The energy and material related impacts of the transition towards low-carbon heating: a case study of the Netherlands

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Chapter 6

Discussion

6.1 Introduction

In this thesis, the energy and material related impacts of the transition towards low-carbon heating in the Netherlands was explored. As a starting point, the size of the current Dutch natural-gas based heating system, and its potential use in a circular economy was analysed in chapter 2. In chapter 3, the development pathways of the Dutch heating system and the operational emissions over time were quantified in the context of the Dutch climate goals (reducing heating-related CO_2 emissions by 90% before 2050). Next, chapter 4 presented the share of primary material demand that could be replaced with secondary materials in the Dutch construction sector in relation to the Dutch circularity goals (reducing primary material demand by 50% before 2030). Finally, based on the results from chapter 3, chapter 5 showed the impact of the transition towards low-carbon heating on the material and operational GHG-emissions of the Dutch heating sector.

This thesis contributes to understanding the transition towards low-carbon heating in the Netherlands, in the context of the Dutch climate and circular policy goals by: 1) showing the stock and flow size of the current and future Dutch heating system; 2) providing a comparison of operational and material-related GHG-emissions over time of this system change; 3) providing an understanding of the impact of this transition on both climate and circular economy policy goals.

This dissertation aimed to answer the following research questions:

1. What is the size of the material stock of the current Dutch natural-gas based heating system, and can this material be used in a circular economy?
2. What are the possible development pathways of the Dutch heating system and operational GHG-emissions towards 2050?
3. What are the consequences of the heating transition for the use of materials and how can this transition contribute to the circular economy transition?
4. What is the impact on GHG-emissions of the transition towards a low-carbon heating system from 2021-2050?

In the following sections 6.2-6.6, we first answer and discuss the research questions. After this, the limitations and future research are discussed in section 6.7. Finally, in section 6.8 the implications of this dissertation are discussed for research and society.

6.2 Material stock of the Dutch-natural-gas based heating system and its application in a circular economy

In total, we find a stock of 1,080 kilotons of materials in the heating boilers, natural gas production installations and gas pipelines for 2020, consisting of mostly steel, PVC, cast iron and copper. Because of the transition towards low-carbon heating, this natural-gas-based heating system will become obsolete over time. Part of this heating system will go into hibernation, part of it will be recovered and recycled while another part could be reused for the distribution of hydrogen or green gas.

Our results in chapter 2 shows that between 1,782 and 2,078 kilotons will flow out from the in-use stock between 2020-2050. Without further action, most of the material stock of the Dutch natural-gas infrastructure will most likely go into hibernation after the use phase, as the recovery of underground obsolete material stocks is often considered unprofitable (Krook et al., 2011). Active policy measures are required from the Dutch government to incentivize collection of these material stock by the network operators.

The future production capacity of hydrogen or green gas will mainly determine the extent to which this gas network can be reused. Generating hydrogen on such a scale that 45% of the Dutch residential buildings could be supplied with heat may also cause problems with the availability of metals, and the significant investment of materials may cancel out part of the intended emission reduction (Kleijn & van der Voet, 2010). In any case, the capacity of the current natural-gas-based heating system will be scaled down in the future, which means that at least part of this heating system will become available for recovery and recycling in a circular economy.

In total, the Dutch natural-gas-based heating system is a valuable urban mine that is comparable to the size of the Dutch electricity grid. Based on current plans, it is likely that only part of the Dutch natural gas infrastructure will be reused for the distribution of hydrogen. The remaining out of-use materials underground are a valuable urban mine of mainly steel, PVC cast iron and copper. Recycling and reusing materials from the natural-gas-based heating system can alleviate some of the material impact of the build-up of the more material-intensive low-carbon heating system.

6.3 Development pathways and operational GHG-emissions of the Dutch heating system towards 2050

We found that attaining the Dutch climate goal of achieving a 90% reduction in operational CO_2 emissions before 2050 requires a drastic change in the current Dutch heating system. With the use of a combination of LT-heating networks and (hybrid) heat pumps, the climate goal is attainable. This will require an increased LV-capacity of the Dutch electricity grid, a renewables-based electricity system, investments in heating network distribution infrastructure and the utilization of low-carbon sources of heat. With the use of HT-heating network, the Netherlands could reach the 2030 climate goal (50% reduction of CO_2 emissions) but would significantly limit further reductions. This is because of the relatively high CO_2 emissions per kWh of urban heat of the HT-heating networks.

Several scenarios of the Berenschot heating scenario report were used to address the uncertainty on the future composition of the low-carbon Dutch heating system. As shown in the findings in chapter 3, the differences in market share of low-carbon heating technologies between the scenarios are relatively small. The market share of heat pump technologies ranges from 55-75%, while the LT heating networks have a 20-40% market share depending on the scenario. Because of these small differences, the operational emissions reduction variation between the scenarios are also limited. In future research, scenarios in which one low-carbon heating technology is dominant should also be explored to cover more varied development pathways of the future Dutch heating system.

Our findings in chapter 3 underline the importance of the sources of heat and electricity in reducing the CO_2 impact of residential heating. Replacing heating technologies is not sufficient on its own, and more low-carbon sources of heat and electricity need to be utilized to achieve significant CO_2 reductions before 2050. We also found that when the heating technology market share of the Berenschot scenarios is used, an operational CO_2 emissions reduction of only 80% can be achieved before 2050. While most of the heating technology market share in these scenarios consist of LT-heating networks and (hybrid) heat pumps, the remaining share of HT-heating networks prevents attaining the Dutch climate goals of 2050.

6.4 Consequences of the heating transition for the use of materials and its potential contribution to the circular economy transition

In chapter 5, we found that the build-up of the Dutch low-carbon heating system will require a material demand of 1,200-3,300 kilotons per year, resulting in a material stock of between 58,000 and 60,000 kilotons in 2050. This material demand is mainly a result of the in-house adjustments required for low-carbon heating such as heat pumps, additional insulation and floor heating, and the material-intensive generation of low-carbon heat.

We compared the material stock of both the natural-gas-based and low-carbon heating system over time for a selection of materials in chapter 2, and found that the low-carbon heating system is more material intensive, and especially more metal-intensive. Because of the increased material intensity, it is important to recover and recycle as much of the soon-to-be obsolete natural-gas-based heating system and the existing buildings as possible.

In chapter 4, we explored to what extent secondary materials generated through urban mining could replace the primary material demand in the Dutch construction sector. We found that with the current construction and demolition plans in the Netherlands, 41% of the primary material demand can be replaced by using secondary materials. In addition, we found that 66% of the generated demolition waste could be recycled. This means that the 2030 circular economy goals are already difficult to attain and that primary material extraction will remain necessary for the construction sector. The recycled content potential is the biggest obstacle in reducing the primary material demand, and using secondary materials are currently seen as a risk by construction companies. New policies are required to focus on retaining material quality while allowing further use of recycled materials as building materials.

The heating system change towards low-carbon heating technologies can also stimulate the transition to a circular economy. The material demand of the heating transition negatively influences the system-wide GHG-emissions reduction, while at the same time it results in a significant release of materials from the old natural-gas-based heating system. The material-related impacts, increased primary material demand and the availability of these significant urban mines can stimulate recycling practices and the use of secondary materials. It is therefore essential for the Dutch government to utilize the out of use natural-gas-based heating system as an urban mine and stimulate recovery and recycling practices. For the build-up of the new low-carbon heating system, the use of secondary could reduce the material-related impacts.

6.5 The impact on GHG-emissions of the transition towards a low-carbon heating system from 2021-2050

Taking into account emissions related to materials has major consequences for the achievability of the Dutch climate goals. Across all three scenarios in the Berenschot scenarios of a future Dutch heating system, an operational emissions-only point of view would lead to the conclusion that an 80% reduction will be achieved. However, the additional material requirements negate part of the emission reduction benefits of the heating transition, to the point that a reduction in system-wide GHG-emissions of no more than 62% to 64% is achievable.

The stated policy goal of reducing urban heating related GHG-emissions by 90% in 2050 is achievable, but only with the right combination of heating technologies and sources of heat (Verhagen et al., 2020). We find that the share of material-related emissions will increase to 40% of the heating system-wide emissions in 2050. Policy is needed from the Dutch government to reduce this material impact. For example, stimulating the use of secondary materials for the build-up of the low-carbon heating system. Furthermore, the heating system will have to be designed with technologies that have a significantly lower material demand. Innovation and dematerialization of heating systems could alleviate some of the material demand and corresponding environmental impact of this transition towards low-carbon heating.

Another strategy to compensate part of the material-related emissions is the accelerated build-up of the low-carbon heating system. Sooner or later, there will be a significant material demand required for the build-up of the low-carbon heating system. By transitioning towards a low-carbon heating system on a more ambitious timeframe, the operational, and therefore cumulative GHG-emissions of the Dutch heating system can be reduced.

6.6 The energy and material-related impacts of the transition towards low-carbon heating

Based on the previous chapters, we can now discuss the main research question: *How is the Dutch heating system expected to change towards 2050, and how does this affect the Dutch policy goals related to climate change and the circular economy?*

In chapter 3 we have shown that to achieve the Dutch climate target of reducing operational CO_2 emissions of urban heating by 90% in 2050, a new low-carbon heating system has to be built up. For this, the electricity grid has to be expanded with additional LV capacity for heat pumps, and heating networks will have to be installed on a large scale. Existing residential buildings will have to be adapted to accommodate low-temperature heating and require increased levels of insulation. In addition, the available sources of low-carbon heat in the Netherlands have to be carefully surveyed as these are essential in achieving the climate target.

The construction of a separate low-carbon heating system has a significant material demand, and is even more material-intensive than the current natural gas-based heating system (chapter 2 & 5). In the second chapter of this thesis, we have also shown that the current natural-gas based heating system will become largely obsolete in the future. This means that a large urban mine of materials can be recovered and recycled for use as secondary materials in the circular economy. The use of secondary materials as a substitution for primary material demand can stimulate recycling practices and reduce material-related impacts.

The associated material demand for this transition to low-carbon heating ensures that the climate target will not be achieved. Even after the build-up of the low-carbon heating system, there will still be a significant material impact from the maintenance of this system. Still, in comparison with the natural-gas-based heating system, considerable operational emissions reductions can be achieved. In order to achieve the Dutch climate target of 2050 after the build-up of the low-carbon heating system, considerable reductions in material-related impacts will have to be realised.

The transition towards low-carbon heating requires adjustments to residential buildings, which also generates a considerable material demand. Chapter 4 shows that it is very challenging to close the Dutch construction and demolition waste cycle. Even in a situation without additional building stock growth, the collection and recycling process cannot recycle 100% of the generated demolition waste, leading to continued demand for primary materials. Achieving the 2030 circular economy policy goal of decreasing primary material demand by 50% will require significant improvements to the current processing of (demolition) waste and recovered materials.

The adjustments required to buildings and the heating system will lead to an increase in material demand, especially for metals. At the same time, the release of a large urban mine in the form of the old natural gas-based heating system and the demolition of buildings offers opportunities for the circular economy. In this situation it could become more attractive to use secondary materials and to invest more in circular economy practices such as recovery, recycling and reuse. In addition, the increased demand for materials offers a chance to use secondary materials to a greater extent. The energy transition, of which the heating transition is part of, could also reduce the impact of material recycling, as this if often an energy-intensive process. Applying circular economy practices in the build-up of the new low-carbon heating system can decrease the material-related impacts, bringing the Netherlands closer to achieving its 2050 climate and circular economy policy goals.

Insight into the impact of this transition towards low-carbon heating on energy and material use is essential to make targeted policy through which both policy goals will be achieved, and the efforts of one do not nullify the efforts of the other.

6.7 Limitations and future research

Method

A limitation of this research is that it does not cover the variety in how much material could become available annually from the old material stocks until 2050. In our analysis, we modelled a linear increase and market share and corresponding material flows due to a lack of data on this topic. In reality, the adoption of low-carbon heating technologies can go a lot faster due to for example, financial stimulus through subsidies. This would cause the increased obsolescence of the natural-gas-based heating system and availability of its material stock for potential urban mining, and could create a mismatch in material demand and secondary material availability over time. The material demand for the build-up of the low-carbon heating could reach its peak well before enough secondary materials are recycled to replace part of the primary demand.

Berenschot scenarios were used to cover the uncertainty about the future composition of the Dutch heating system. All the scenarios describe a combination of multiple low-carbon heating technologies in use for 2050. More extreme scenarios in which the composition of the future heating system tends more towards one dominant heating technology should also be explored. The current heating system in the Netherlands is predominantly natural-gas-based, and therefore one-sided heating technology scenarios ought to not remain completely unexplored.

Data

Another limitation of this research is that at this moment there is a limited number of available sources on the material data of the low-carbon heating technologies. With more data on materials in low-carbon heating systems, it would have been easier to model the material demand scenarios more accurately. Furthermore, for heating networks technologies, implied data was used due to a lack of information. Especially the infrastructure prices of the heating networks are generally unspecified.

Recommendations for future research

A recommendation for further research would be on the combined heating and cooling demand of the future Dutch heating system. With an increasing demand for residential cooling in the Netherlands, the utilization of heat pumps could prevent or replace independent cooling solutions and the corresponding materials. It is also important to research to what extent the use of low-carbon electricity can reduce the impact of recycling and reuse processes.

Other recommendations for future research include a further exploration of the materials and corresponding environmental impact of the current fossil-fuel based energy system. In this dissertation we included the natural gas system in the Netherlands, while the overall fossil fuel system that a low-carbon heating system could replace is more complex and extensive. Only after analyzing both systems with completely equal system boundaries can we determine if the low-carbon heating (and energy) system is more material-intensive. Furthermore, it is also worth exploring what the impact is of the transition towards low-carbon heating on the critical material demand. While we included critical materials, it was not the main focus of the research. Further quantification of critical materials in this system change would most likely result in higher stocks in the energy system, but more importantly would highlight a potential strategic importance for the Netherlands to acquire a secure supply. In existing stocks of the currently used heating system, most other materials are already present, but for critical materials a stock still has to be built-up in the form of a new low-carbon energy system.

The development of this transition towards low-carbon heating could also be influenced by energy storage solutions. At present, the use of energy storage is limited, but in the future, this could have a strong influence on the system (Petrović & Karlsson, 2016). Phase change materials (PCM's), improvements in battery technology and localized hydrogen storage present a potentially disruptive development for the overall energy grid (heat and electricity). The material demand for such a large-scale transition of an energy system could also influence, or even disrupt critical material supply chains (Sprecher et al., 2017). These developments should be considered in future research on this topic.

6.8 Implications

Implications for research

This research has shown that the transition towards low-carbon heating, just as with the energy transition, leads to an increased use of materials and corresponding material impacts. These results are valid for our used case study of the Netherlands, and are potentially applicable to neighbouring countries in the EU that also heavily utilize natural-gas for space heating.

Assuming the outcomes of our study are also valid for the rest of the world, this means that:

- A global transition towards low-carbon heating will contribute to an increased demand for materials, especially for metals and insulation materials. Potential shortages in material availability could stimulate circular economy practices such as recovery, recycling and reuse.
- Buildings and legacy heating systems could be used as a source of secondary materials through urban mining. With the increasing material demand and the environmental impacts of primary material production, secondary material extraction will most likely play an increasingly important role.
- Energy transition and circular economy policy goals will need to be further integrated to achieve considerable emission reductions. Accounting for potential trade-offs while incorporating both policy goals is something that has to incorporated in climate research and policy making.
- The total environmental impact of urban heating will first increase as a result of the material-related impacts. After the build-up of the low-carbon heating system, the environmental impact of urban heating can decrease significantly.

In reality, the comparison between the Netherlands and other countries, especially ones outside the EU becomes more difficult, as other built environments can have an increased level of insulation, and utilize different heating technologies. Furthermore, the demand for heating outweighs the demand for cooling in the Netherlands, while in other countries such as China and India the cooling demand is more important for the energy use of buildings. Because of these differences it is also important to externally validate these outcomes with studies on the heating system and the transition towards low-carbon heating (and cooling) in other countries (Flyvbjerg, 2006).

Implications for society

Climate and CE-policy are inextricably linked. With the build-up of the low-carbon heating system, an increased material intensity must be taken into account. Promotion of CE practices by the Dutch government could help to reduce the material-related impacts of the low-carbon heating system.

The low-carbon heating system will be further integrated in the electricity sector than the natural-gas-based heating system. After the transition there will be a considerable overlap between the electricity and heating system due to the application and use of heat pump technologies. This could mean that policy directed to change one part of this energy system can also impact the other parts as these are more integrated than before.

Wide-scale implementation of financial incentives for home-owners can accelerate this transition towards low-carbon heating. Sooner or later, there will be a significant material demand required for the build-up of the low-carbon heating system, generating a considerable environmental impact in the form of material-related emissions. Accelerating the transition towards low-carbon heating on a more ambitious timeframe can reduce the cumulative system-wide GHG-emissions of the Dutch heating sector.