Integrating the gain, hedonic and normative aspects in a cost-benefit analysis and decision support tool for transition to natural gas-free neighbourhoods

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Colophon

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Management summary

1) Motivation and research objective

Existing buildings are responsible for 30% of the CO_2 emissions worldwide and 16% in the Netherlands (CBS, 2020). This needs to be drastically reduced in the coming years, to make a planned shift towards a climate-neutral energy system by 2050. One of the major challenges here is upgrading the heating systems of owner-occupied homes. 84% of the Dutch housing stock is still heated with natural gas and 57,4% of the Dutch houses are owner-occupied (CBS, 2021a; CLO, 2020). The upgrade decision needs to be taken by home owners. The considerable costs of the alternative heating systems together with the lack of good insight into the benefits often reduce the willingness to upgrade. This study aims to provide a holistic insight into the financial, technical and social effects of heating system upgrades for individual home owners and clusters of home owners. The study is done for two main alternatives to natural gas heating: all-electric and district heating. More specifically, this thesis develops a decision support tool to facilitate home-owners in housing clusters in their transition from natural gas towards a more sustainable heating technique optimizing the implementation and taking the gain (financial), hedonic (comfort-related) and normative (environmental) aspects into account.

2) Methodology

The research goal is achieved in three steps. First, a limited Cost-Benefit Analysis (LCBA) is performed that evaluates and compares the costs and benefits of the alternative heating techniques for an individual home-owner over the time horizon 2020-2050. The LCBA follows the generally accepted CBA methodology (Romijn & Renes, 2013), but applied only to *individual home-owner* costs and benefits. The included effects are grouped into gain (financial), hedonic (comfort-related) and normative (environment-related) based on the Goal Framing Theory of Lindenberg & Steg (2007). The baseline scenario includes heating with natural gas and a switch to a hybrid heat pump in 2036. Two heating alternatives are: district heating at middle temperature (70°C heat and switch in 2023) and all-electric with an air-to-water heat pump (switch in 2023), see Figure 1. The LCBA is performed under two scenarios – high and low growth of energy prices. The development of energy prices is predicted based on research of the PBL. The low scenario involves the development of the variable natural gas price of +40% and variable electricity price of -34%. The high scenario involves the development of the variable natural gas price of +103% and variable electricity price of +17%. The net present value is calculated using a discount rate of 2.25%. The LCBA is done for a reference housing cluster inspired by homes in neighbourhood 't Ven in the city of Eindhoven. The main dwelling properties that are included in the LCBA model are dwelling size, construction year, type of dwelling, energy label, and distance to the district heating network.

	Baseline alternative	District heating 1	All-electric 1
Heating	*NG*	DH	AHP
Cooking	*NG*	ID	ID
Hybrid heat pump	*X*		
Air-to-water heat pump			X
Connection district heating network		X	
Insulation	*D->B*	B	B
Mechanical ventilation	*X*	X	
Mechanical ventilation with heat recovery			X
Solar panels		X	X
Replace fuse box		X	X
Shift to 3x 25 A electricity connection	*X*	X	X
Remove gas connection		X	X
Electric cooking		X	X
LT radiators			X

Figure 1: Interventions of the baseline and policy alternatives (NG: natural gas, DH: district heating, ID: induction, E: electricity, AHP: air-to-water heat pump, D: insulation label D, B: insulation label B)

Second, a multi-objective optimization model is developed that not only optimizes between pre-defined alternative heating options and the status quo as LCBA does, but also has additional decision support options. It can advise on (i) the most suitable moment of switching, (ii) whether additional dwelling upgrades (solar panels, insulation) should be implemented. Further, the user can indicate individual preferences for comfort, environmental and financial effects. Techniques of Mixed-Integer Linear Programming (MILP) are used to model the optimization solution, coded in Python (packages PULP and PYOMO).

Third, both the LCBA and the optimization are processed in a decision-supporting dashboard that can be used by home-owners as well as municipalities and other parties responsible for boosting the energy transition in homes. The dashboard was created using R Shiny while the interaction with the Python model had been established with Reticulate.

3) Findings

3.1.) Limited cost-benefit analysis

Figure 2 gives an overview of the individual costs and benefits that have been included in the LCBA. Based on the results of the LCBA the following can be concluded:

Gain/ Financial effects for homeowners

1. Based on the Net Present Value of financial effects, it is financially beneficial to switch to District heating or All-electric in the scenario of high growth in energy prices. Switching yields cost savings (NPV) of 7% for District heating and 12% for All-electric, compared to the baseline.
2. In case of low growth, All-electric generates small savings of 2% costs. District heating involves however 10% higher costs than the baseline alternative.
3. The distribution of the costs and benefits over time differs for All-electric and District heating. District heating requires lower initial investment (among other things it does not need adjusting the radiators or heat recovery ventilation) and generates lower yearly savings. All-electric reaches high yearly savings at the cost of a high upfront spending.
4. The properties of the houses have limited impact on the feasibility of District heating. In the high scenario, the cost savings for different studied houses range from 5% to 8%. For all-electric, the properties of the houses make much more difference. Depending on the housing type, the cost savings can be as low as 8% and as high as 18%.
5. A larger distance to the heating network makes district heating less attractive. In a high scenario, switching to district heating is profitable for houses located at a distance of up to 50-60 meters to the network.

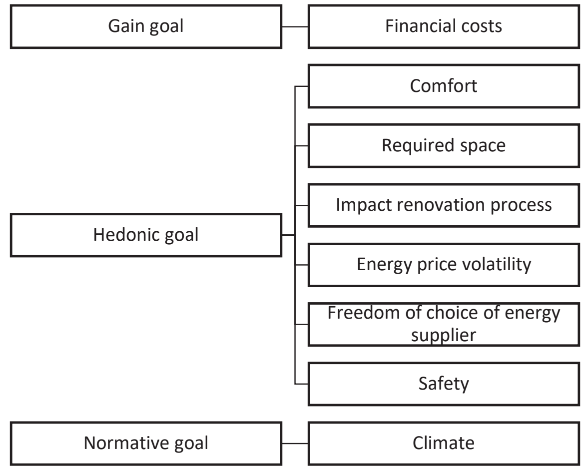

Figure 2: Overview of the effects

6. A larger size of the housing cluster results in a positive impact on the costs for district heating. The costs will result in 8% savings compared to the baseline alternative.

Hedonic/comfort and normative/environmental effects for individual homeowners

1. The total of hedonic/comfort effects is similar for both District heating and All electric and does not differ much from the baseline. The specific effects do differ though.
   a. Both alternative techniques offer an improvement in safety (smaller risk on and less accidents with the heating technique) as compared to natural gas.
   b. All-electric yields addition comfort due to the heat recovery ventilation. This comes at the cost of longer renovation works and larger required space.
   c. District heating has a negative effect connected to the risk of monopolistic behaviour of heat suppliers.
2. Both policy alternatives result in a major decrease in CO_2 emission compared to the baseline alternative. District heating saves 58% and All-electric 73%.

3.2.) Multi-objective dynamic optimization

The assumptions of LCBA concerning the concrete implementation of alternative techniques (year of switch, size of housing cluster, additional measures such as solar panels) do not need to be optimal. Using the optimization model improvements to this can be made:

1. Many different implementations of techniques can be compared quickly and efficiently,

searching for the best solution. Therefore, findings of these techniques can be collected quickly.

2. Housing types and characteristics, the size of the cluster, and location relative to the district heating can be easily adjusted.
3. User input is enabled. For example, in the current version, the user can compare techniques based on her individual-specific relative preferences for gain, hedonic and normative effects. For instance, for people who are mainly concerned about gain/financial effects, postponing the district heating in high scenario, until the moment that renovation is required in baseline (2036) may be attractive. This result does not hold however if environmental effects play an important role.

3.3) The dashboard

The dashboard provides the opportunity for the homeowner to use the optimization models. The municipality of Eindhoven indicated that the dashboard could contribute to informing homeowners about the heating techniques.

4) Conclusions

Overall, there are multiple factors influencing the decision of homeowners to implement natural gas-free renovations. When an alternative heating technique is implemented, it has multiple direct effects on the homeowner. By optimizing the implementation of the heating techniques, and taking the different variables and cluster into account, a better understanding of the effects is created. Making these models accessible to homeowners, will help to inform this group.

The research contributes to multiple fields of research. First of all, insight is generated into the factors influencing the decisions of homeowners for implementing natural gas-free renovations. In the field of CBA for sustainable heating techniques, a contribution is made to getting a better insight into the effects on the major stakeholder, the homeowner. By creating optimization models the gained insights can be optimized and the different objectives can be combined in finding the most suitable implementation. Furthermore, due to these models, an understanding of the effects of the different alternatives can be obtained very quickly per cluster. Via the dashboard, the model can also be made accessible to the stakeholder which makes it usefull for homeowners and municipality.

Limitations

1. The required high amount of assumptions;
   a. Subsidies have been included in the calculation of investment costs as is in 2022. Changes in subsidies will affect the results. It results in higher costs for the installation of insulation, heat pumps, solar panels, and the connection of district heating.
   b. The limitations of the electricity network have not been taken into account. Furthermore, for the connection costs of District heating, an existing network has been taken into account
   c. The relative preferences between gain, hedonic and normative effects have been based on a single study of social housing tenants.
   d. Per extra dwelling included in the cluster, the connection price is reduced by 5% (up to 50%).
   e. The heat price is disconnected from the natural gas price in 2024.
2. The dashboard needs to be further tested on a focus group before it can be widely used.

Further research:

1. Further research into the preferences of homeowners for natural gas-free heating techniques. The current research uses the weights of Wielders (2021) for the goals.
2. Expanding research into the effects of implementing heating techniques on large-scale housing clusters.
3. Further research on comfort levels of homeowners and their comfort preferences.
4. Further CBA research incorporates the indirect social effects of the heating techniques.
5. Expanding the optimization models and the created dashboard to increase usability. By improving the dashboard for the users the usability can be increased.

5) References

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