Modelling of Residential Hybrid Renewable Energy System

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Introduction

The development and investment in Low Carbon Technologies (LCT's) has seen a rise in the last years due to the shift in attention towards climate change and sustainability.

It is important to guarantee that these technologies are not only environmentally viable but also economically viable as a way of incentivising Danish families and households to invest in them.

It was with this in mind that we have, through different mathematical models in GAMS, using various taxation and LCT's, evaluated the most profitable situation for different households that fulfills both heat and electricity demands.

Objectives

The main objectives of this project were:

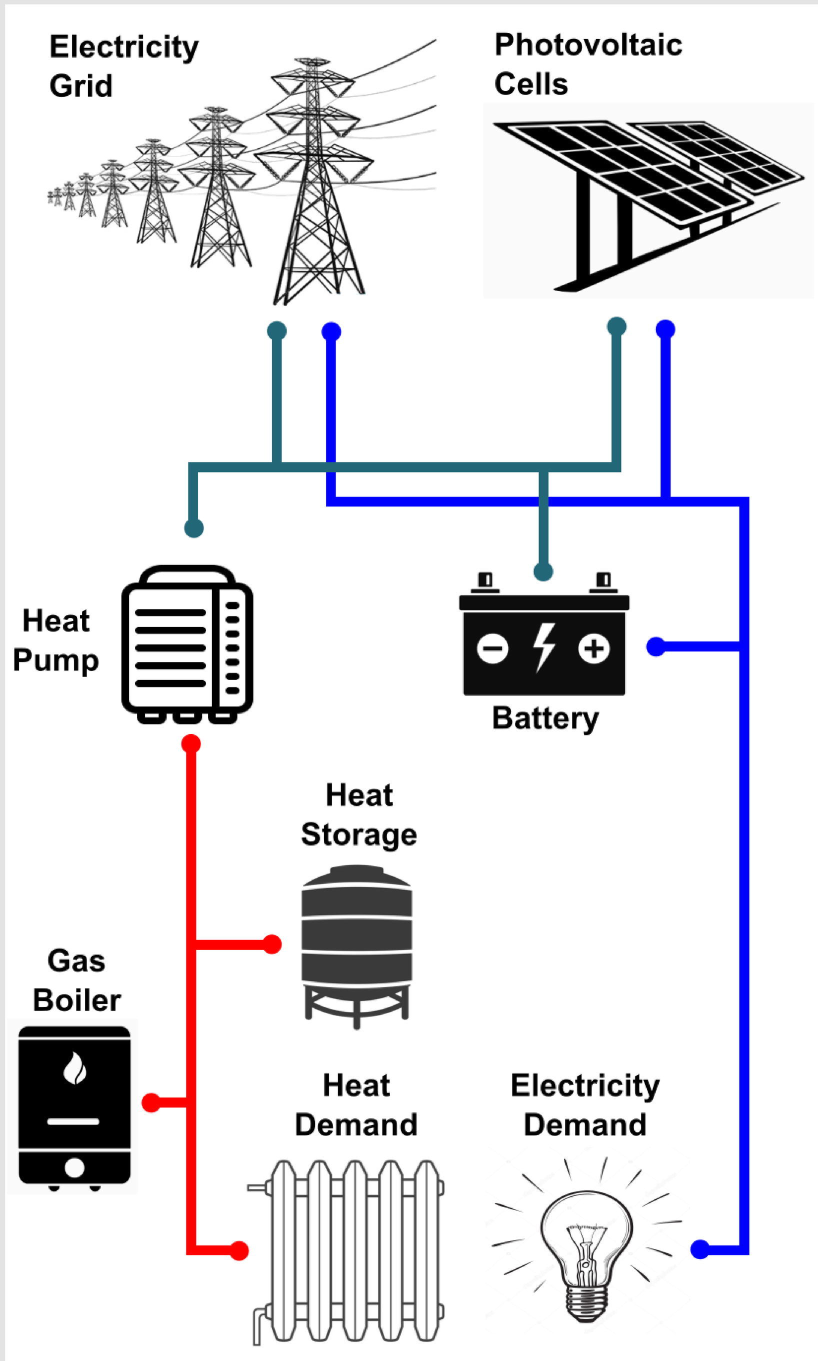
- Formulating a basic model and implementing it on GAMS that calculates the energy costs (heat and electricity) using only the grid and a gas boiler;
- Formulating and implementing an optimal model that considers different low carbon technologies and determines the best energy system layout;
- Applying the two models to 4 different representative Danish households;
- Reflecting on the social and economical implications of the models results for different households;
- Comparing the 2 models and analyzing how they react to changes in the parameters such as tax variations.

Methodology

Two models have been developed:

- A basic model – includes only the possibility of getting electricity through the grid and heat through a gas boiler;
- An optimized model – finds the best capacity combination of 6 different options:
  1. Grid;
  2. Gas Boiler;
  3. Heat Pump;
  4. Photovoltaic Cells;
  5. Battery;
  6. Heat Storage;

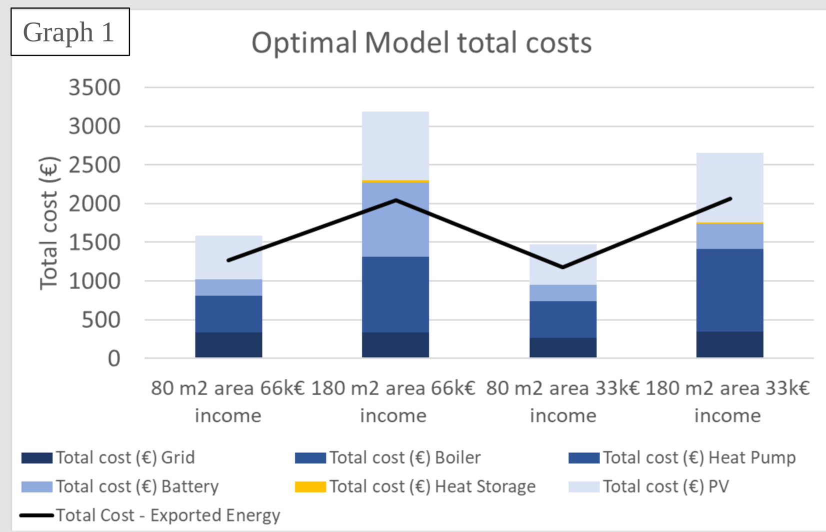
The optimized model also allows for energy exportation at the time varying spot price.
The system configuration for the optimized model is schematized in following figure.

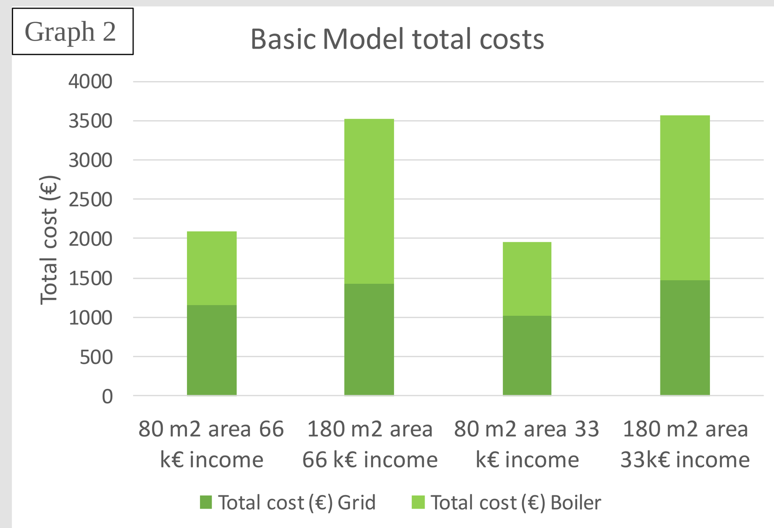


These 2 models were compared in the simple case with realistic Danish taxes, tariffs, network costs and capital costs and for a scenario in which the electrical consumption taxes are greatly increased and decreased in 10% intervals. The optimized model was further inspected for the electrical consumption tax change scenario, namely the capacity investment for different technologies was analyzed.

Discussion

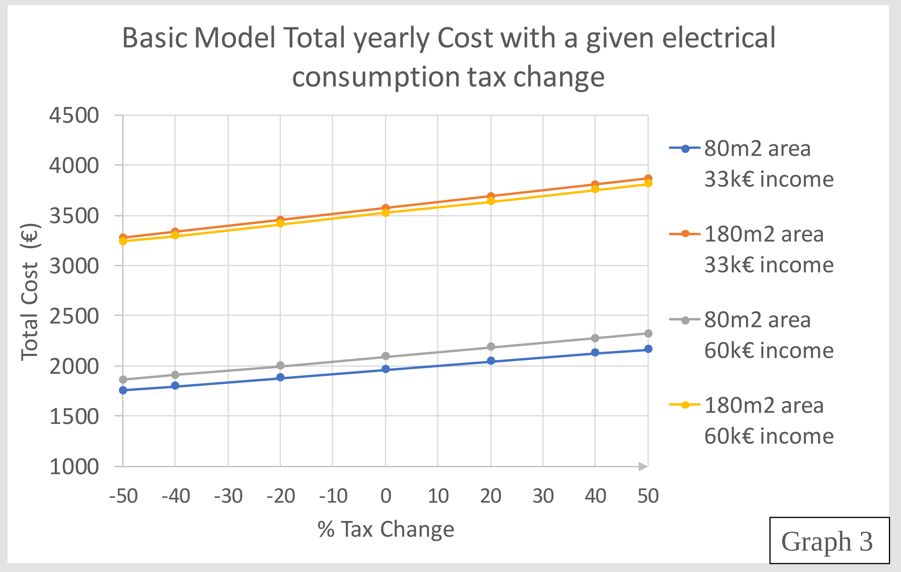
- The Optimal model can develop energy system layouts which allow for a reduction in costs of about 40%.
- The Optimal model invests in all LCT's for the households with the biggest heat and electricity demands.
- In general, the heat pump is preferred over the boiler.
- The Optimal model highly invests on solar energy.
- CO_2 emissions were not considered but the optimal model would likely have lower carbon emissions.

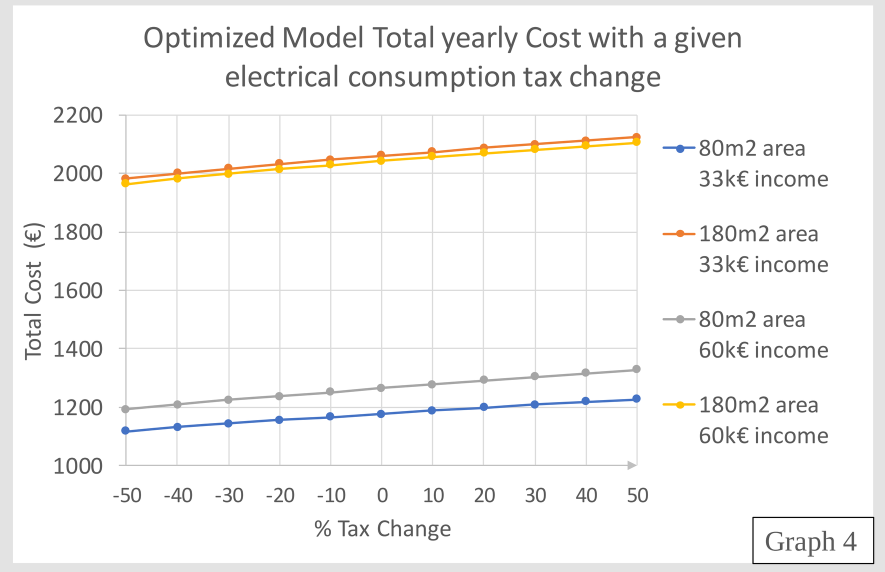




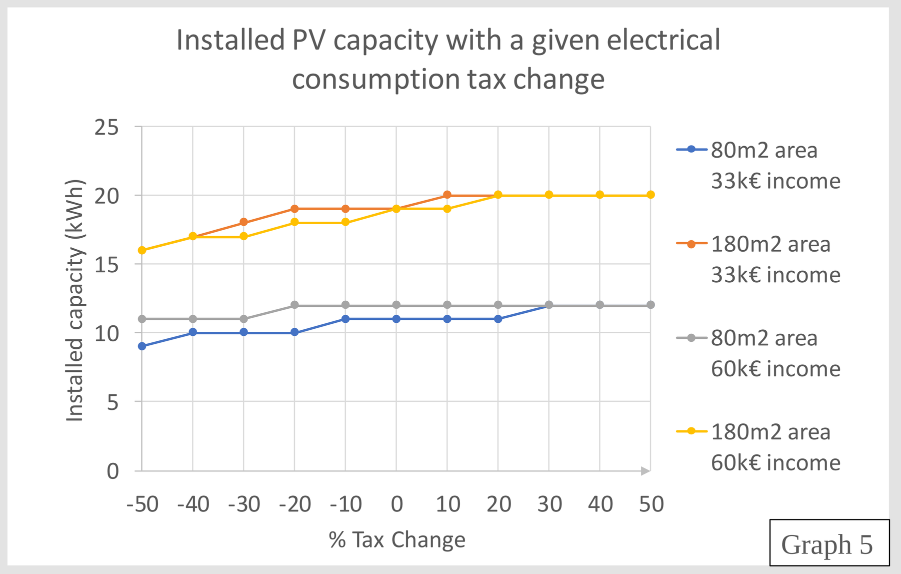
Household	Optimal Model					Basic Model	Cost Savings (%)
	Boiler	Heat Pump	Battery	Heat Storage	PV	Boiler	
80 m2 area 60k€ income	1	1	4	0	12	2	39
180 m2 area 33k€ income	1	3	6	2	19	4	42
80 m2 area 33k€ income	1	1	4	0	11	2	40
180 m2 area 60k€ income	1	2	6	2	19	4	42

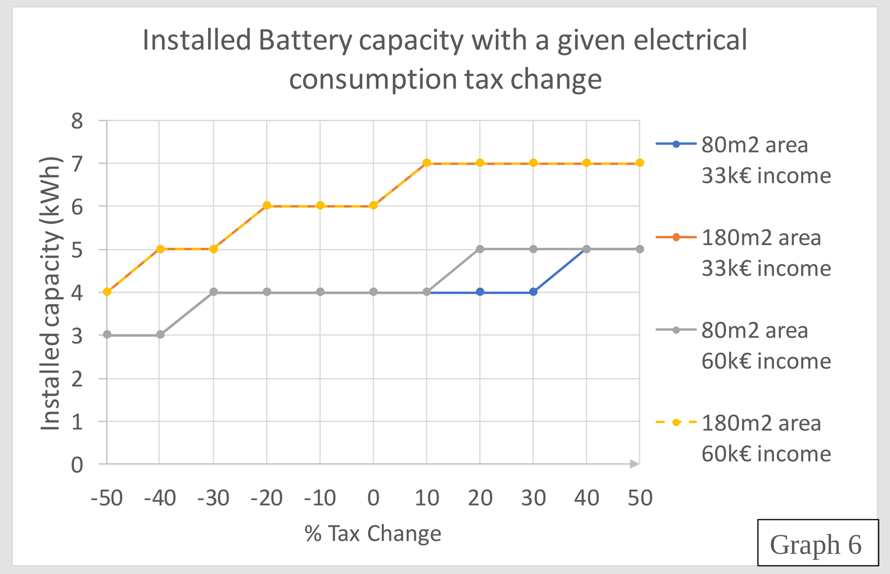
From graphs 3 and 4 it is easily seen that for the optimized model a change in taxes does not correspond to a big change in total cost when compared to the change in the basic model. This is due to the higher flexibility proportioned by the LCT's.





From graphs 5 and 6 we see that an increase in electrical consumption taxes leads to a bigger investment in LCT's, namely in solar cells, which reach the cap the model allows for a given area household at around 30% increase and an investment in batteries which helps to redistribute the PV production in a more uniform way. An important thing to note is that a reduction in tax can lead to a decrease in PV investment which is undesirable for environmental reasons.





In the PV installed capacity graph we can see that the optimized model hits a cap. This cap is, in the higher area households, 20 kWh. In the smaller households it corresponds to a roof area limitation. This area limitation could mean creating undesired socioeconomic differences when increasing the electrical consumption tax. The issue is further enhanced if we are to consider people that cannot install PVs such as those living in an apartment. Finding a solution for households with limited roof size seems key to incentivizing PV investment.

Conclusion

- This study led to the development of 2 models, a simple model and an optimized model that considers many different low carbon technologies;
- The optimized model proved to lead to much lower total costs than the basic model reducing the costs in close to 40%;
- The optimized model proved, as expected, to be more flexible when subject to change, namely to a change in electrical consumption tax;
- The optimized model can be used as a tool to explore different scenarios such as tax changes;
- The optimized model predicts an increase/decrease in PV and battery investment with an increase/decrease in the electrical consumption tax;
- It is important to remember that although an increase in electrical consumption tax could lead to an increase in PV investment it could also mean creating social economic differences due to a limit in roof size and capital of some families.

References

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