Accounting for socio-technical nodes in future sustainable heat strategies for French residential buildings

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The residential sector is one of the largest energy consuming sectors in France, accounting for 28% of the final energy demand in 2018 (Ministry of Ecological and Solidarity Transition, 2020a). In terms of carbon emissions, residential buildings account for around 12% of the total emission 405 MtCO2e in 2018 (Ministry of Ecological and Solidarity Transition, 2020c) due to the predominant use of fossil fuels to supply households' space heating, water heating and cooking needs. Hence an effective decarbonization of the residential heat supply system has been identified as a pillar of the recent update of the French carbon neutrality strategy (SNBC) for 2050. This strategy calls for a 40% reduction of GHG emission compared to 1990 by 2030 and a net zero emission target by 2050 (Ministry of Ecological and Solidarity Transition, 2020b).

Facing with this environmental challenge, a rapid roll-out of technical solutions to improve energy efficiency has been promoted in both demand and supply side of the residential heat sector. On the demand side, this could be done by improving buildings' thermal performance (renovation or setting up higher standards for new constructions). The part of heat provided by passive solar energy or internal heat load can be more important if the envelops are more smartly designed. (CSTB, 2015; Ministry of Ecological and Solidarity Transition, 2020d). On the supply side, it is vital to use less carbon-intensive sources. Several competing options have been proposed, for example replacing traditional boilers by efficient gas boilers or gas fueled heat pumps associated with higher shares of renewables biogas in the gas network, a large-scaled development of district heating to promote the use of solid biomass, increased electrification by individual heating pumps, and hydrogen.

However, statistic studies indicated that building characteristics (surface area to be heated, primary energy sources of heating system, thermal envelops related to the construction period, etc.) explain about more than half of the variation of building's energy consumption (CSTB, 2015a; Ministry of the Environment Energy and the Sea, 2017; ONPE, 2020). This means that while a technology roll-out is needed, the socioeconomic dimension which better reflects human-centered drivers must also be accounting for***.*** Socio-economic characteristics of household, such as household composition, revenue, occupations are proven to have a direct impact on energy consumption through their consumption behaviors and an indirect impact through their housing choice, thus the thermal characteristics of their dwelling (Gram-Hanssen, 2013; Hansen, 2016).

This paper proposes to implement socioeconomic related constraints in a technology optimization model to assess the impact of a better accounting of household's characteristics in a transition to a carbon neutral heat system.

By integrating socio-economic aspects in optimal technology portfolio analysis, we believe that this paper will help identify specific socio-technological nodes and make recommendations for the optimal distribution of efforts, such as the share of investment/financial support and technical solutions for each socio-economic group.

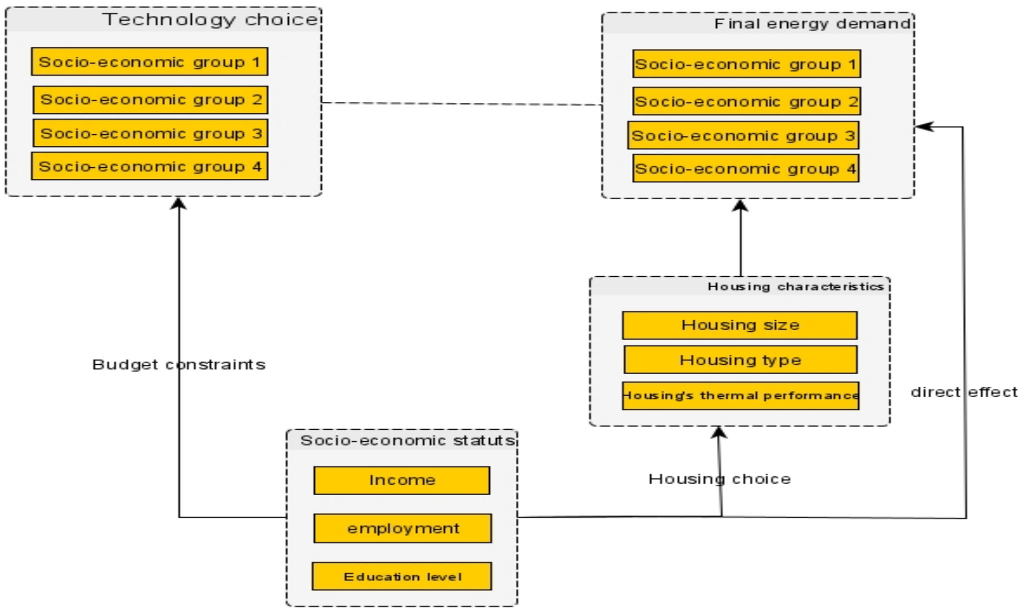

Figure 1 Path diagram of causality structure

Above diagram represents the direct and indirect effect of household's socio-economic characteristics on final energy demand and its impact on technology choice. Reviewed papers indicate that household income, employment status, and education level of the household are among the most decisive socio-economic factors to household energy consumption level. According to statistic evidences, Income seems to have a more complex impact on energy demand than a simple correlation due to its effect on housing characteristics (Estiri, 2015; Hansen, 2016; Santamouris et al., 2007).

The influence of consumption patterns of a household on its final energy demand level can be illustrated by the ratio between the theoretical energy bills estimated from DPE[1] label and the real one that they paid. Comparing theoretical consumptions and real consumption data, an analysis for France (CSTB, 2015a). showed that the average French households consume up to 40% less energy than what a theoretical building model shows. This ratio is more important for modest families who live in low energy performance housings.

[1] Which designates energy performance level of buildings, range from A to G, A is the best level for buildings consuming less than 50 kWh of primary energy per meter square and G for those who consume more than 450 kWh.

An example of indirect effect can be provided by the employment status which indirectly impacts household energy consumption through occupancy time of housing decided by the nature of professional practice (Estiri, 2015; Yu et al., 2011). And education level seems to closely link with household energy saving behaviors (Sweeney et al., 2013; Zhao et al., 2019). It is also proven that household's socio-demographic characteristics, especially household size and composition, are directly related to residential heat consumption level (Guerra Santin et al., 2009).

The optimal technology pathway up to 2070 is then computed for each socio-economic group using a bottom-up prospective model of the French residential heat sector. To characterize this pathway, we use a TIMES modelling approach which first describes the energy system as a linear system of all available options and then computes an optimal topology by minimizing the total discount cost of the system. The interaction of the socio-economic step with the technology roll-out in the residential heat sector can be described as in figure 2.

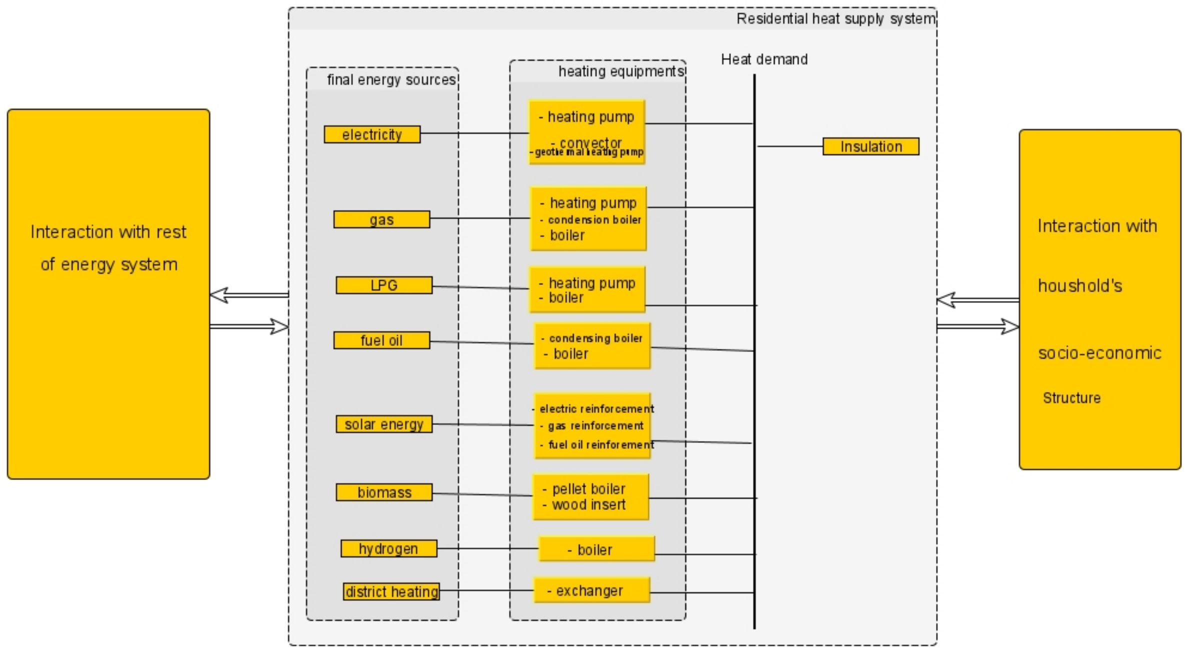

Figure 2 model structure for socio-economic group X

The residential heat sector module optimizes the heat supply and insulation technologies for each household group. It interacts with the socio-economic layer and the rest of the energy system. In our proposed model, socio-economic features impact the heat supply system via the population in each category, the evolution of the useful heat demand and the budget constraints for each group. This can indirectly influence the available tech portfolio as collective housings and small flats will for instance be less likely to use ground heat pumps.

The interaction with the rest of the energy system is twofold. On one side we need to consider the availability of primary energy resources, the expansion of the power system and the expansion of the gas supply system with renewable gas or power to gas routes. On the other side, when a global CO2 mitigation target is considered, the effort in the residential sector will depend on the effort in the rest of the system.

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