less carbon emission compared to 2015 and ***complete decarbonization*** by 2050
PPE: Detailed guidelines by sector by step of 4 year to achieve mitigation goal, PPE 2019-2023, PPE 2023-2028



residential final energy balance, 2019



2019 GHG emission by sector linked with energy usages, in Mt CO2e

Efforts are required to reduce residential heat emission:
Current emission is 63 $MtCO_2e$,
Around 40% of final energy balance is fossil based

More efficient, low carbon technology is to be invested in future in order to achieve carbon neutrality

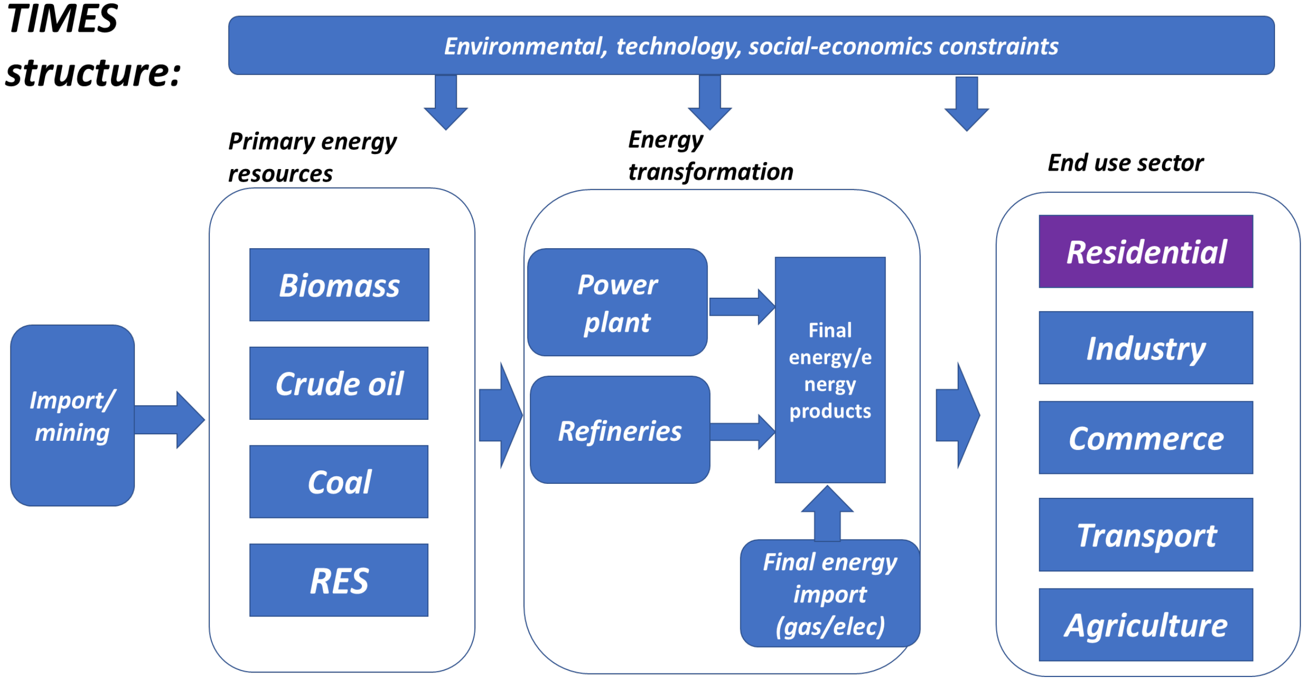
Solar thermal, condensing boilers, thermal insulation, heat pumps

We need also consider distribution of efforts among energy end-use sectors, since:

- *the environmental goal is over emission of all energy system*
- *Limited potential of decarbonized energy sources require optimized investment choice*

Modeling approach to find out optimized solution for energy transition

TIMES structure:



TIMES-FR: 5 end-use sectors, residential, industry, commerce, transport, agriculture

Demand break-out: 22 industrial demand, 14 transport demand, 6 residential demand, 18 tertiary demand, 4 agriculture demand

Residential: *SH for house, SH for apartment, DWH for house, DWH for apartment, cooking, specific electricity usages*

TIMES model:

- Bottom-up model which captures the complexity of energy system from primary energy source to useful energy demand
- Technical-economic optimization with demand-supply equilibrium over a defined time horizon
- Flexible temporal, geographical and sectoral definition, commodity flows (trade) among regions

$$\boldsymbol{min}\,(\boldsymbol{NPV}) = \boldsymbol{min}\left(\sum_{r=1}^{R}\sum_{y \in YEARS}(1 + d_{r,y})^{REFYR-y} * \boldsymbol{ANNCOST}(\boldsymbol{r},\boldsymbol{y})\right)$$

NPV is the Net Present Value of the total cost for all regions over the whole time horizon;

$d_{r,y}$ is the general discount rate;

$REFYR$ is the reference year for discounting;

$YEARS$ is the set of years in which costs are incurred;

R is the set of regions in the scope of the study.

$ANNCOST(r,y)$ is the total annual cost in region r and year y;

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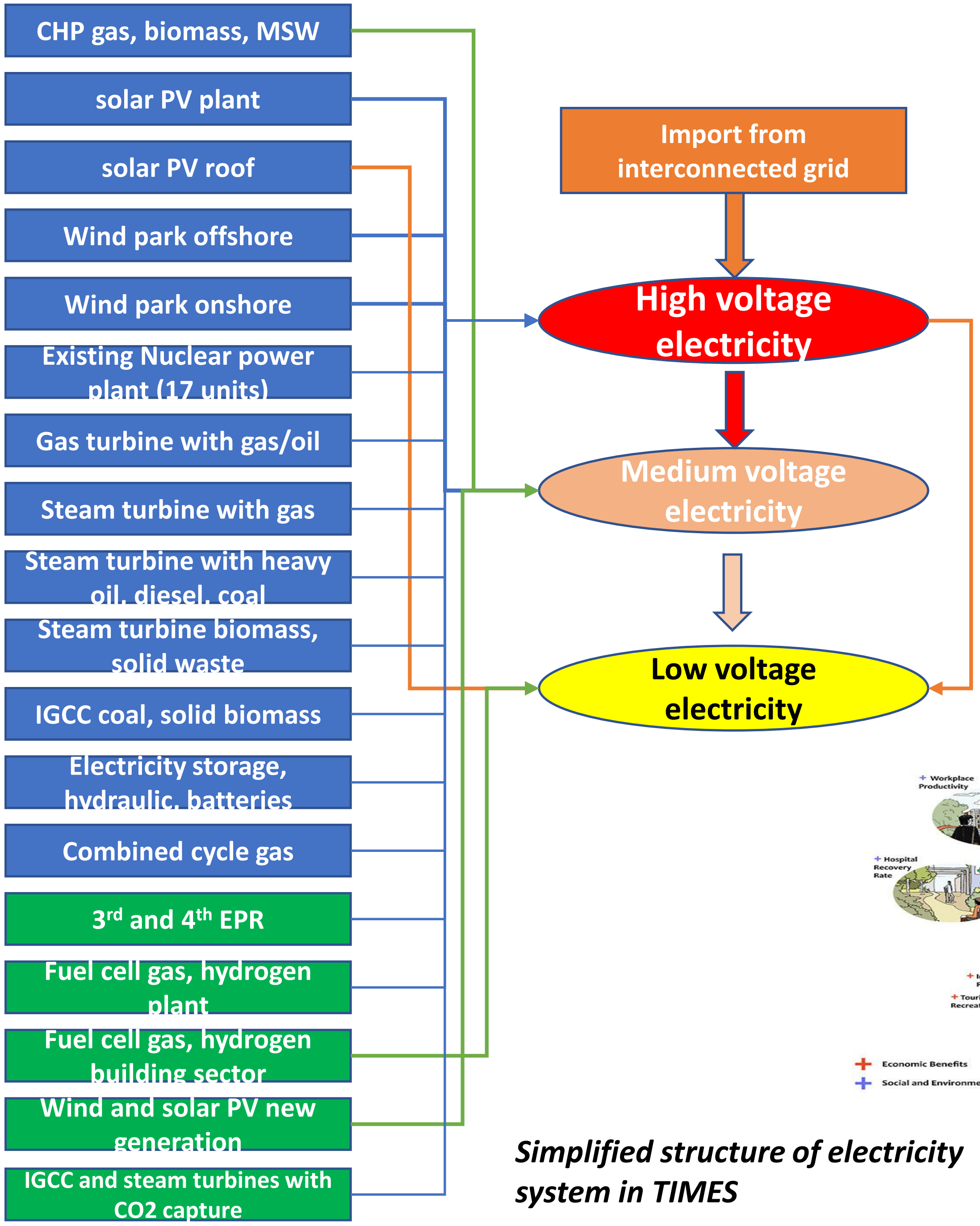


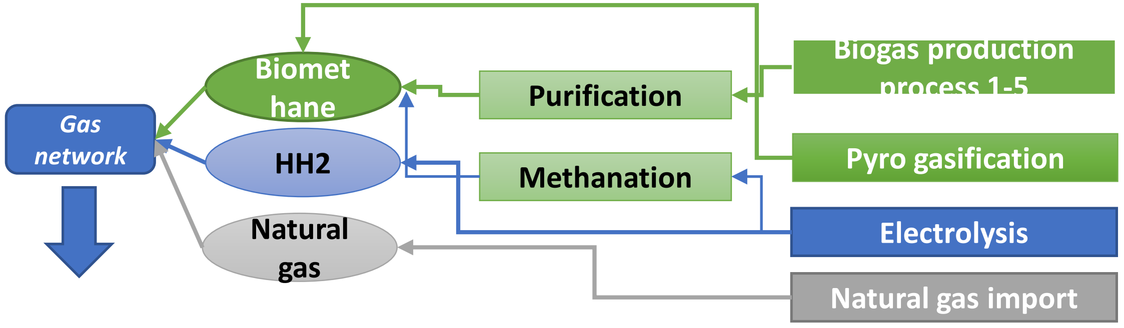
Detailed representation of electricity system in TIMES-FR:

Around 100 types of power plant modelled

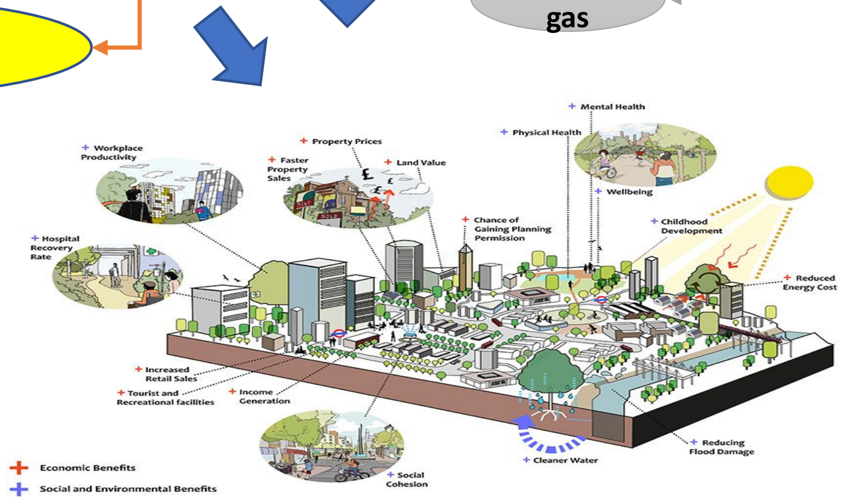
Interpretation of peak electricity production: % of installed capacity contributed to peak, Thermal/nuclear plants, storage >> RES (solar, wind)

Import/export electricity via interconnection modelled

Voltage transformation from high voltage to low for end uses, grid loss at 7%



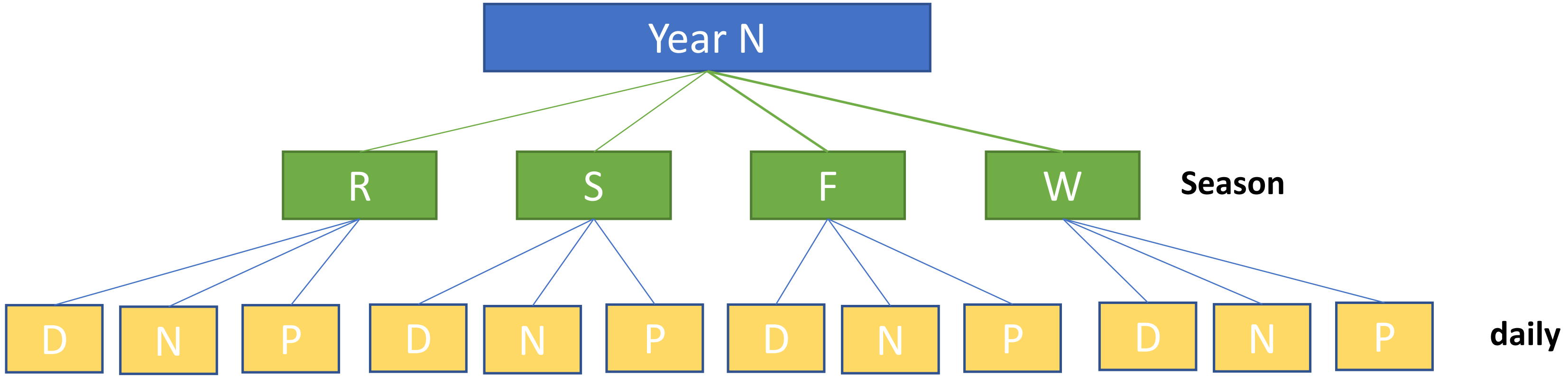
Simplified structure of gas system in TIMES



End uses

Simplified structure of electricity system in TIMES

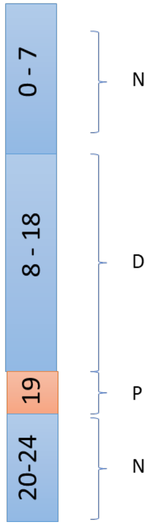
Time slices in TIMES-FR



Seasons	N. of Days	Fraction	DD/MM
R	77	0.211	15/03-31/05
S	91	0.249	01/06-30/08
F	77	0.211	31/08-15/11
W	120	0.329	16/11-14/03
Total	365	1.00	

Time of day	D	N	P	Total
R	55	108	5	168
S	55	108	5	168
F	55	108	5	168
W	55	108	5	168

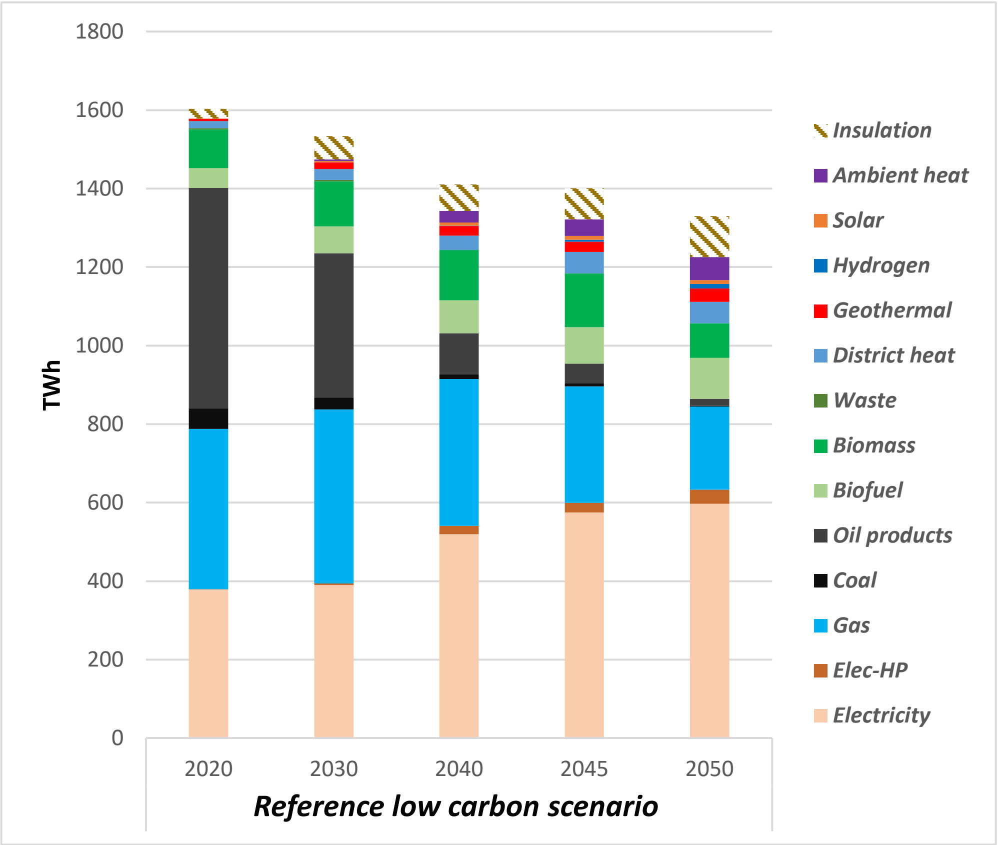
Intra-day breakout



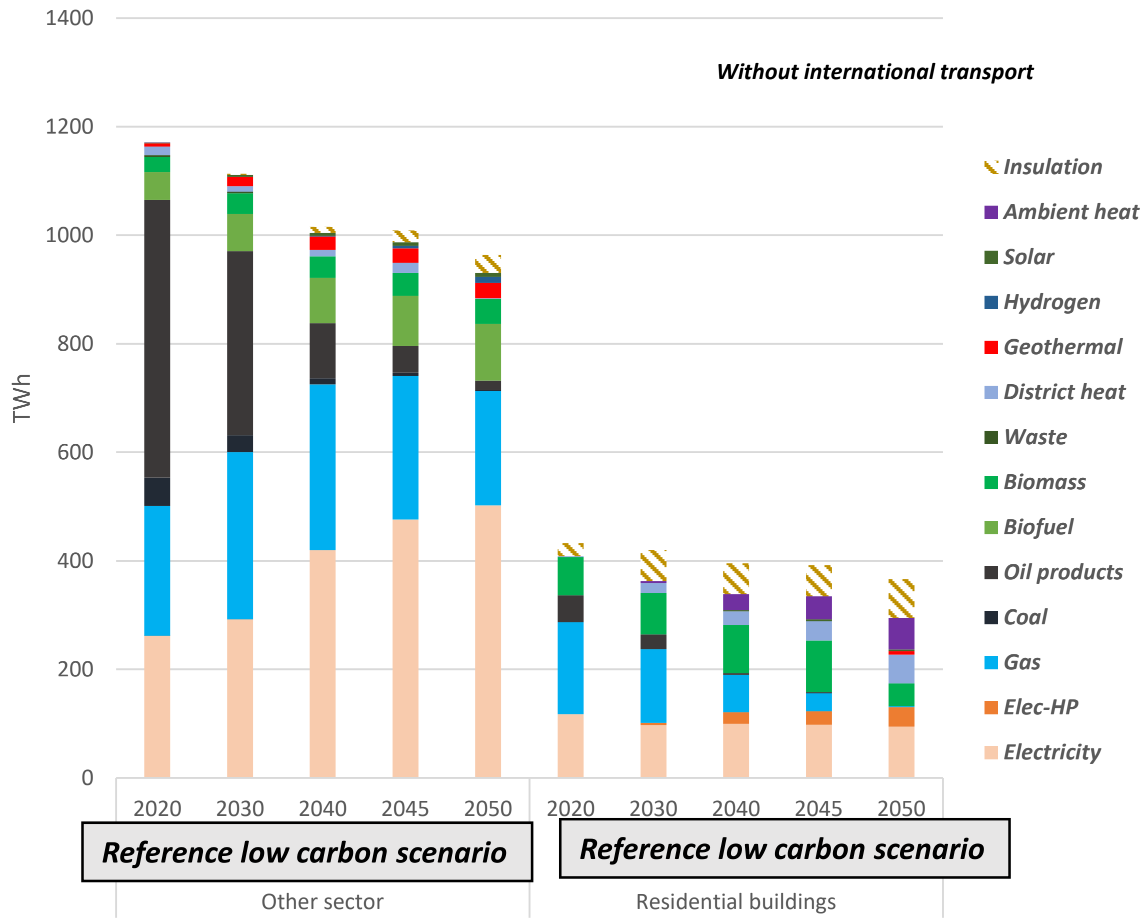
Break-out by 12 time slices seasonal and daily:

- Representation of specific energy supply-demand situation, in particular peak period
- Electricity load curve with 12 period type

Optimized solution under carbon neutrality context



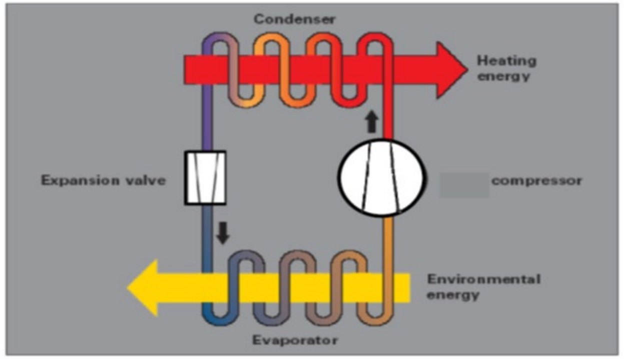
Final energy demand till 2050 for entire system



Observation: gradual electrification to achieve carbon neutrality for all sectors, with efforts from other energy vectors such as geothermal, solar, biogas, etc.
Increase of energy efficiency from thermal insulation is important solution for both residential and tertiary buildings
HPs play an important role in decarbonizing residential energy consumption, 35 TWh of electricity consumed by HPs in 2050

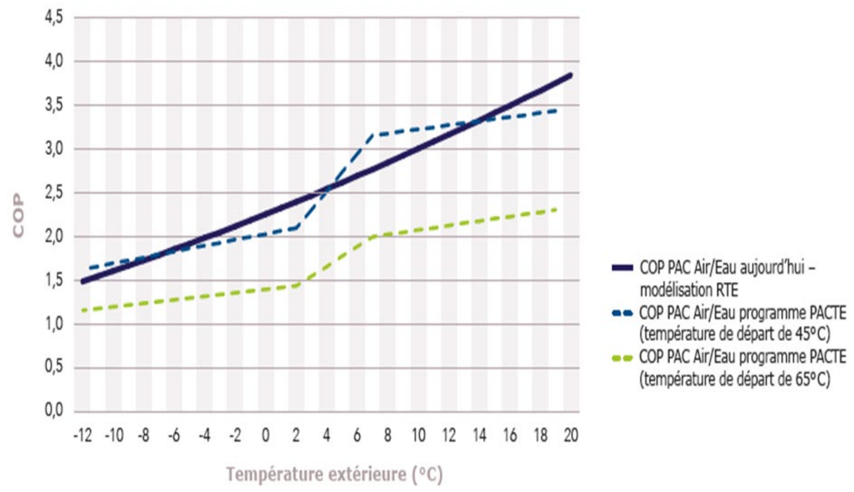
Risk of low energy efficiency of HPs under extreme cold situation

Efficient technology solution: residential heat pumps



Heat pump: extract heat from atmosphere, water or underground structure to provide space heating or DHW for houses
Considerable energy efficiency: the COP can reach to 3-4
Important role in France energy policies (SNBC, PPE): planning to reach to 2.2 millions of air sourced HP in 2028, around 3 times of 2017 level

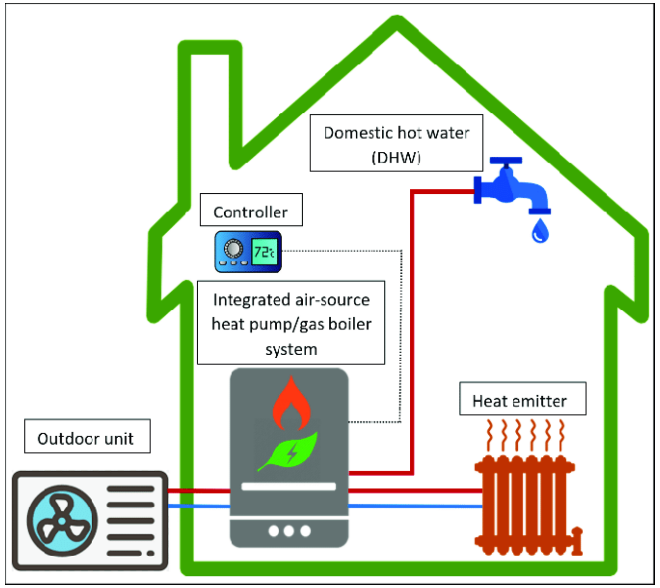
Figure 2.17 Évolution du COP en fonction de la température – PAC air-eau actuelle



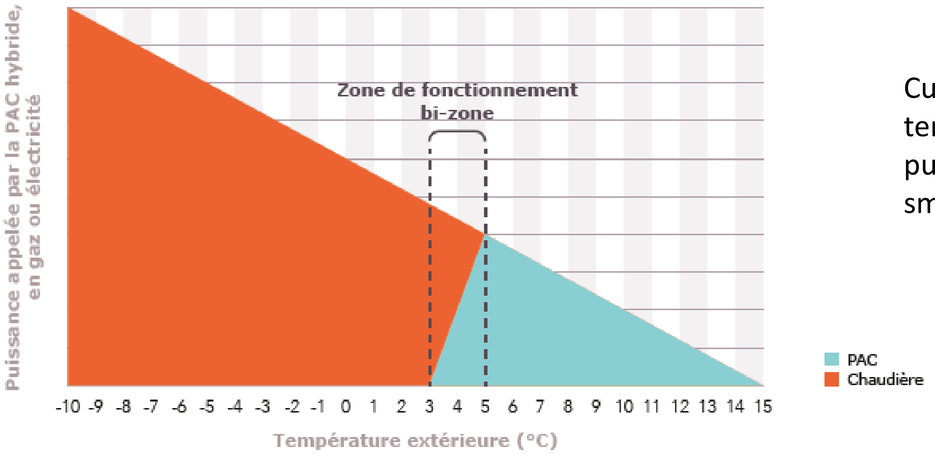
Shortage: the energy efficiency (COP) of heat pumps depends highly on outside temperature conditions. For extreme cold periods (outside temperature below 0 °C), the COP significantly reduces.
The performance is much lower when higher outlet water temperature is required

Consequence for electricity system:
HPs can generate very high electricity demand during peak period
In case of massive integration:
capacity of current electricity grid might not be sufficient for massive integration of HPs in building sector ➔ supply risk
Gird expansion for only peak demand ➔ risk of overinvestment for long term
Need to consider as well extreme cold situation!

Hybrid Heat pump as alternative solution to conventional HPs



A hybrid heat pump is composed by a smaller HP and a condensing gas boiler
Compared with standalone HP: switch to gas mode during extreme cold period
effects:
- Beneficial for energy system, guarantee of energy security
- For long-term, reducing peak power call so that massive grid expansion might not be required
- Improvement of overall energy efficiency
- Economic for households: possible to switch energy source according to price signal



Source: RTE/ADEME

Current situation: the major market tendency is on standalone HPs, hybrid heat pump is matured technology but with very small market share

Research question: the long-term impact of HPs and HHPs on electricity supply system in France
Specific question: the future investment choice concerning HPs and HHPs by French energy system on a carbon neutrality context
Effects of HHP on peak electricity power call, under an extreme cold situation for the future
The role of HP and HHPs in residential energy transition

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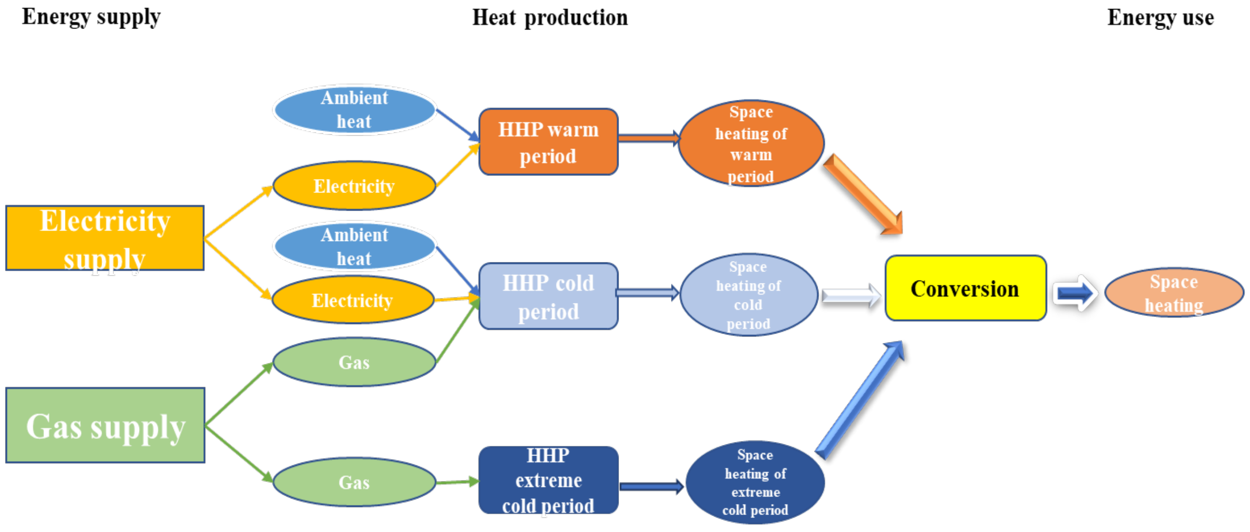
Improved modeling structure

- *Step One: Detailed presentation of different types of HPs in TIMES-FR*
- *Step Two: Interpretation of extreme cold period*

Step One: Detailed presentation of different types of HPs in TIMES-FR



5 types of HPs presented: air-sourced normal + advance, HHP normal + advanced, ground sourced HP
Interpreting variation of energy performance and operating mode across 3 temperature range: warm, cold and extreme cold
Significant difference in HP performance across three periods, especially air-sourced HPs
HHP use only gas boiler when temperature below 0, mix mode for cold period, and only HP during warm period
Improve of HP performance from 2035 (linked with technology progress)

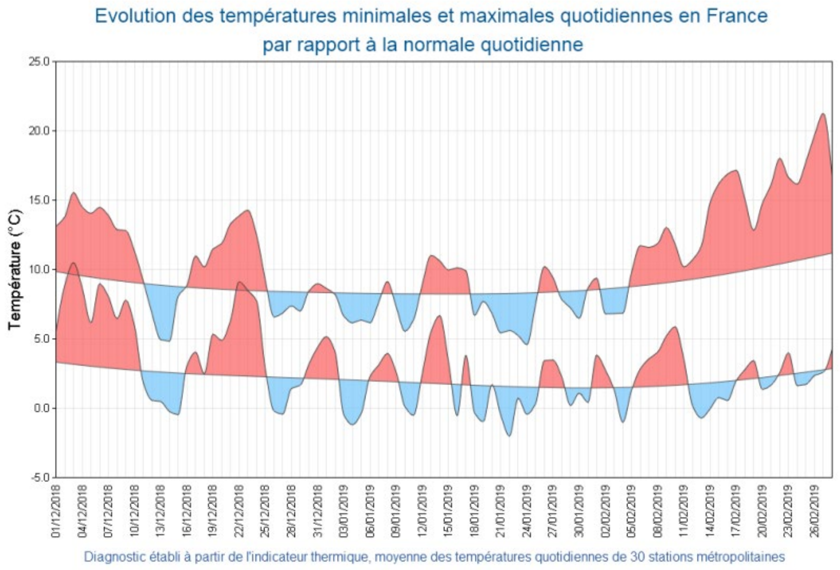
Tech type	Period	COP (W45) observed value current	Value taken in model	COP hypothesis 2035	Value taken scenario 2035	Operating mode (HHP)
Air-sourced HHP air to air	Warm (3°C)	2.0-2.9	2.45	2.7-3.8	3.25	HP alone
	Cold (0°C - 3°C)	1.9-2.0	1.95	2.5-2.7	2.6	HP 50%, gas boiler 50%
	Extreme cold (-0°C)	1.3-1.9	1.6	1.7-2.5	2.1	Gas boiler 100%
Air-sourced HHP advanced (air to water)	Warm	2.25-3.5	2.875	3.2-5	4.1	HP alone
	Cold	2-2.25	2.125	2.9-3.2	3.05	HP 50%, gas boiler 50%
	Extreme cold	1.7-2	1.85	2-2.9	2.45	Gas boiler 100%
Air-sourced HP air to air	Warm	2.0-2.9	2.45	2.7-3.8	3.25	
	Cold	1.9-2.0	1.95	2.5-2.7	2.6	
	Extreme cold	1.3-1.9	1.6	1.7-2.5	2.1	
Air-sourced HP advanced air to water	Warm	2.25-3.5	2.875	3.2-5	4.1	
	Cold	2-2.25	2.125	2.9-3.2	3.05	
	Extreme cold	1.7-2	1.85	2-2.9	2.45	
Ground-sourced HP	Warm		4.35			
	Cold		3.5			
	Extreme cold		2.65			

Source: RTE/ADEME

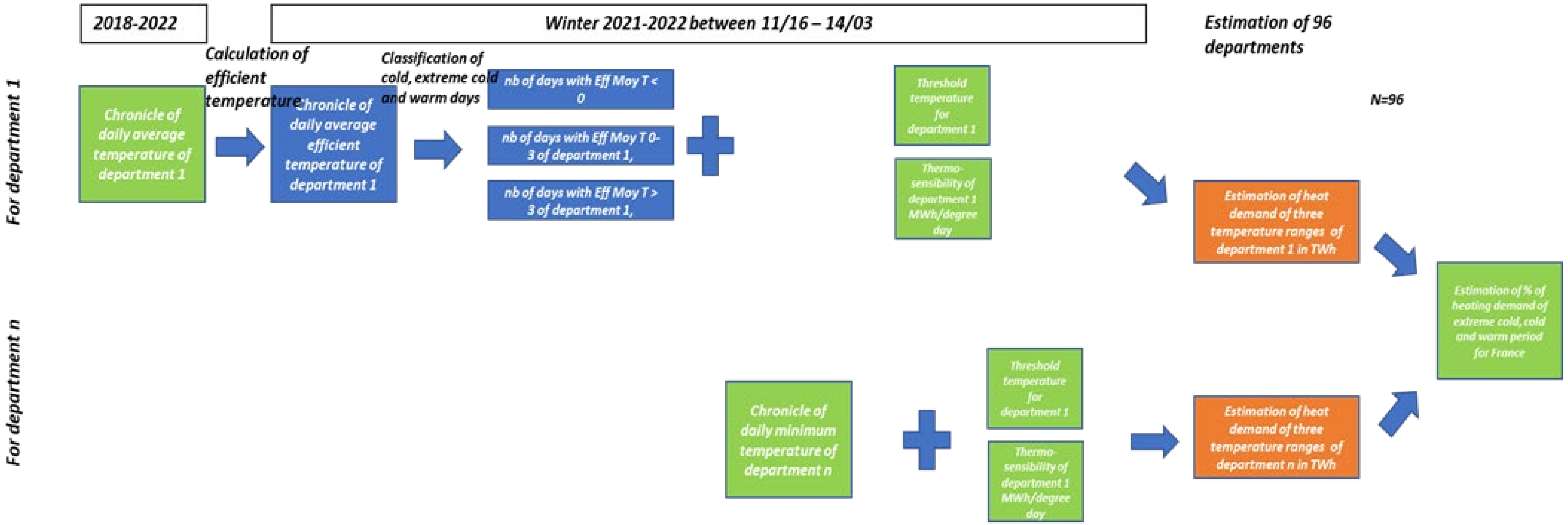
Step Two: define the extreme cold period in the model

This can be translated by % of heat demand from warm, cold and extreme cold period for all time slices

Climate reference: situation of 2018/2019 winter, several consecutive cold wave in January



Statistical processing to obtain weight of heat demand over three periods: chronicle of daily efficient average temperature + thermal sensibility data on department level



Method to estimate the weight of heat demand through three periods

Efficient temperature (ET):

Teff(J) = 0,64 T(J) + 0,24 T(J-1) + 0,12 T(J-2)

Efficient temperature of day N is related with the temperature level of N-1 and N-2, and it allows to consider the building thermal inertia when estimating demand profile

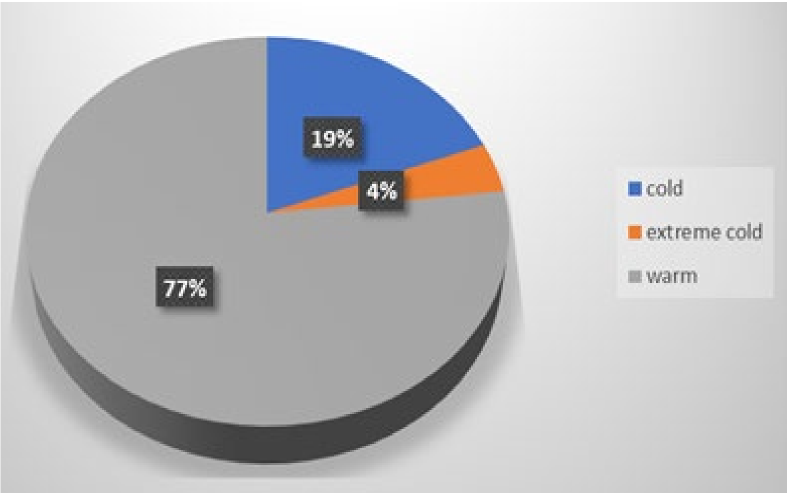
Thermal sensibility: MWh/degree day, threshold temperature 18 °C

Daily departmental heat demand: thermal sensibility * diff(threshold temperature, average ET)

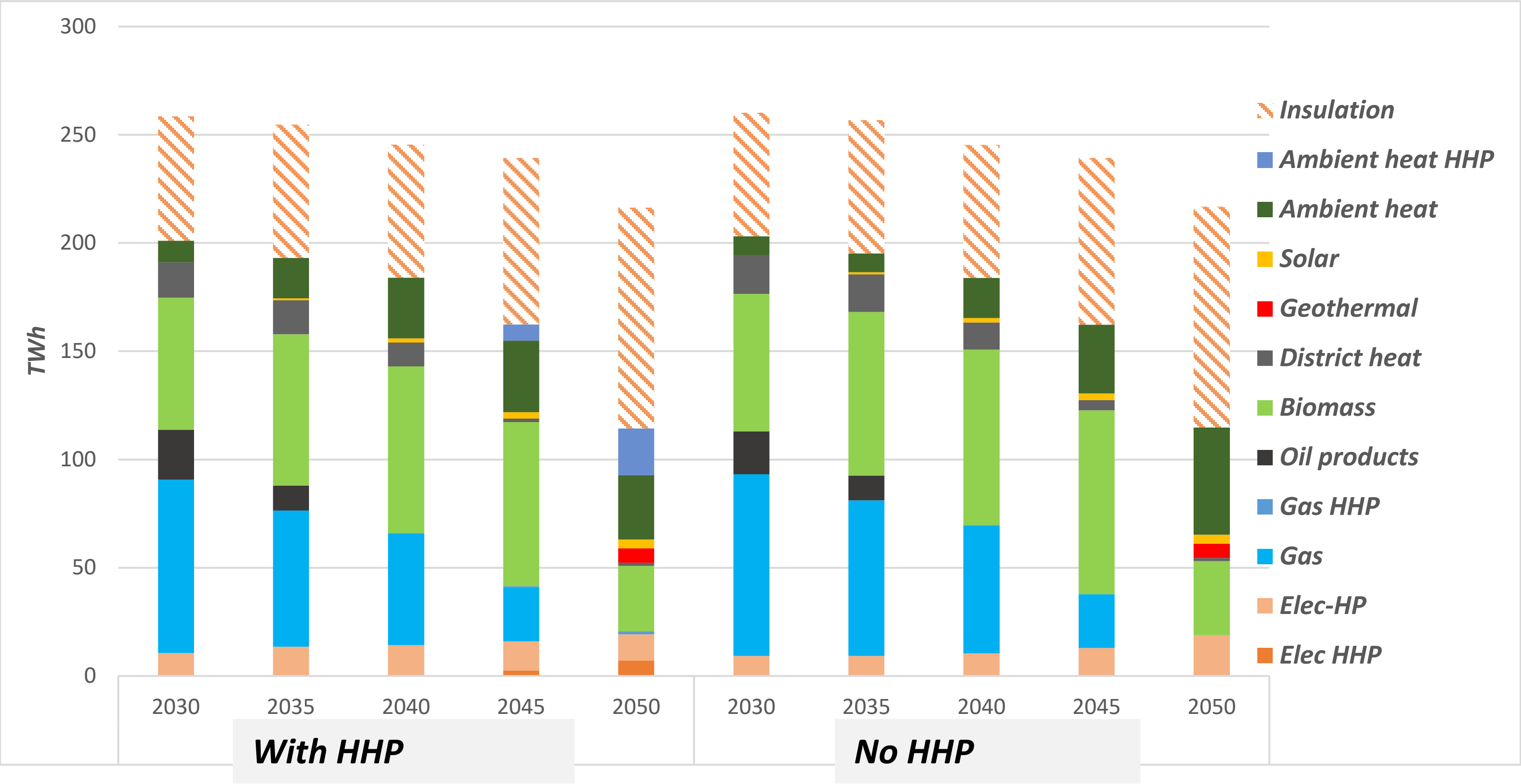
French situation = addition of 95 departments (Metropolitan France except Corse)

Scenario approach: distribution of heat demand and possibility to invest in HHP

Break-out of heat demand on National level, from statistical analysis

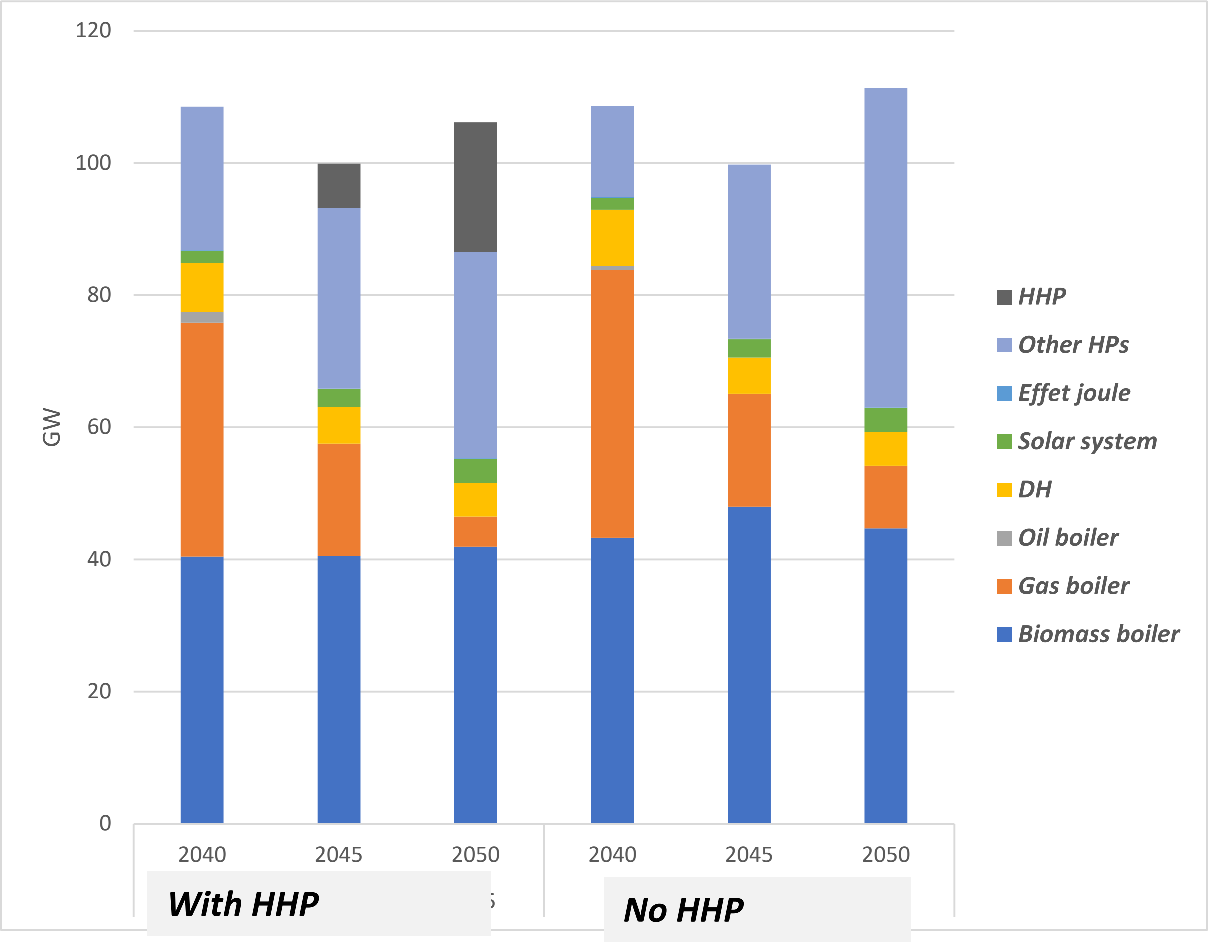


Comparison:
More relevant to install HHPs and HPs vs only HPs in the future



Residential final energy demand for space heating:
Considerable part of heat is produced by HPs in both cases.
With possibility to invest in HHP, 13 TWh electricity consumption by HHP, allowing for usage of 40 TWh of ambient heat.
Thermal insulation can reduce 50% of final energy demand for space heating in both cases

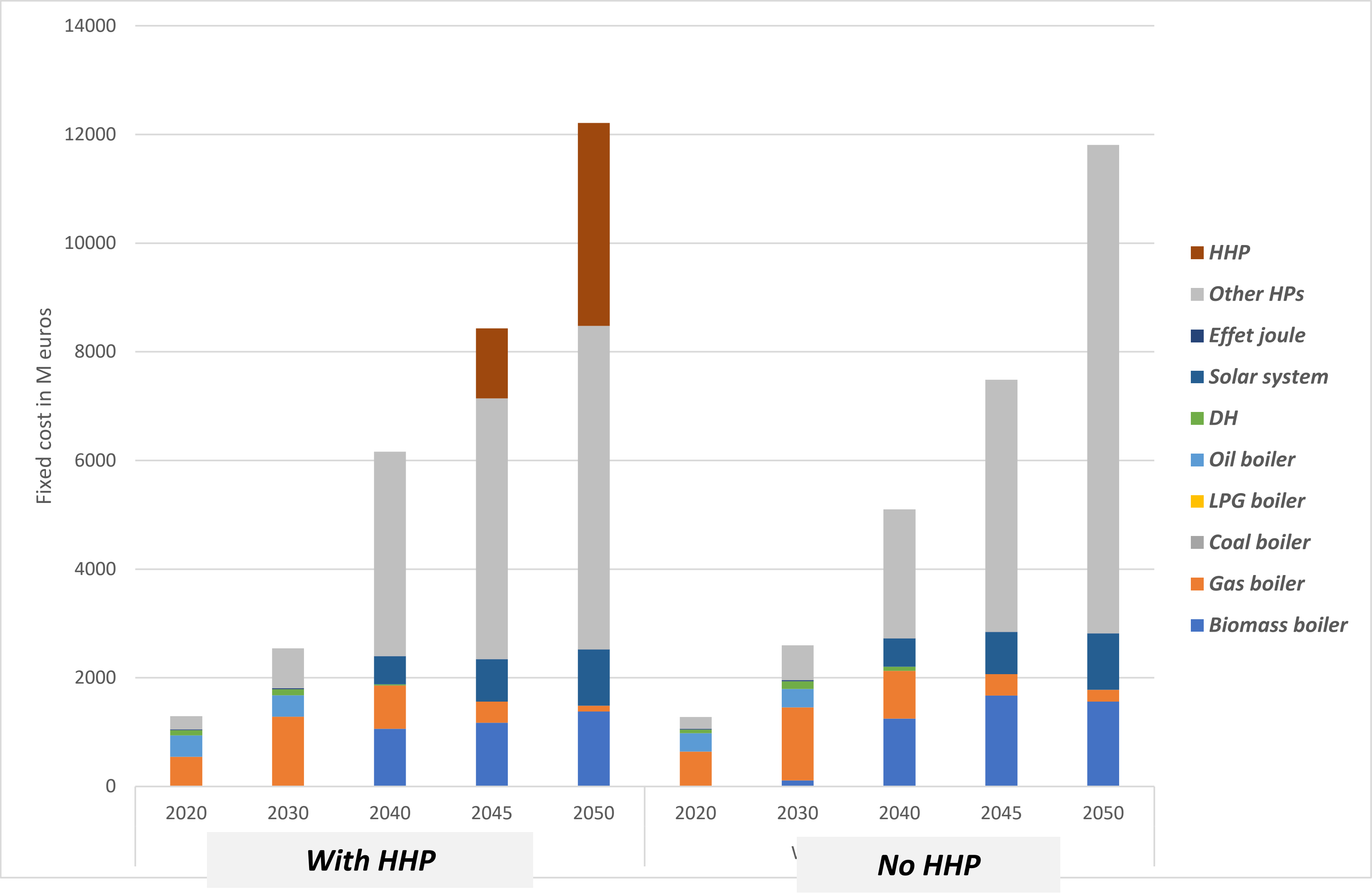
Preliminary results



Installed capacity of space heating equipment for residential buildings without insulation

2050 Situation:

- Case with possibility to install HHP: 20 GW of HHP in 2050, equivalent to around 2-3 million of households, overall HP capacity more than 50 GW
- Without HHP possibility, residential system continue to invest in standalone HPs of geothermal and air source
- Total capacity required for space heating is around 108 GW in case with HHP investment, slightly lower than only HP case (3GW less), less gas boiler remained in stock (5GW less)



Keynote:
From 2040, annual fixed cost for space heating equipment higher with HHP installation than case without

Annual fixed cost for heating equipment (Inv + fixed OM), without investment in thermal efficiency

Preliminary results

Conclusion

- Heat pump plays an important role for decarbonizing residential energy mix.

Under carbon neutrality context, around 60 TWh of ambient heat and 40 TWh of electricity consumption of HPs presented in residential energy mix of 2050

- Accounting for efficiency losses in case of cold to extreme cold situation is important to design resilient systems
- The proposed methodology enables an integration of heat demand for different temperature ranges (warm, cold, extreme cold periods) in a systemic long term planning model

The system choose to invest important capacity of hybrid heat pump since 2040, and in 2050, the residential buildings will install 20 GW of HHP, equivalent to 2-3 million of housings.

- As the CO_2 ambitions becomes more stringent integration, there is less gas boilers and more HHP in residential becomes more relevant to reduce the effect of lower heat pump efficiency.
- *Integration of HHP in residential system may reduce required equipment capacity for heating, and less gas boiler is required in 2050. However, this increases investment cost of residential heating system*

Future extensions to improve the modeling framework:

- Include more behavior inertia (contrast between fully optimized and partial persistence of investments in alternative solutions)
- Insulation deployment rate (here the observed barriers for effective insulation are omitted)
- Comparison with visions from institutional stakeholders (published sectoral visions, interviews)

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Thank you!