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

Verhagen, T.J.

Summary

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The almost unsatiable demand for energy of our modern society has created a strong reliance on fossil fuels. Of all the greenhouse gases produced in the world, energy production is responsible for 72% (IEA, 2020). To reduce emissions and adapt to the impacts of climate change, 196 countries signed the Paris agreement in 2015. In this agreement, countries aim to achieve a climate neutral world by 2050, and therefore completely abolish the use of fossil fuels. For the energy sector, this has resulted in the energy transition; the shift from fossil-based systems of energy production and consumption to renewable energy sources.

Energy transition research has mainly focussed on the electricity sector and transport fuels (Liang et al., 2022; Tang et al., 2021). Up to now, very little attention has been paid to the heating sector. This thesis fills that gap by exploring a critical piece of the energy transition: the transition towards fossil-free urban heating. Buildings are responsible for 40% of the global energy demand, of which most is used for space heating. Three-quarters of this energy demand is met by using fossil fuels (IEA, 2021).

The existing heating system, including in-house heating, infrastructure, and energy production, will have to be adapted to accommodate low-carbon heating technologies that operate on different sources of heat. Furthermore, to realize the transition towards a low-carbon heating system, many changes will have to be made to buildings. All the changes required for the transition towards low-carbon heating to buildings, infrastructure and energy production will over time lead to: 1) the obsolescence of the current Dutch natural-gas-based heating system and; 2) the build-up of a separate low-carbon heating system. At the same time, it is unknown how much material the build-up of this low-carbon heating system will require, and if this transition towards low-carbon heating will make the Dutch 2050 climate goal of reducing heating-related GHG emission by 90% attainable.

The aim of this thesis is to investigate the transition towards low-carbon heating in the Netherlands, in the context of the Dutch climate and circular policy goals. This results in the following **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?*

We use the Netherlands as a contemporary case study as its heating system is heavily reliant on the use of natural gas. In 2017, the political decision was taken to transition towards fossil-free urban heating, on a very ambitious time-schedule: heating-related CO2

emissions should be reduced by 50% before 2030, and 90% before 2050 (Rijksoverheid, 2017). For the existing Dutch building stock, this means that more than 80% are to be renovated. Besides the transition towards low-carbon heating, the Dutch government also formulated circular economy policy to reduce the country-wide use of primary materials (minerals, metals, and fossil fuels) by 50% before 2030, and become fully circular by 2050.

For the development scenarios of the composition of the Dutch heating system, we mainly use the heating scenarios report by Berenschot (Berenschot, 2020a). This report explores multiple heating system pathways for the Netherlands from 2020-2050 based on the local availability of sources of heat.

To answer the main research question, chapter 1 to 5 offered answers to each of the research questions mentioned below:

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?

In chapter 2, we found 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. 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.

2. What are the possible development pathways and operational GHG-emissions of the Dutch heating system towards 2050?

In chapter 3 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 (Verhagen et al., 2020). With the use of a combination of LT-heating networks and (hybrid) heat pumps, the climate goal is technically 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.

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.

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?

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. In chapter 4 we also 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.

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.

4. What is 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. In chapter 4, we found that 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. We find that the share of material-related emissions will increase to 40% of the heating system-wide emissions in 2050.

Overall, chapters 2 to 5 showed that 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 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. For example, the possibility of reusing the existing Dutch natural gas grid for the distribution of renewable gasses such as hydrogen or biogas. 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, 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.

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. Legacy heating systems could be used as a source of secondary materials through urban mining.
- 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. 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).

This dissertation has shown that both policy goals do not only go hand in hand, but also influence each other (where possibly also negatively). The transition towards a low-carbon heating system is essential to achieve the 2050 climate targets. At the same time, the build-up of a low-carbon heating system increases primary material extraction, making it more difficult to achieve the Dutch Circular Economy policy goals. The energy transition however, of which the heating transition is part of, could also reduce the negative environmental impact of material recycling, as this if often an energy-intensive process.

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.