MASTER

Discussing the policy mix framework for Germany's heat transition

From the EU Renewable Energy Directive to an effective German implementation

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Discussing the policy mix framework for Germany's heat transition

From the EU Renewable Energy Directive to an effective German implementation

Master Thesis

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Keywords

Renewable heating; EU Regulation; Renewable Energy Directive; Germany; Heat Transition; Policy mix; stakeholder analysis; Heating & Cooling; District heating

List of abbreviations

BMWK	Federal Ministry for Economic Affairs and Climate Action (German: Bundesministerium für Wirtschaft und Klimaschutz)
CCS	Carbon Capture and Storage
CHP	Combined Heat-Power (installation, plant, also called cogeneration)
DH	District Heating
DHW	Domestic Hot Water
EAB	European Advisory Board
EED	Energy Efficiency Directive by the European Union
EU	European Union
HC	Heating & Cooling
IS	Innovation Sciences
LULUCF	Land use, land use change & forestry
NECP	National Energy and Climate Plan (German: Integrierter Nationaler Energie- und Klimaplan)
NSG	National Stakeholder Group
OPEX	Operational Expenditures
P2H	Power to heat
RE	Renewable Energy
RED	Renewable Energy Directive by the European Union
REDI4HEAT	RED Implementation for Heating and Cooling
RES	Renewable Energy Sources
TWh/a	Tera watt hours annually
WP	Work Package

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Summary

Heating and cooling represent a significant share of our energy system and therefore a significant part of the challenge to reduce CO_2-emissions. In Germany, and most of Europe, heating and cooling account for 50% of the total energy demand and 80% of the demand from residential buildings, services, and industry (BMWi, 2020). Most of this demand is still satisfied by natural gas. In line with the (revised) EU Renewable Energy Directive, the German government must increase its efforts to transition to a decarbonized heating system. It is a complex field with many actors, technological options and uncertainties, and a complex regulatory field. Other than in the decarbonization of the power system, the heat transition requires the cooperation of millions of households and hundreds of heat-supplying companies with different vested interests.

This thesis aims to gain an overview of the current heating (and cooling) sector and Germany, especially of the policy situation that shapes the sector, and to identify challenges and possible solutions pointed out by stakeholders to accelerate the transition towards a renewable heating system. It adds to the REDI4HEAT project by the German Energy Agency and its EU consortium, the scope in which this thesis research was conducted.

This thesis analyzes the current policy situation concerning heating and cooling in Germany, using the policy mix framework proposed by Rogge & Reichardt (Rogge & Reichardt, 2016). This framework makes it possible to take an analytical look at a current or a proposed policy mix by reviewing its strategic and instrumental elements, policy processes, dimensions, and characteristics of these aspects.

Furthermore, a stakeholder analysis is performed, mapping the stakeholders with interests in the heat transition and identifying their challenges, and their proposed solutions and policy changes. The stakeholder analysis was conducted by forming a National Stakeholder Group (NSG) and conducting scientific interviews with a selection of these stakeholders.

The Research questions this thesis aims to answer are:
Which policy strategy and policy instruments can accelerate Germany's transition to renewable heating and cooling?

1. *What is the current state of renewable heating and cooling in Germany? What are Germany's current policy strategy and instruments, analyzed through the Policy Mix framework, and to what extent are they coherent?*
2. *Who are the relevant stakeholders? What are their aims and roles in the German heat transition?*
3. *What are the most critical action fields for a successful heat transition? What are the bottlenecks that need to be addressed?*
4. *Which fields of action and associated policy strategies & instruments are necessary to enable stakeholders to achieve the targets for renewable heating, and how do they fit into the policy mix?*

The main findings of this thesis suggest that while Germany's national strategy aligns with the EU's goal on heating and cooling, the specific policy instruments are not fully aligned with this strategy. German must overcome these implementation issues if it wants to adhere to the 0.8%-points yearly increase of renewable energy sources in heating and cooling, which become binding in the revised Renewable Energy Directive II. These issues concern:

1. **Economic and regulatory barriers**. For example, there is a difference in CO_2-prices paid by consumers and heat-supplying companies. The price difference between renewable electricity and gas hinders the electrification of industry. Furthermore, counterproductive subsidies still support new gas-based Combined Heat and Power plants (CHP).
2. **Bureaucratic hurdles**, such as local regulations that obstruct the expansion of district heating networks.
3. The **deficit of skilled workforce**, which is necessary for every branch of the energy transition. For the heat transition in particular, skilled workers who install heat pumps, expand district heating networks, or help decarbonize them, are in high demand.
4. **Social challenges**, which again occur from price differences between electricity and gas and the high investment price to install a renewable heating appliance (even with subsidies), must also be overcome. Here, the general issue is that switching to renewable heating does not come with the economic benefits that currently make switching to renewable electricity (by installing solar PV) so attractive.

These issues were identified by the stakeholder analysis. In addition, the stakeholders made a wide variety of policy suggestions. The main action points are distilled from these suggestions and are aggregated into the following recommendations.

There must be **an improved policy plan to support the strategic goal.** Policy instruments must be more consistently aligned with the goal. This includes deciding when national policies in the field of renewable heating may override regulation on lower government levels, to ensure consistency. Moreover, a stronger choice must be made regarding technology openness. It must be made possible to shape policy instruments that steer the technology in the right direction while excluding undesired technologies, avoiding lock-in.

This plan **must include answers to the pricing problems.** The national and EU CO_2-price should be aligned, and a decarbonization-electricity price, bridging the gap between renewable electricity and gas, should be used to stimulate electrification. Cost-neutrality, another rule that currently slows the transition down, should be changed so that (renewable) district heating becomes competitive compared to current or future gas prices.

Social aspects should play a more significant role. The heat transition will affect people in their homes and is currently uneconomical. A social solution, probably involving generous subsidy programs, must be found for house owners and renters to afford the necessary renovation, heating system change, and higher operational costs of renewable heating.

1 Introduction: the heat transition challenge and the REDI4HEAT project

1.1 The European heat transition challenge

Heating and cooling represent a significant part of the challenge to decarbonize our economies. In Germany, similarly to most European countries, heating and cooling represent 50% of the total energy demand and 80% of the demand from residential buildings, services, and industry (BMWi, 2020), and most of this demand is still satisfied by natural gas (See Figure 3 and Figure 4 in chapter 2). The energy transition in the heating and cooling sector has not received the same amount of attention as, for example, the transition towards renewables in electricity production. This applies to government strategy and implementation, but a research gap regarding heat transitions has also been noticed in academia (Harvey-Scholes et al., 2022). Many EU Member States have yet to develop a suitable strategy for heating and cooling, and most are struggling to implement it. The ones that already have a high share of Renewable Energy in Heating – traditionally Scandinavian, Baltic, and partially Eastern European states - have this mainly due to an existing reliance on district heating with a high share of biomass or waste incineration (see Figure 1). Germany and the Netherlands have a relatively low share of renewable energy sources (RES) due to a traditional reliance on decentral heat production using gas or oil (Toptarif & Thermondo, 2016). One thing is clear: the heating and cooling sector is lagging behind and needs an impulse to accelerate the transition towards a sustainable heat and cooling production.

The European Union seeks to address this challenge within the revised Renewable Energy Directive (RED) II (European Commission, 2021a), especially in the amendments to articles 23 and 24. These state a binding, gradually increasing renewable target for heating and cooling, with a 0.8%-point per year increase until 2026 and 1.1%-point between 2026 and 2030 (currently: 1.1% indicative). Furthermore, they include an indicative 2.1%-point yearly increase of renewables in district heating and cooling systems (now: 1% indicative) (Council of the EU, 2023). The most important parts of the proposed amendment can be read in Textbox 1. The amendment also requires each Member State to assess the potential for renewables and the use of waste heat and cold, which must be updated every five years. It must be noted that these amendments were still in the trilog phase during the writing of this thesis, and a provisional deal was reached only on March 30th, 2023. The different options are discussed in more detail in chapter 5.

Even with this small uncertainty, the direction of the amendment was and is clear: pushing for more renewables in the heating and cooling sector. Furthermore, the translation into national policy and implementation is more of an ongoing process than one clearly defined moment. Therefore, looking into the challenges and necessary policy changes to implement this upcoming EU policy was already possible. However, the EU policy only comprises a limited explanation of how the revised RED II should be implemented, leaving much of the responsibility for the implementation and conversion into national law to the Member States. This is where the REDI4HEAT project comes in, on which this master thesis will be based. This project will support the implementation process of the EU regulations at the national level by discussing implementation options and needs with relevant stakeholders. Subsequently, the national results will be compared between the European member states in order to provide recommendations for gaps to be closed, and best practice examples are exchanged.

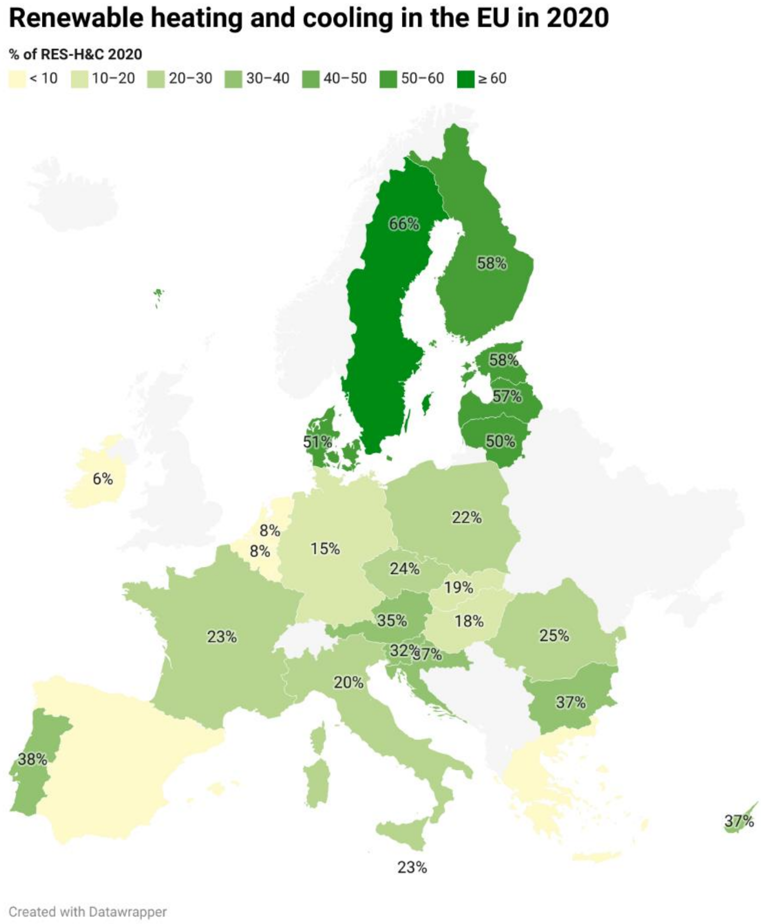

Figure 1. EU comparison of RES share in H&C in 2020 and 2030 target. Source: NECPs of each EU Member State, internal aggregation in REDI4HEAT project.

Important amendments under RED II concerning heating and cooling:

Article 23 paragraph 1 is replaced by:
In order to promote the use of renewable energy in the heating and cooling sector, each Member State shall, **increase the share of renewable energy in that sector by at least 0.8 percentage points** as an annual average calculated for the periods 2021 to 2025 **and at least 1.1 percentage points as an annual average calculated for the periods 2026 to 2030**, starting from the share of renewable energy in the heating and cooling sector in 2020, expressed in terms of national share of gross final energy consumption and calculated in accordance with the methodology set out in Article 7.

Article 23 paragraph 1a is inserted:
Member States shall **carry out an assessment of their potential of energy from renewable sources** and of the use of waste heat and cold in the heating and cooling sector including, where appropriate, an analysis of areas suitable for their deployment at low ecological risk and of the potential for small-scale household projects. The assessment shall set out milestones and measures to in increase renewables in heating and cooling and, where appropriate, the use of waste heat and cold through district heating and cooling with a view of establishing a long-term national strategy to decarbonize heating and cooling.

Article 24 paragraph 4 is replaced by:
Member States shall endeavor to increase the share of energy from renewable sources and from waste heat and cold in district heating and cooling by at least 2.1 percentage points as an annual average calculated for the period 2021 to 2025 and for the period 2026 to 2030, starting from the share of energy from renewable sources and from waste heat and cold in district heating and cooling in 2020, and shall lay down the measures necessary to that end. The share of renewable energy shall be expressed in terms of share of gross final energy consumption in district heating and cooling adjusted to normal average climatic conditions.

Textbox 1. Important amendments under RED II concerning heating and cooling (Council of the EU, 2023; European Commission, 2021b Art. 1. Para. 12 & 13; European Commission, 2022).

1.2 Introduction to the REDI4HEAT project

This thesis research has been conducted within the context of the EU project REDI4HEAT (RED Implementation for heating and cooling). Therefore, the project, its consortium, and more particularly dena, where this thesis was written, are introduced before we continue towards the substantive part of this thesis.

1.2.1 REDI4HEAT and its consortium

The REDI4HEAT project is carried out to assist EU Member States and provide policy recommendations and tools to accelerate the transition towards renewable heating and cooling. A consortium of 12 European partners is involved. Next to dena, the following partners are responsible for the REDI4HEAT project: to start, the Greek Centre for Renewable Energy Sources and Savings (CRES) has the project leadership. Like dena, it is a public entity supervised by the government, and its central role is advising the government on energy topics. Furthermore, there are three more Scientific institutes: Energy Institute Hrvoje Pozar (Croatia), Portuguese Energy Agency ADENE, Polish National Energy Conservation Agency KAPE, six umbrella organizations: Solar Heat Europe (Belgium), European Heat Pump Association (Belgium), European Geothermal Energy Council (Belgium), Euroheat & Power (Belgium), Bioenergy Europe (Belgium), Energy cities association (France) and one private company, Trinomics (Netherlands). The 3-year-long project started in October 2022. During the project, dena will, among other tasks, monitor and encourage national initiatives integrating the EU policy and develop a toolbox for the heat transition.

1.2.2 EU LIFE

REDI4HEAT is funded by EU LIFE (*L'Instrument Financier pour l'Environnement*), a European funding instrument. EU LIFE had several program cycles and is currently in the 2021-2027 cycle, with a €5.45 billion budget and four sub-programs: Nature and Biodiversity, Circular Economy and Quality of life, Climate Change Mitigation and Adaptation, and Clean Energy Transition (CET) (CINEA, 2023). In the 2021 call for proposals, one topic was in the division Clean Energy Transition (CET)-Policy: *"Towards an effective implementation of key legislation in the field of sustainable energy,"* to which the REDI4HEAT consortium applied with a project concerning the implementation of legislation in the field of heating and cooling.

1.2.3 dena

The German Energy Agency is a state-owned company that provides consultancy services within Germany and internationally to achieve Germany's energy transition and climate change mitigation targets. In addition, it does research and provides advice on the future of the energy market to the government and private parties by working together with various stakeholders. The company was founded in 2000 and currently has around 500 employees (dena, 2023).

1.3 Aim and research questions of the thesis

As a part of the REDI4HEAT project, this master thesis will explore the current conditions in the heating and cooling sector in Germany and the challenges that various stakeholders encounter in the transition to more renewable energy in the heating and cooling sector. This thesis focuses on the policy part of this challenge. Policy is crucial, as it can steer the heat transition in a particular direction: it can stimulate and regulate change. Moreover, stakeholders expect the government to set the course. At the moment, the heat transition is not fast enough, so the policies are not adequate. To begin with, the German policy situation will be analyzed using the policy mix framework, including current policies, planned or announced policies, and policies (or policy changes) suggested by stakeholders. This framework enables categorizing policy into a strategic and an instrumental component, which helps to gain an overview of the policy situation. The policy mix framework will be discussed in more detail in chapter 3. After analyzing the current policy mix, this thesis aims to identify bottlenecks and changes that might improve the policy mix, leading to an accelerated heat transition.

1.3.1 Research questions

To outline the content of the thesis, the following research questions have been formulated:

Which policy strategy and policy instruments can accelerate Germany's transition to renewable heating and cooling?

5. *What is the current state of renewable heating and cooling in Germany? What are Germany's current policy strategy and instruments, analyzed through the Policy Mix framework, and to what extent are they coherent?*
6. *Who are the relevant stakeholders? What are their aims and roles in the German heat transition?*
7. *What are the most critical action fields for a successful heat transition? What are the bottlenecks that need to be addressed?*
8. *Which fields of action and associated policy strategies & instruments are necessary to enable stakeholders to achieve the targets for renewable heating, and how do they fit into the policy mix?*

1.4 Scientific & Societal relevance of the research

The combination of (EU) policy, technology, and innovation within the energy transition and the involvement of various companies and stakeholders makes this a relevant and current topic for Innovation Sciences (IS). Scientifically, it is relevant to see how policy can accelerate the heat transition. From the IS learning objectives, my research will include Scientific disciplines (understanding and applying IS concepts and theoretical frameworks) and doing research (formulating research problems, developing and executing a research plan, and identifying typical IS problems). I will have to take account of the temporal, technological, and social context, as the heat transition takes place in a dynamically changing (geo)political landscape. I will develop the co-operating and communicating learning objective by working in a German organization and an international project, working together with different cultural backgrounds in both German and English. Developing the policy recommendations during my research will address the learning objective 'competent in designing'. Lastly, I find it relevant and motivating that my work for the master thesis also contributes to the REDI4HEAT project.

1.5 Scope and structure of the thesis

The thesis is structured as follows. After the introduction and target formulation (this chapter), chapter 2 will give a thematic introduction to the German heating and cooling sector. Then, chapter 3 introduces the literature on innovation policy and outlines the framework used to analyze the German policy situation. Chapter 4 explains the methods used to answer the research question. Chapters 5 to 8 discuss and answer each of the sub-research questions in turn; chapter 5 addresses Germany's policy position; chapter 6 introduces the stakeholders and their role in the heat transition; chapter 7 explains the stakeholders' main challenges; and chapter 8 reviews their policy suggestions. Lastly, chapter 9 concludes the thesis, while chapter 10 comprises the discussion and limitations.

2 Setting the stage: the German heating and cooling sector

This chapter will give an overview of the energy use in Germany for heating & cooling and other sectors. Furthermore, the respective shares of renewable energy sources in the different sectors are discussed, and the challenges that the heating & cooling sector faces.

2.1 Germany's Energiewende-challenge

It is important to know where Germany is coming from to understand its position in the energy transition. Setting it apart from other countries, Germany has a long history of efforts to renew the energy system. Starting from the 1972 'Limits to Growth' report by the Club of Rome, via a growing environmental movement and the formation of the Green Party, the term 'Energiewende' was coined to define the moving away from oil, but most of all, from nuclear power. With the addition of CO_2 Targets following the 1997 Kyoto Protocol, the German energy transition (commonly called "Energiewende") had a second target: the reduction of CO_2 emissions, of which Germany was the sixth largest emitter at the time (Wettengel, 2020). However, the challenge of simultaneously phasing out nuclear and coal power slowed the overall transition down. Nevertheless, around 80-90% of Germany's citizens support the Energiewende (Hake et al., 2015). By April 2023, the last nuclear power plants will be decommissioned, and the originally first of Germany's Energiewende goals will be finally achieved (Janzing, 2023). However, the second part of the challenge is still not close to the target, especially not in the heating and cooling sector. The record year 2022 showed 46% renewable energy in power production, but only 18% in heat and 7% in transport, with a total average of around 20% (Agora Energiewende, 2023a).

2.2 Current shares of renewable energy sources in Germany

The share of renewable energy sources (RES) in Germany's energy system is increasing but develops differently in various sectors. Figure 3 and Figure 4 illustrate Germany's progress and its challenge in renewable heating and cooling (using data from the German Federal Ministry of Economic Affairs and Climate Action, the BMWK). Note that, in Figure 2, the target for renewable heat is not 50% RES but 50% climate-neutral heat. This nuance means that industrial residual heat and waste incineration also count towards this goal. In the electricity sector, the share of renewable energy has steadily increased since 1989, up to 41% in 2021 and even 46% in 2022 (Agora Energiewende, 2023a); see Figure 2. At the same time, the share of RES in the heating & cooling sector has only increased to 16.2% of the final energy consumption for heating and cooling, and only 18.5% in district heating. The targets that Germany has set for the increased share in renewables in HC are further discussed in section 5.2.

Figure 4 shows the division of the energy consumption in Germany in 2021. Around half is attributed to the heating & cooling sector, while the transport sector and electricity production only use around 23% of the German gross national energy consumption each. This implies that while heating and cooling constitute the largest energy demand, it currently has the second lowest share of renewable sources, except for the transport sector. Moreover, while the electricity sector is celebrated because its share of renewables is increasing rapidly, it has a minor relative share. Therefore, the next big challenge will be accelerating the transition towards renewable heating and cooling in the German

"Wärmewende." The following section dives deeper into the dynamic of the German heating and cooling sector.

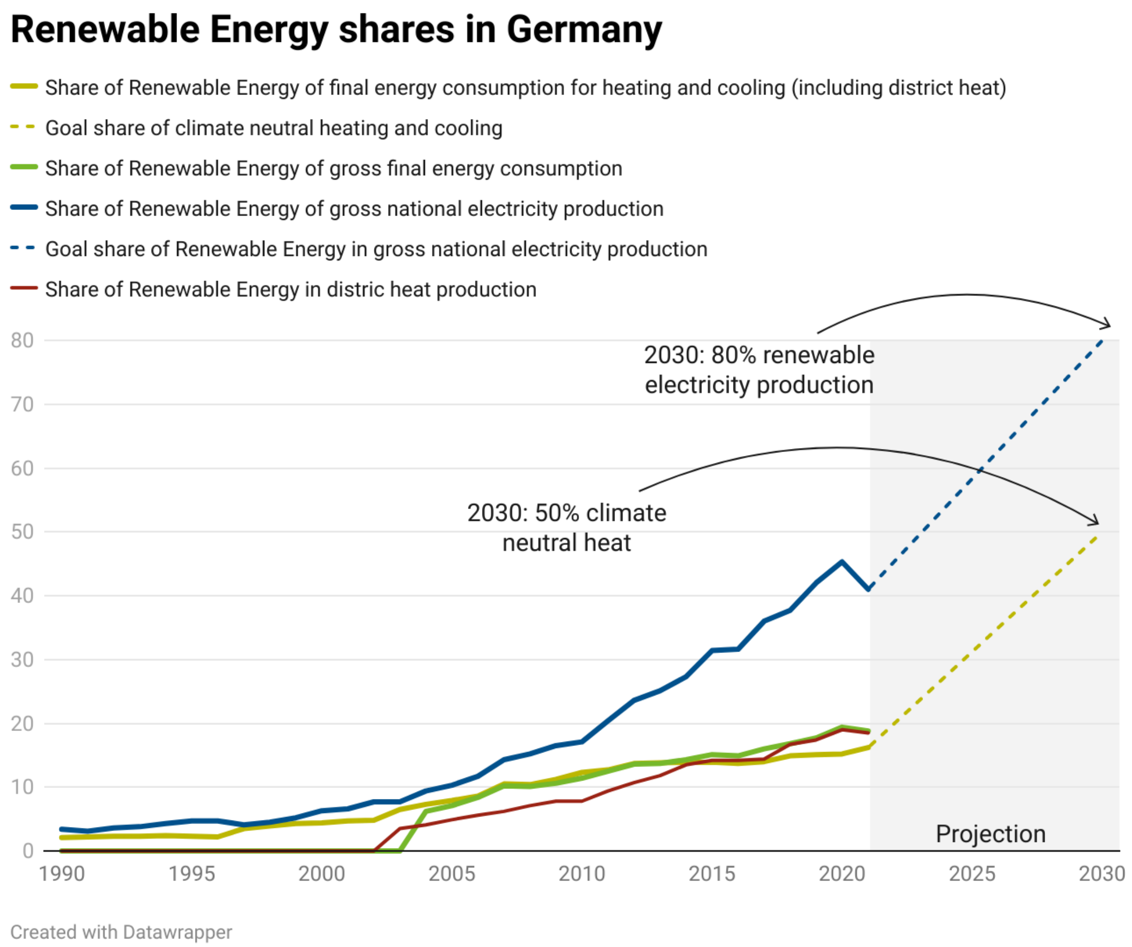

Figure 2. Share of renewable energy sources in the Final energy consumption, electricity production, heating & cooling, and district heat production. Based on BWMK.[1]

[1] https://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien_in_Zahlen/Zeitren

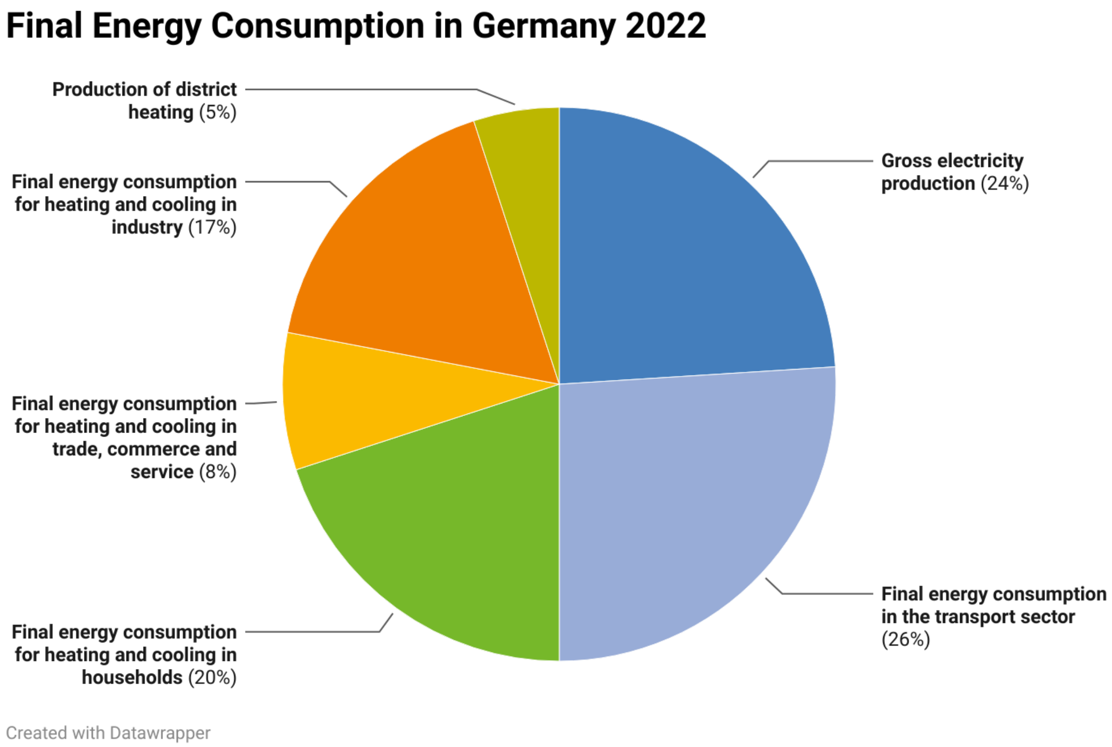

Figure 3. Gross final energy consumption of electricity production, transport, and various heating & cooling sectors. Based on BMWK.[2]

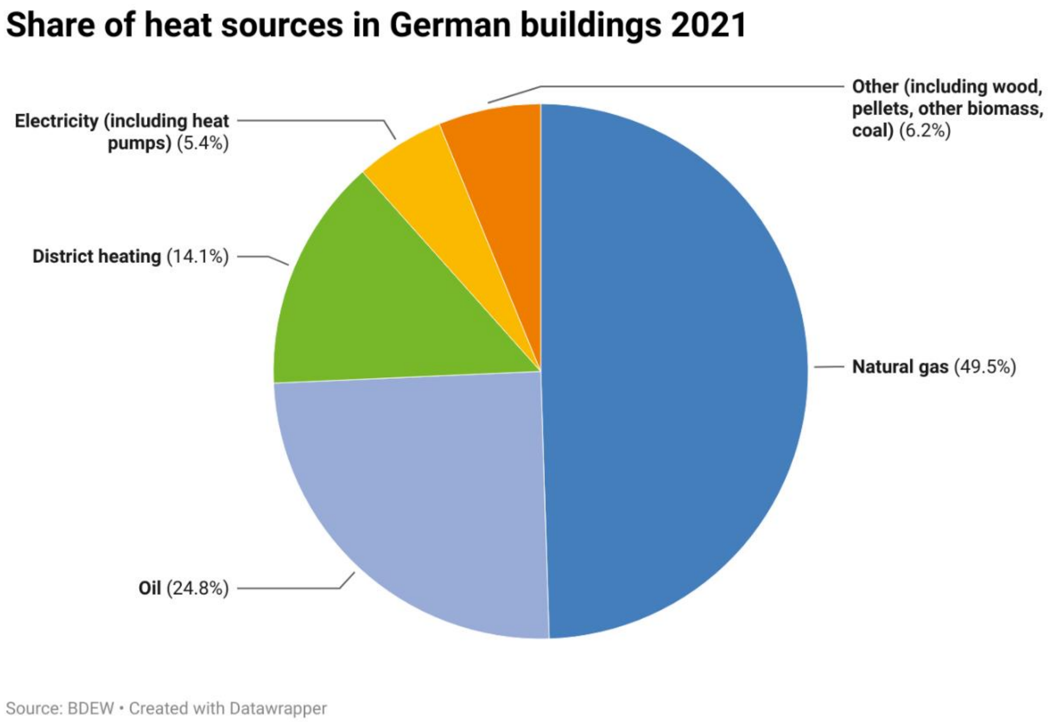

Figure 4. Share of heat sources in German buildings. Based on BDEW.[3]

[2] https://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien_in_Zahlen/Zeitren

[3] https://www.bdew.de/service/daten-und-grafiken/beheizungsstruktur-wohnungsbestand/

2.3 Heating and cooling demand by sector

To restate the introduction: more than 50% of the German final energy demand comes from heating and cooling: 53% in 2018 (BMWi, 2020), and in 2022 only 18% of that was renewable.

2.3.1 Space heating and domestic hot water

In the residential sector, space heating (427 TWh/a), domestic hot water (approximately 100 TWh/a) and process heating and cooling applications (69 TWh/a) account for around 94% of the total energy demand of the residential sector of 636 TWh/a (note that process heating and cooling is omitted here) (BMWi, 2020). Of the 24 million heating appliances in German households, 80% are fossil-based, mainly using heating oil or gas (dena, 2022b); see Figure 4. In addition, some cities have district heating systems powered by gas- or coal-powered cogeneration plants and supply 14% of German households (Schneller et al., 2018).

Building renovation is much slower than necessary. Moreover, although 300.000 heat pumps, biomass, and solarthermal heaters have applied for subsidies, 37.000 gas-hybrid heating systems have also been applied. Next to that, 600.000 new gas boilers were sold, and 45.000 oil boilers (Thomas et al., 2022). So, even though heat pumps are a matured and available technology, they only make up around a third of all newly sold space heating appliances; the rest is still fossil-based.

2.3.2 Services

The final energy demand of the services sector is around 375 TWh/a, 234 TWh/a of which 62% is accounted for by heating and cooling. Similar to the residential sector, most of this (168 TWh/a) is used for space heating (BMWi, 2020).

2.3.3 Industrial process heat

Heating and cooling applications in the industrial sector make up 556 TWh/a or 76% of the yearly energy final energy demand of around 736 TWh/a. Of this, 556 TWh/a, 90% or 496 TWh/a is used for process heating, which is particularly relevant in the industrial sector. The rest is used for space heating in industry and a minor role for cooling applications. The industrial sector has a specific demand for heating in higher temperatures, and currently, this heat is generated with fossil energy carriers, such as natural gas or other process gases. Even though this is usually done with highly efficient CHP-plants, which are more efficient than combustion-only or condensation power plants, they use fossil gases which render a climate-neutral heat production, without carbon capture and storage (CCS) not yet possible (IN4climate.NRW, 2021).

2.4 Introduction to the heating and cooling technologies

As shown in the section before, the heat demand is divided roughly equally between the two major consumption sectors: Industry and Buildings. Heat supply for industry and the built environment can come in two forms: a central or decentralized system. Both forms can be applied with either renewable energy sources or fossil fuels.

2.4.1 Decentralized heating

In a decentralized heating system, every building or industrial user produces heat at the place where it is used, while the fuel is transported to the building or industrial facility. In households and other buildings, this is usually natural gas, oil, or sometimes coal, to be burned in a boiler, which then supplies heat and hot water. 72.5% of Germans indicate that their house is heated with oil or gas in this method (Toptarif & Thermondo, 2016). In addition, some households use biomass (wood) in a hearth or biomass installation, or an increasingly popular option is to obtain heat and domestic hot water (DHW) from a heat pump which converts air into heat (warm water) with the help of electricity, for example from a photovoltaic (PV) installation (Ortner et al., 2021). As a result, the share of heat pumps has steadily increased, accounting for 2.8% of household space heating systems (dena, 2022b). Similarly, process heat in the industry sector can be generated with natural gas, oil, coal, or power-to-heat generation in large heat pumps.

2.4.2 Centralized heating (district heating)

A decentralized heating system uses either of these heat generation technologies on a larger scale. It transfers the heat to the end user using a district heating (DH) system, using a network of highly insulated pipes, which deliver hot water to the end user. Depending on the water's temperature, this can also be used as process heat in the industry (Schneller et al., 2018). Around 14% of German households are connected to a district heating system (Schneller et al., 2018).

The advantages of district heating are that heat can be centrally produced in a highly efficient manner. Other energy sources can be used as well, next to traditional ones: bioenergy, biogas (directly combusted or upgraded to biomethane for using it like natural gas), geothermal energy, solar thermal energy, and waste heat from industry, electricity production and waste incineration (Clausen, 2017). Furthermore, the combined plants that produce electricity and heat (cogeneration or combined heat and power plants, CHP) can provide flexibility, which is becoming increasingly important in an electricity system mainly powered by volatile renewables. CHP plants can switch between heat and power generation, and some can even reverse the process and convert grid electricity to heat (Maaß, Möhring, et al., 2021).

On the other hand, transporting heat through pipes is inefficient (district heating networks lose 8-12% of the heat by transportation, 10.8% average in 2021[4]), making transporting heat over large distances impossible. As a result, district heating networks tend to be used more locally as a municipality's public utility (Clausen, 2017). Since these heat suppliers are not physically linked to others, local monopolies exist on heating supply. Moreover, the heat suppliers might differ in various ways. For example, they have different procedures, use different base temperatures in the pipes (which affects the technical feasibility of adding renewable heat to the network), and do not exchange information and best practices as much as large, interlinked electricity providers do. Thus, there are fewer network effects for heat suppliers.

[4] Based on BMWK https://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien_in_Zahlen/Zeitreihen

Nonetheless, DH systems are a vital future technology for space heating in densely built areas (Schneller et al., 2018). Especially the 4th generation district heating is promising, which operates at lower temperatures (below 70 °C), has a lower energy demand, and optimizes the interaction of energy sources, distribution, and consumption (Thorsen et al., 2020).

2.4.3 Heating and cooling in industry

With home heating and domestic hot water being the lion's share of the heating demand, the 20% used in the industrial sector must also be mentioned. From small glass or ceramic manufactories to immense industrial facilities for steel production, process heat is used in industrial applications ranging from 100 °C to 3000 °C for melting, reforming, hardening, casting, drying and much more (BMWi, 2020). Because of the diverse application and the differing temperature demands, industrial process heat is especially challenging to decarbonize and is dominated by fossil fuels, mainly gas. Later in this thesis, the discussion whether these applications can or should be electrified or switched to hydrogen will be addressed.

2.4.4 Energy efficiency in the heating sector

Unquestionably, efficiency aspects play an important role in the heat transition independent of whether a home is heated using a central or a decentralized system. Better building insulation decreases the heat demand and thus lowers emissions if a fossil heating system is used. In Germany, efforts are being made to increase the rate of building renovation, but this implementation is currently too slow (Engelmann et al., 2021). Similarly, industrial users always make an effort to increase energy efficiency for economic and environmental reasons. It is important to realize that both home insulation as energy efficiency in the energy-intensive industry will have a considerable contribution to limiting emissions from this sector. Even more so, it should be the first step ('Efficiency first') (IEA, 2020), before switching the whole supply to renewables. However, to narrow the scope, this thesis will focus on the production side of heat and not on the efficiency side.

2.4.5 Cooling

Cooling is mentioned throughout the thesis because heating and cooling are seen together in a sector, the HC-sector, and is addressed as such in the EU policy documents and also in the project within which this thesis has been written. However, the 'cooling' transition in that sense is currently of marginal interest in Germany, for several reasons. Firstly, the medium temperature climate makes it a very small part of the energy demand – less than 5% of Germany's thermal energy demand (BMWi, 2020). Secondly, 100% of the cooling energy is drawn from the electricity grid (using air-conditioning), making the cooling transition completely linked to the classic electricity part of the Energiewende. According to the comprehensive assessment of heating and cooling (2020), the demand for cooling (air conditioning) is expected to increase in Germany but will still only represent around 4% of the energy consumption of heating and cooling combined in 2050 (BMWi, 2020). So, in spite of rising temperatures, the focus will remain on increasing the share of RES in heating. Therefore, cooling will not be addressed further in this thesis apart from it being mentioned as part of the heating and cooling sector.

2.4.6 Multiple benefits effect of the heat transition

Next to environmental benefits resulting from reduced CO_2-emissions, there are more benefits to the heat transition – consisting of both energy efficiency in buildings and switching to a renewable heating appliance. This is referred to as the multiple benefits effect. For space heating, this includes increased comfort, health benefits due to the prevention of moister and cold, reduced import dependence and price fluctuations, and increased GDP due to the added value in renovated buildings (European Commission, 2021c). In addition, the energy system can benefit from the increased flexibility, when excess electricity can be converted to heat, or vice-versa (Harvey-Scholes et al., 2022).

2.5 Conceptual differences between heat & electricity transition

As a last topic within this chapter, I want to include some basic differences between the heat and the electricity sectors and their respective energy transitions, to give an understanding of the specific problems the HC sector faces, which we will discuss in more detail later in this thesis.

There are five main differences between the two energy transition branches.

1. The electricity grid is in essence a nationwide, even Europe wide network, where energy-input is mainly centrally organized (and increasingly decentral with PV) but can essentially be fed-in anywhere. It is transferred throughout the network and can be used anywhere. On the other hand, the heating is provided both decentral with boilers in the building, or in district heating grids for each city or region. These district heating networks are not interlinked, so network effects do not apply.
2. Therefore, the ownership of these networks is widely dispersed. Whereas German electricity is provided by four transmission system operators (TenneT, Amprion, 50Hertz and TransnetBW), there are around 550 district heating companies with a network (DHCs), of around 1000 energy supplying companies (Clausen, 2017).
3. Furthermore, the consumers have to be more actively involved: (renewable) electricity comes out of the power outlet and does not necessarily require any action by the homeowner. On the other hand, to install renewable heating, millions of households need internal building-technical changes, either to install district heating, a heat pump or something else, and to install insulation (Thamling & Rau, 2022).
4. In the electricity sector, there are already many best-practice examples for the use of wind and solar energy and, due to many research projects, targeted political guidelines. In the heat transition, the transition paths have not fully crystalized yet and several technological paths are open. The solution might also differ for each region or city, so each local heat transition has a strong individual character.
5. Lastly but most importantly: renewable electricity has proven to be economical, both decentral in roof-PV as for big electricity companies, where new wind parks are more economical than coal or gas plants. That is not necessarily the case for renewable heating, which is currently expensive and could remain so in the near future, due to high investment and implementation costs. That imposes an additional challenge to shape the heat transition in a just way for everyone, that makes sure that everyone can afford to heat their

house. Faster implementation of heat pumps in households will require them to be subsidized (Öko-Institut & Fraunhofer ISE, 2022).

2.6 Changing the system

To conclude this section: heating is a substantial part of Germany's energy demand, using around 50% of Final Energy Demand; 18% is currently renewable. 3/5 is used in the buildings (by households or services), using either a central or decentral heating system, and 2/5 is accounted for by industry, which mainly generate their own, high temperature heat. In the next section, the innovation policy literature is introduced.

3 Introduction to innovation policy literature

This thesis revolves around the creation and improvement of policies to accelerate the heat transition in Germany, in line with EU policy. Therefore, it is important to have a suitable framework to analyze these policies systematically. Some considered options were, for example Strategic Niche Management (Schot & Geels, 2008) and the Multi-Level Perspective (Geels, 2002), as these discuss strategies to help innovations develop into incumbent, widespread technologies. However, while the heat transition challenge in Germany includes innovation challenges and ramping up technology, the focus is more on the interplay of policies to stimulate the build-up of existing technologies. The technical solutions are for the most part available and relatively simple, and they are not, in that sense, innovations that need to be shielded. However, it is about accelerating their growth paths above the natural curve, which requires government intervention to achieve.

Therefore, instead of the more classic transition theories, the chosen framework for the policy-analyzation part of this thesis is the 'Policy Mix' as conceptualized by Rogge & Reichardt (2016). The framework includes the strategy and instruments, over the different dimensions such as government level (EU, national) and time, and using its characteristics (consistency, coherence, credibility, and comprehensiveness) (Edmondson et al., 2019; Hansmeier et al., 2021; Rogge & Reichardt, 2016). Hansmeier et al. (2021) find that there is increased attention to actors and their agency, as well as policies, as aspects of socio-technical system change, and they welcome more emphasis on those topics as opposed to the traditional transition theories (Hansmeier et al., 2021). Furthermore, Kern et al. (2019) show that the policy mix framework has been increasingly used as a lens for research into making & evaluating policy, and mention policy making & implementation, as well as co-evolution of policy mixes and socio-technical systems as major themes for which the framework is used (Kern et al., 2019). This makes the policy mix framework an ideal lens to evaluate the current heating & cooling policies through and may provide guidance for the recommendations part of this thesis about the development of new heating & cooling policies. Therefore, a detailed overview of the policy mix framework is provided below.

Firstly, Rogge & Reichardt have analyzed several definition of the term 'Policy Mix' and identified three main features: they (1) include *objectives*, either abstract or objective, (2) *interaction* between its elements such as effectiveness and efficiency, and (3) the *dynamic nature* of policy is stressed, pointing out that it has developed or evolved (Rogge & Reichardt, 2016). Based on this, the authors proceed to broaden the scope, in the sense that the dynamic nature must be extended so that it captures the *real-world complexity* of policy mixes in the field of sustainability transitions, that it needs to incorporate policy processes *"by which policies emerge explicitly, interact and have effects"* (Flanagan et al., 2011), so that the concept explains the process and evolution of the policy mix but also its effects, and lastly must include a *strategic component* (Rogge & Reichardt, 2016).

Based on this, they define the policy mix as "a combination of the three building blocks elements, processes, and characteristics, which can be specified using different dimensions" (Rogge & Reichardt, 2016). These building blocks are explained in more detail below and portrayed graphically in Figure 5.

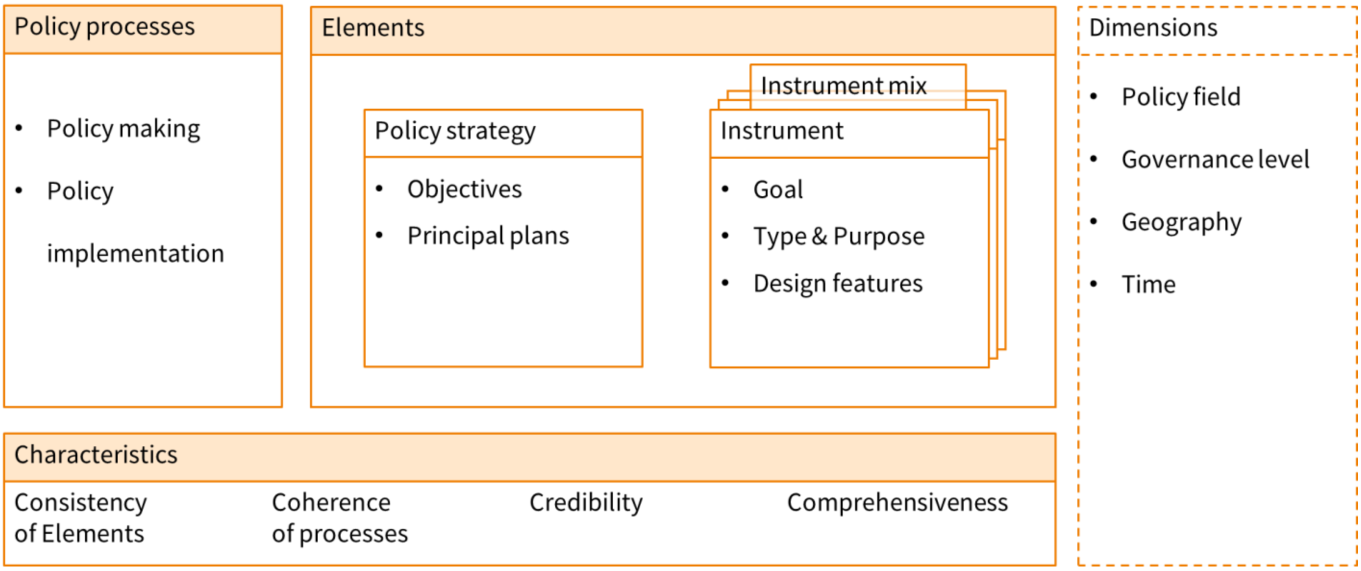

Figure 5. Building blocks of the extended policy mix concept, remade from Rogge & Reichardt (2016).

3.1 The policy mix framework

3.1.1 Block 1: Elements

Policy strategy

Drawing from strategic management literature, the authors find that policy strategy "*consists of a combination of interdependent ends (goals) and means (policies) to achieve these ends*" and define it as a *combination of policy objectives* (usually long-term targets with quantifiable ambition levels) and the *principal plans for achieving them* (outlining the general path to achieve the targets, strategic action plans and roadmaps). In our case, this could concern the communicated targets for 2030 and 2050, the National Energy & Climate Plan (NECP) and, for example the Municipal Heat Plan (*Kommunale Wärmeplanung)* (Rogge & Reichardt, 2016). What the NECP and municipal heat plan entail is explained later.

Instruments

These concern the concrete tools to achieve the objectives from the policy strategy, for example the Energy Efficiency law *EEG* or the EU Emission Trading System. Many synonyms are used for this term, such as measures, programs, and policies – especially 'policy' has a very broad definition – which in this thesis will be omitted as a synonym for instrument for clarity reasons. Instruments have specific goals as well but in contrast to the objectives of the policy strategy, concern the intended effect of the instrument, which should contribute to the objective of the policy strategy. Rogge & Reichardt use a 3x3 matrix (Table 1) to define the different *Instrument types* (regulation, economic instruments, and information, also known as sticks, carrots, and sermons) and *instrument purposes* (technology push, demand-pull, and systemic concerns).

	Technology push	Demand pull	Systematic
Economic instruments	R&D grants, loans, tax incentives, state equity assistance	Subsidies, feed-in tariffs, trading systems, taxes, deposit refund systems, public procurement, export credit guarantees	Tax and subsidy reforms, infrastructure provision, cooperative R&D grants
Regulation	Patent law, Intellectual Property Rights	Performance standards, prohibition of (old) products/practices, application constraints	Market design, grid access guarantee, priority feed-in, environmental liability law
Information	Training and qualification, entrepreneurship training, scientific workshops	Training on new technologies, rating, and labeling programs, and public information campaigns	Education system, thematic meetings, public debates, cooperative R&D programs, clusters

Table 1. Matrix of instrument types and purposes, taken from Rogge & Reichardt (2016).

Instrument design features & instrument mix

The design of a policy instrument might be more important than its type. These features include descriptive design features such as the legal form, the target actors and duration, and abstract features such as (at least) stringency, level of support, predictability, flexibility, differentiation and depth (Rogge & Reichardt, 2016). When there is interplay with other instruments, which is usually the case, this is referred to as the instrument mix – this is only a part of the policy mix.

3.1.2 Block 2: Policy processes

These processes determine the content of the policy mix and thus how the strategy and instruments develop. The authors define it as a "*political problem-solving process among constrained social actors in the search for solutions to societal problems – with the government as a primary agent taking conscious, deliberate, authoritative and often interrelated decisions".* Policy processes occur at various stages of policymaking, including problem formulation, agenda setting, implementation, assessment, etc.

Policy processes can be differentiated into *policy making* and *policy implementation*. For the first, it is argued that policy adaptation and learning are crucial features, which makes monitoring and evaluation important, as well as participatory processes, and secondly that it is a highly political process that often encounters change resistance from actors with vested interests. As for policy implementation, defined as *"the arrangements by authorities and other actors for putting policy instruments into action",* it is particularly concerned with the instrument mix, as poor implementation may reduce the policies' potential (Rogge & Reichardt, 2016). Lastly, the authors point out the *style* of the policy process (for example the kind of goal setting and flexibility) may influence the policy mix.

3.1.3 Block 3: Characteristics

Consistency of elements

Rogge & Reichardt suggest *consistency* as a term to capture how different elements of the policy mix align. This can be about the current state, looking at the alignment of elements within the policy mix over time, or in relative terms, for example by looking at different degrees of consistency across dimensions such as geography or governance level. To be consistent, the policy mix needs to be at least free of contradictions, but strong consistency would need some complementary policies or synergies.

The authors define consistency at three levels: strategy, instrument mix, and consistency of the instrument mix with the strategy. The first level captures whether the objectives align, which means these could be achieved at the same time without trade-offs. In our case: the objective to achieve 1.1% additional renewable energy in the heating & cooling sector should not oppose the objective of energy security at home. It also means that the supporting plans should be free of contradictions. The second level is about the instrument mix. When instruments reinforce each other, and not oppose, as a tool to achieve their policy objectives, they are consistent. The third and last level concerns the interplay of instrument mix and policy strategy, which means that policy strategy and instrument mix should work together and contribute to the achievement of the policy objective. It means that there is both first- and second-level consistency (Rogge & Reichardt, 2016).

Coherence of processes

Somewhat vaguely defined, Rogge & Reichardt find policy coherence "as referring to synergistic and systematic policy making and implementation processes contributing – either directly or indirectly – towards the achievement of policy objectives", with three main features: (1) it addresses coherence of policy processes across different fields and governance levels, (2) needs systematic capabilities of policymakers and (3) is differentiated into a direct and indirect effect of coherence, in which direct effects are about how coherence influences actors and therefore the performance of the policy mix, while indirect effects are about coherence influencing the (consistency of) policy mix elements and thereby influencing their performance indirectly.

The authors find that *policy integration* and *coordination* are important to improve policy coherence. The first is about 'bigger picture thinking' across policy sectors, the second about coordinating tasks among of public sector organizations involved in the policy. Lastly, they point out that complete coherence and consistency might be impossible, and that aiming for maximum coherence is good, it is only a performance indicator next to more classic criteria such as effectiveness and efficiency (Rogge & Reichardt, 2016).

Credibility

Credibility of a policy mix is defined as "*the extent to which the policy mix is believable and reliable*", overall and in regard to its elements and processes (Rogge & Reichardt, 2016). It may be influenced by factors such as commitment from political leaders, and promising operationalization with a consistent instrument mix, or possibly public belief in the goals of the policy. Credibility may be an important factor in the achievement of the policies' objectives.

Comprehensiveness

Comprehensiveness captures how extensive the elements are, and to which degree the processes are based on extensive decision-making. For a comprehensive policy mix, this means that the mix contains at least a strategy with objectives and plans, and at least one instrument operationalizing this policy strategy. A comprehensive instrument mix needs to address all market, system and institutional failures to some degree, combining technology-push, demand-pull and systemic concerns instrument purposes. The comprehensiveness of the policy process is influenced by its structure, rigor and thoroughness (Rogge & Reichardt, 2016).

3.1.4 Dimensions

The above-described building blocks can be applied along some dimensions which define the space in which they interact. They include (but are not limited to) the following dimensions: Policy field, governance level, geography, and time.

Policy field refers to the domain, e.g., climate, energy, environment, technology, etc. This is important as inconsistencies between policy fields can make policy mixes ineffective. The *governance* level is about different vertical and horizontal governance levels. Vertically, we differentiate between local, federal, national, and EU levels, and government departures vs. implementing agencies. Horizontally, differentiation happens between different entities on the same level, for example, government departments of different policy fields. Furthermore, there is the *geographic* dimension, which is about the geographic space the policy mix stems from and influences. Lastly, *time* is an important dimension to consider, as the policy mix with all its characteristics change over time – goals are adjusted or ambition levels raised, the instrument mix may change (or parts of it causing different interactions), and policy processes may also change over time (Rogge & Reichardt, 2016). Additionally, one could consider geopolitical events within this *time* dimension. A recent example would be the covid-19 pandemic, and more applicable to the energy and heat transition, there is the Russian invasion of Ukraine.

3.2 Application of the policy mix framework

The policy mix framework has been used in the literature to explain socio-technical transitions in a similar method as intended for this thesis. For example, Johnstone et al. use this framework to compare disruptions in the clean energy transition between Germany, the UK (Johnstone et al., 2020), and Denmark (Johnstone et al., 2021). Rogge et al. (2020) applied it to the decarbonization transition of the German electricity system (Rogge et al., 2020). The idea is to apply this lens to the somewhat underdeveloped heating- and cooling sector, adding interesting insights to this field.

4 Methodology

This chapter describes the research method of my thesis. I will first describe the link between the thesis and the project I participated in, which served as a prerequisite for the way I was able to conduct the research. I will then proceed with the specific method used for each subquestion.

I have combined the thesis research with an internship at the German Energy Agency in Berlin. This internship helped the research in several ways. Firstly, as the dena is a national energy agency, there are strong links with German industries, experts, stakeholders in the heating- and cooling sector, and the German Ministry of economic affairs and climate action (BMWK). Secondly, the REDI4HEAT project I have participated in is an EU-wide project and thereby creates new links between energy agencies, NGO's and consultancy firms throughout the EU. These capabilities and opportunities within the dena and the project helped me to address my research questions adequately. Lastly, the goals for the dena-workpackages within REDI4HEAT for the first six months also include the overview of the previous and current policies and a dialog with stakeholders. So, there is also a time-span link between the project and my thesis research, which helped me to keep pace.

Now we turn to the specific sub-questions. An overview can be seen in Table 2. Subquestion 1 is addressed with literature research into EU and National policy on the subject and assessments, such as the 2015 & 2020 comprehensive assessment of the heating and cooling sector, using the Roger & Reichardt policy mix lens. More specifically, current and expected policies are categorized into strategy and instruments on either EU or German national level. Subquestions 2, 3 and 4 will be addressed with a literature and project research, followed by a stakeholder analysis. This consists of a Stakeholder workshop conducted within the scope of the REDI4HEAT project and interviews done separately with selected stakeholders. The policy mix framework will also guide the answers to these questions, as they provide an appropriate terminology for the described aspects. However, as the interviews and NSG-workshop do not use the entire policy mix structure, the categorization in either strategy or instrument is used here. The combination of a stakeholder group, interviews, literature research and document analysis make this a 'multimethod research approach.'

Subquestion	Method
RQ 1: Current & expected policies	Document analysis (NECP, comprehensive assessment, regulations)
RQ 2: Stakeholders' roles	Stakeholder mapping, Interviews
RQ 3: Action fields and bottlenecks	Interviews, position papers
RQ 4: Suggested policy strategy & instruments	Interviews

Table 2. Subquestions and corresponding research method.

4.1 National Stakeholder Group Workshop

One of the methods used by the REDi4Heat project is the formation of a National Stakeholder Group (NSG), which includes representatives from all relevant stakeholders. This was done in the five participating EU Member States (Greece, Portugal, Croatia, Poland, and Germany) with at least five, but typically around fifteen organizations. There are three online meetings in 2023, one of which was held on 16 February 2023, during my internship. I helped form the National Stakeholder Group based on earlier dena-contacts in the sector, with the preparations and notetaking during the NSG workshop. The participants in the German National Stakeholder group are listed in Table 3. The selection of these stakeholders were project choices; however, the aim was to have at least one for each group (heat suppliers, district heating networks, scientific institutes, industrial users, government bodies, and experts). Where possible, existing dena contacts were used (for example, if the stakeholder already participated in another project), and in other cases, the organization was contacted by email.

The group workshop was held using the video platform Zoom. The meeting was moderated and recorded for notetaking, and Conceptboard was used as a meeting tool. The first workshop was used to stocktake the different stakeholders' opinions on the (proposed) EU goal concerning renewable heating and cooling and the challenges they encountered during the heat transition on a technological, economical, regulatory, and social level. So, it addressed similar questions as my interviews, but now discussed in a broader audience. The agenda and the result of the Conceptboard can be found in Annex II.

Stakeholder category	Organization
District Heating Network	Ostdeutsches Stadtwerk (OSW) *Anonymised*
Heat Suppliers	Bundesverband der Energie- und Wasserwirtschaft (BDEW)
District Heating Network	Stadtwerke Bremen (SWB)/Wesernetz
Scientific Institute	Agora Energiewende
Industrial users	Verband Energieabnehmender Unternehmen (VEA)
Experts	Steinbeis Transferzentrum für Energie- und Umwelttechnik
Heat suppliers	Deutscher Industrieverband Concentrated Solar Power (DCSP)
Heat suppliers	Bundesverband Bioenergie
Scientific Institute	Fraunhofer ISE
Government bodies	Deutsches Institut für Urbanistik (difu)
Heat suppliers	Bundesverband Wärmepumpe (BWP)
Scientific institute	Institut für Energie und Umweltforschung Heidelberg (IFEU)
Heat suppliers/government bodies	Bundesverband Energiespeicher Systeme (BVES)
Heat suppliers	Verband der Industriellen Energie- & Kraftwirtschaft (VIK)
Scientific institute	Forschungsgesellschaft für Energiewirtschaft (ffe)
Government bodies	Senatsverwaltung Berlin
Heat suppliers/government bodies	Verband Kommunale Unternehmen (VKU)

Table 3. German National Stakeholder group for the heating transition.

4.2 Interviews with relevant stakeholders

Five organizations from the NSG were selected and contacted to arrange an interview to discuss the topic in more detail. At least one NSG member from each stakeholder category was interviewed so that each group would be represented. Additionally, two dena-experts and one DUH expert (Environmental Action Germany) were interviewed. While the DUH was not included in the NSG, they offer a critical view into the policy situation and the role of other stakeholders, such as heat suppliers, which is why they were selected for an interview. The dena-experts were selected to include a neutral view in the discussion.

The interviews were held using a semi-structured method. The interview guide contained a set of standard questions and several tailored towards the specific stakeholder. The guides can be found in Annex I. Furthermore, when the answers sparked additional questions, these were asked immediately. The interviews were held in German, recorded, and then transcribed. The transcriptions were first composed in proper written language (slightly improved from colloquial language) and sent to the interviewee to allow corrections and additions. Next, the interviews were analyzed using theme-color coding and written comments. The color coding and analyzed interviews can be found in Annex I. Next to the analysis per Interviewee, a document was kept with the most important points of each interviewee, with a list of the main consensuses and discussion points when comparing the interviews. Finally, the results of the interviews are used to identify the challenges faced by the stakeholders (or problem areas if they are not actors), answering RQ3, as well as the policy strategy and instruments they find appropriate to address these, leading to the answer to RQ4.

Stakeholder category	Organization	Name	Function	Duration	Date
DH-network (Government owned)	Ostdeutsches Stadtwerk (OSW)	JT, TS Anonymized	Head of Energy Economics department; Expert area development and heat planning.	36:51	13.02 2023
Heat Suppliers	Bundesverband der Energie- und Wasserwirtschaft (BDEW)	Andreas Klingemann	Head of Heating department	36:51	14.02 2023
DH-network (government owned)	Stadtwerke Bremen (SWB)/Wesernetz	Peer Herbe	Senior manager heating department	41:17	06.02 2023
Scientific Institute	Agora Energiewende	Uta Weiß	Head of buildings and District heating program	31:19	15.02 2023
Industrial users	Bundesverband Energie-Abnehmer (VEA)	Eva Schreiner	Head of Berlin office	32:08	17.02 2023
Experts	Dena	Carla Groß	Senior Expert Energy efficiency	24:47	31.01 2023
Experts	Dena	Sabine Erdmann	Senior Expert Planning and consultant climate neutral buildings	40:23	02.02 2023
Environmental NGOs	Deutsche Umwelthilfe (DUH)	Elisabeth Staudt	Senior expert Energy and climate protection	56:02	08.02 2023

Table 4. List of the interviewed organizations.

4.3 Document Analysis

For the literature part, the ScienceDirect search engine was used, using a combination of the following keywords: policy mix, energy policy, heating and cooling, sustainability, and transition. This resulted in articles that were mainly from the academic journals Research Policy, Energy, and Energy Research and Social Science. In addition, some articles were taken from the authors' library collected during the bachelor and master courses.

As for the policy document analysis, the EU documents were taken from EUR-lex, sometimes using their 'consolidated' versions (for example for the RED II) for a clear overview of the different amendments. The NECPs and their evaluations could be found on the EU sites. In addition, position papers from stakeholders or experts and reports from scientific institutes were found using regular web searches. During the searching and reading process, citation software Citavi was used, which helps to sort and store knowledge, notes, and quotations.

5 Germany's policy position on heating and cooling

This is the first of the four 'results' chapters and focuses on Germany's past, present, and upcoming policies concerning renewable heating and cooling. In the end, the chapter aims to answer research question 1.

5.1 Current and upcoming policy at the EU level

The following section will give an overview of strategic and instrument levels of policies. This section focuses on the EU, the next on the German level. For the classification of the policies, the Rogge and Reichardt (2016) policy mix concept is used (Rogge & Reichardt, 2016). A schematic overview of the EU and German policies at strategic and instrument level is shown in Figure 6, the specific policies are further discussed in the text.

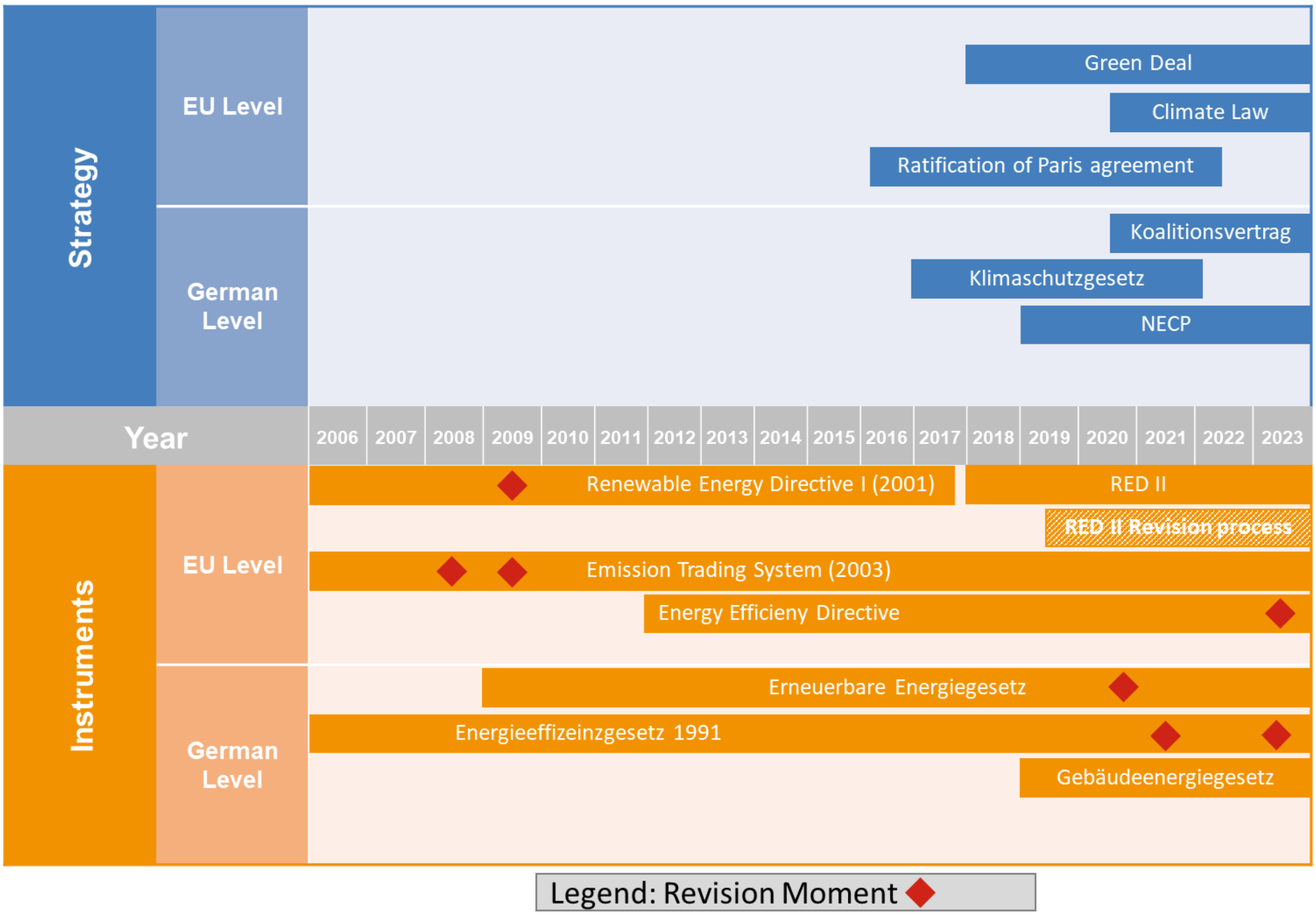

Figure 6. Policy mix for Renewable heating and cooling from EU and German perspective.

5.1.1 Strategy level: EU's ratification of the Paris agreement, the EU climate law and the green deal

Climate change mitigation has been a long-term objective of the European Union, with a rising ambition level. Strategically, the instruments discussed in this chapter fall under the implications of the EU's ratification of the Paris Agreement, which happened in 2016. Here, the EU agreed to taking effort to limit global warming well below 2 °C and pursuing efforts to limit it to 1.5 °C (European

Commission, 2016). Strategically, that has been worked out into the European Green Deal, which sets out a package of policies to reduce GHG emissions in the EU by at least 55% in 2030 and to make Europe a climate neutral continent by 2050 (European Commission, 2019). The goals of this plan have been put into law by the European Climate Law (European Commission, 2021b). Policy instruments that concern climate change, such as the Renewable Energy Directive (RED), Energy Efficiency Directive (EED) and EU Emission Trading System (EU ETS), are (being) amended to align with this policy strategy and include articles about the heating and cooling sector. Even though it is not an official strategy document such as the Green Deal, the “Roadmap Policy support for heating and cooling decarbonization” can be considered strategically guiding in the development of new policy instruments concerning the HC sector (European Commission, 2021c).

5.1.2 Instrument level: RED II (revision) and other EU policy

Current policies concerning the supply of renewable energies in the heating and cooling sector stem from the EU Renewable Energy Directive II (European Commission, 2018b). Energy efficiency policies, such as energy efficiency in buildings, stem from the Energy Efficiency Directive (EED) and Energy Performance of Buildings Directive (EPBD) (European Commission, 2012, 2018a). Of course, energy efficiency plays a big role in the heat transition, and these are therefore important policies. However, this thesis focuses on the supply of renewable energy in heating and cooling and therefore focuses on the RED II and subsequent national policies.

As mentioned in the introduction, an amendment to the RED II was under trilog discussion in Brussels during this thesis research. Towards the end, on March 30th 2023 an agreement was reached (Council of the EU, 2023), concluding the discussion on the council position: a binding average of 0.8%-points for the period 2021-2025 and 1.1%-points for 2026-2030. This outcome was unclear during the research, and all three options shown in Table 5 were considered. Even though the precise outcome was unclear, the discussion mainly entailed implementation details, and the general gist of the amendment was clear: the ambition level for renewable heating and cooling is raised, and only the precise annual percentage, as well as the obligation level, need to be determined. Furthermore, the original position was an indicative 1.1%-points increase under the original REDII and was not achieved in Germany, so an increase at the implementation level would be required in all circumstances. As the RED II (revision) instructs national governments to act accordingly and implement the instructions at the national level, the REDII and similar EU policies can be placed in the instrument field of the policy mix.

COMMISSION	PARLIAMENT	COUNCIL
• Binding average annual increase of **1.1%-points** for the periods 2021-2025 and 2026-2030. *Currently: 1.1% indicative)* • Increase of **1.5%-points** where waste H&C is used (waste HC can count up to 40% of the annual increase)	• Indicative average annual increase of **2.3%-points** for the periods 2021-2025 and 2026-2030 • Increase of **2.8%-points** where waste H&C is used (waste HC can count up to 40% of the annual increase)	• Binding average annual increase of **0.8%-points** for the period 2021-2025 and **1.1%-points** for 2026-2030

Table 5. Trilog discussion positions of the European Commission, Parliament and Council on renewable heating and cooling targets during the Renewable Energy Directive revision process. REDI4HEAT internal document.

5.2 Current and upcoming policy at German national level

In this section, emphasis is laid on the German national level, which – following the EU strategy – has its own strategy and instrument level, but now narrowed down to Germany.

5.2.1 Strategy level: climate protection law, National Energy and Climate Plan (NECP) and 'Ampel' coalition agreement

Germany's goal to reduce 65% of its GHG emissions by 2030, 88% by 2040, and become climate neutral by 2045 are put into law in the Klimaschutzgesetz (climate protection law) (Bundesregierung Deutschland, 2019). For the HC sector, this is narrowed down to the goal of 50% climate-neutral heat by 2030 (SPD, Bündnis 90/Die Grünen, und FDP, 2021).

Germany has also developed a National Energy and Climate Plan (NECP), the *Integrierter Nationaler Energie- und Klimaplan.* Because it has been based on an older emission reduction goal, its plans are meant to reduce emissions by 55% comparative to 1990. This should be achieved by ramping up the amount of renewables to 30% of the energy production while reducing the primary energy consumption by 30% through increased energy efficiency. The focus areas are the electricity, heat, and mobility sectors (BMWK, 2020). The plan states that about two-thirds of Germany's heating demand stems from the built environment and one-third of process heating and cooling in industries. Germany's NECP sets several goals for the heating sector, including district heating (27% in 2030), but simultaneously acknowledges that both the current and the (in 2020) planned policies were insufficient to reach these goals, see Figure 7. Moreover, note that the 2021 coalition agreement increased the ambition level by setting a 50% climate-neutral heat goal in 2030 (SPD, Bündnis 90/Die Grünen, und FDP, 2021). These goals are not fully comparable because climate-neutral heat also includes industrial residual heat and waste incineration, but the goal communicates an increased ambition level. Because the German NECP plans policies on the national level but is not formed into law, it is placed on the strategy field of the policy mix.

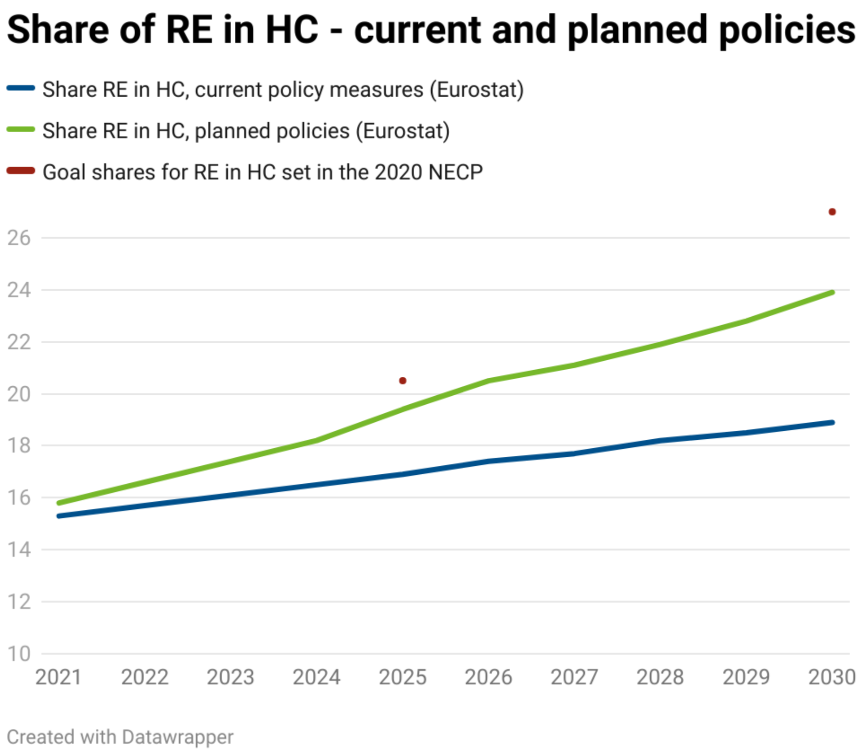

Figure 7. Forecast of the share of Renewable Energy in the heating and cooling sector in the scenario of current – and planned policy measures. Source: NECP, Eurostat.

Assessment of the heating- and cooling parts of the German NECP by the European Commission

The European Commission evaluates all the NECPs and publishes assessment reports for each country. This report states that Germany's current plan will almost close the gap to the 2030 ESR (Effort Sharing Regulation) target from 14% to 3%. However, it finds that the NECP lacks detail on the expected impacts of some measures and appears insufficient to ensure the targets are reached, most of all in the heating and cooling sector (European Commission, 2020).

Germany's aim to achieve a 27% share of RES in the HC sector in 2030 aligns with the indicative target of 1.3% annually and 1% for District Heating. It criticizes that even though an increase in waste heat is expected, that contribution is not quantified. The RES increase in heating and cooling mostly comes from biomass, next to heat pumps, geothermal and solarthermal. The assessment criticizes that these planned measures are insufficient because there is too little detail on their effects; furthermore, there is no impact assessment on the impact of biomass on the LULUCF sink (European Commission, 2020).

5.2.2 Instrument level

The most important German instruments concerning renewable (heating and cooling) energy are the Gebäudeenergiegesetz (Building efficiency law, GEG) (revised 2018/2019, new draft in 2023), the Erneuerbare-Energien-Gesetz (Renewable Energy law, EEG), and the Kraft-Wärme-Kopplungs-Gesetz (CHP-law, KWKG) 2019, the latter however still subsidizes new (fossil) CHP plants, as they were seen as more efficient energy and heat suppliers.

Another important law that prohibits further electricity production from coal plans in 2038 is the 2020 Kohle-Ausstiegsgesetz (coal-exit law, KohleAusG) (Bundesregierung Deutschland, 2020). For parts of Germany, this goal is increased to a complete phasing out coal by 2030 (SPD, Bündnis 90/Die Grünen, und FDP, 2022).

More relevant policy instruments on HC are listed in Table 6. The list is not extensive, but it shows the variety of policy instruments used to address the current heat transition. Moreover, inconsistencies can be observed, for example, when comparing the subsidy programs targeting fossil CHP on the one side and building renovation and changing space-heating appliances on the other. Furthermore, it shows how district heating is more leniently regulated with no price regulation and complete transparency, which is the case for electricity and gas.

Policy instrument	Last amendment	Type	Relevant content
Erneuerbare-Energien-Gesetz (EEG) 1991/2000	2023	Current law	Sets 80% Renewable electricity goal for 2030
Gebäaudeenergiegesetz (GEG) 2019	2023	Current law	Combines efficiency law with renewable heating law; regulates building energy efficiency.
Bundesförderung für Effiziente Gebäude (BEG)	2023	Subsidy program	Subsidies for building renovation; subsidy for change of space-heating appliance with reduction of at least 65%.
Energie-Effizienzgesetz (EEG) 1991	2023	Current law	Support for green hydrogen and biomass; tendering of new plants
Kraft-Wärme-Kupplungs-Gesetz (KWKG) 2015	2023	Current law	Subsidies for new (efficient) CHP plants. Bonus for including renewable energies.
Kohle-Ausstiegsgesetz 2020	2020	Current law	Prohibits further electricity production by coal from 2038
Koalitionsvertrag Ampel 2021-2025	2021	Coalition agreement/Policy plan	Phase-out of coal by 2030
Energiewirtschaftsgesetz (EnWG) 1934	2022	Current law	Full regulation of gas- electricity supply, prices, and transparency
Verordnung über Allgemeine Bedingungen für die Versorgung mit Fernwärme (AVBFernwärmeV) 1984	2021	Current law	No price regulation for district heating except misconduct control by the federal cartel office; price transparency but no transparency for RE-shares
Brennstoff-Emission-Handelsgesetz (BEHG) 2019	2022	Current law	Regulation of CO_2-emission trade for sectors not covered by the EU ETS from 2021 onwards. Prices range from €25/ton CO_2-eq. to 30 in 2022 and 2023; from 2026 onwards, there is an auction.

65%-RES in space heating appliances	Expected 2023	Intended policy	Prohibition of installing space heating appliances below 65%-RES content after January 1st. 2024
Gesetz zur kommunalen Wärmeplanung	Expected 2023	Intended policy	Municipalities have to compose a municipal heat plan. All potential local sources of heat must be identified

Table 6. Overview of policy instruments concerning renewable heating and cooling. Source: internal aggregation within dena project on regulating third party-access in district heating.

In 2022, BMWK minister Robert Habeck announced a rule making at least a RE level of 65% mandatory in new buildings and new heating appliances, starting January 1st 2024 (BMWK & BMWSB, 2022a). This has not been put into law yet but is an instrument that should increase the number of renewable heating appliances (heat pumps, district heating connections) in homes. The 65% almost means a prohibition of gas boilers, but it is also possible to use a hybrid application. At the same time, the minister announced a goal to install 500.000 new heat pumps every year (BMWK & BMWSB, 2022b).

Another planned law is the municipal heat planning law, which was announced in a discussion paper by the BWMK. It suggests that every municipality should conceptualize a regional heat plan to efficiently coordinate how heating technology should be used (BMWK, 2022a). This idea is welcomed by both renewable energy associations and municipalities, including several reservations (on, for example, the municipality being the shareholder of the local utility company) (BEE, 2022; DStGB, 2022).

5.3 Applying the policy mix framework

Considering all this information on the German heat transition and the related EU and German policy, it is possible to fill in the policy mix framework which was established in the introduction. This gives a good overview of the policy situation.

5.3.1 Block 1 - Elements

Strategy:

The strategy part of the policy mix is firmly represented. Germany has clear Long term policy objectives, which are Paris aligned: Carbon neutral in 2045, a 65% reduction by 2030 compared to 1990 levels (Bundesregierung Deutschland, 2019). Furthermore, a goal of 50% renewable heat is set for 2030. However, this is only published in the coalition agreement at the moment of writing (April 2023) and has not yet been put into law (SPD, Bündnis 90/Die Grünen, und FDP, 2021). To go along with these national goals, Germany has (in accordance with the EU Renewable Energy Directive) published an NECP with an overarching plan, including the proposal for regional heat planning. So, the strategy element is present and clear.

Instruments:

Many policy instruments influence the heating and cooling sector, from energy efficiency in buildings to central and decentral heat supply. However, only some of these have been aligned with the strategy. Other instruments in the field stem from before and do not steer towards the same goal.

For example, the subsidies for gas CHP do not align with the RES goal. On the other hand, the 65%-renewable heating instrument, and the local heat planning instrument work towards the overarching strategy.

Instrument design & features of instrument mix:

In the instrument design and features element, the stringency level and interplay with other elements is considered. Looking at stringency, Germany is – unstereotypical – not so stringent. Climate, and heat transition regulation is usually in subsidy form, or in a vaguely defined form without concrete prohibitions or mandatory actions. An example of this is the mentioned plan to restrict new buildings to implement a heating source with 65% renewables – instead of an outright prohibition of gas and oil boilers (BMWK & BMWSB, 2022a). In interplay with other instruments, especially the combination with instruments on other government levels is difficult. Nationally defined goals and plans are interfered by regional (Bundes) or municipal regulations such as Monument preservation.

5.3.2 Block 2 – policy processes

On the national level, policy shaping happens at the ministries. These will propose policy instruments, or devise plans, and publish these before they are discussed in the coalition meeting, after which they can be changed and subsequently sent to the parliament. For example, the 65%-RES in heating appliances rule was first published and is now discussed in the coalition (BMWK & BMWSB, 2022a). Often, a participatory part is included, with roundtables where stakeholders can engage in the new policy, or a process in which stakeholders can hand in position papers – in some cases, dena is implementing these stakeholder dialogues. Another route is a combined policy package, usually as a result of a coalition meeting to resolve several issues at once, or to tackle a crisis: for example, due to the energy crisis resulting from the Ukraine war, an 'Easter Package' was produces to address the energy crisis (BMWK, 2022b). After policies have been formed at the national level, they need to be translated into regional, and later into local laws.

5.3.3 Block 3 – Characteristics

Consistency of elements

In a sense, new laws are being developed that fit within the bigger policy objective, climate neutral by 2045, and for heating 50% emission reduction by 2030. However, some older regulation is in place (such as the KWKG, which subsidizes gas heating), that is not fully aligned. More inconsistencies arise when looking at the municipal and regional levels. Moreover, even though the climate goals are the same for different government fields, sectors and ministries respond differently. For example, the energy and climate ministry and the traffic ministry underly the same policy goal, but the energy and climate ministry responds with more ambitious policy instruments.

Coherence of processes

Coherence of process is vaguely defined in the framework, and therefore difficult to fill in. The concept is about policy integration and coordination. This entails bigger-picture thinking across policy sectors and coordinating tasks among public sector organizations. The synergy in the heating sector is obvious: a secure, sustainable, and affordable heating supply in the built environment ties in with the theme of energy poverty alleviation and health. A heat transition without addressing energy poverty will not work.

Credibility

Criticism is mainly aimed at the big 'how' questions on the operationalization of the policy goal and its instruments. For example, these include economic and technical questions, and implementation questions such as the deficit of skilled workers. They do not target the aim of the policy or the why: at least from the perspective of the relevant stakeholders, the credibility of the policy is not questioned. (Except the environmental NGO, who find it is lacking).

Comprehensiveness

The energy transition, and with that the heat transition policy goal and subsequent mix may not be perfect, considering the points laid out above, but it does consist of a strategy with objectives and instruments that address the market. It has not fully crystallized yet, and open questions remain, including the discussions about decentral hydrogen, technology openness, and third-party access to address monopolies surrounding district heating.

5.4 Dimensions

Figure 8 describes the dimensions of the EU policy on renewable heating and cooling (RHC). Interestingly, the policy mix around RHC moves between many dimensions – except the field. The field is energy and climate – possibly with links to the building and industrial sectors. Regarding the governance level, policy on this topic clearly follows the 'chain of command' in that sense, from the EU to the national level, at which it is applied and influences regional and municipal governance. Geographically, the dimension moves from a large scale (EU/Europe) towards Germany and its regions. Finally, timewise, the EU policy is currently in its run-up (parliament adoption is estimated to follow in late-2023 or 2024), after which it will be translated into national law. However, we must not forget the cyclical nature of EU and national policies – both at the EU and national level, policy (instruments) regarding RHC are already in place.

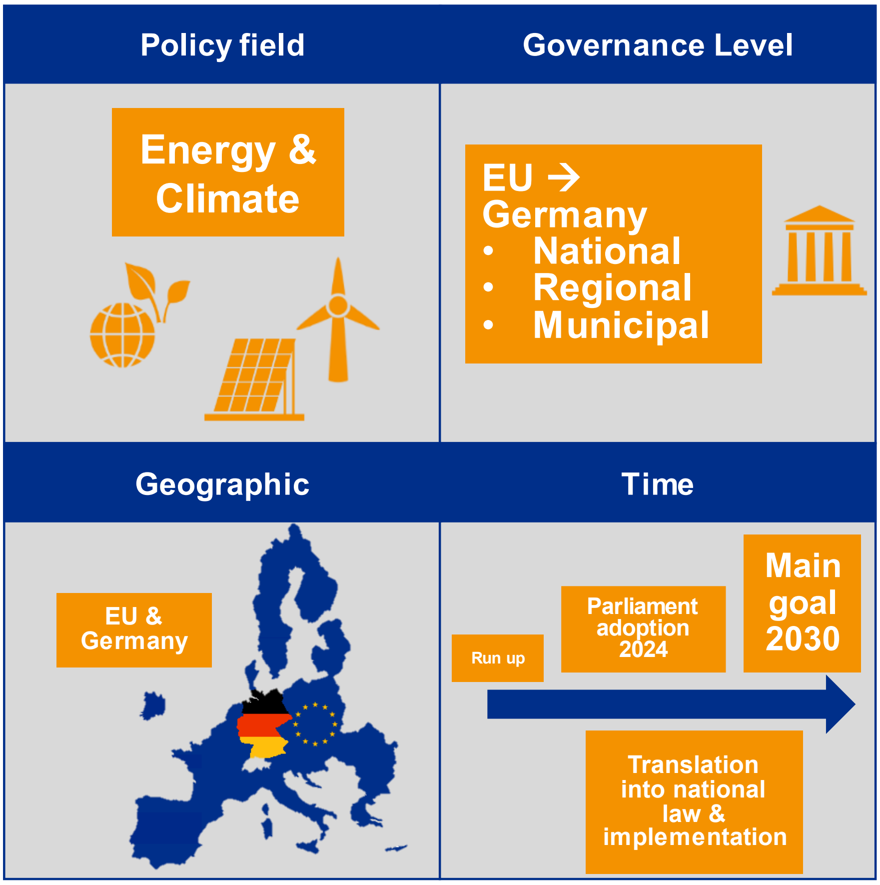

Figure 8. Policy mix dimensions: From EU law to national implementation.

5.5 *Answer to RQ1: what is the current state of RHC in Germany?*

The amount of renewable energy in heating and cooling in Germany is comparatively low, with only 18% compared to 46% in electricity. Building renovation is too slow, and newly installed heating appliances are still mostly fossil-based. Both large and small-scale industries are dependent on natural gas.

Both on the strategy as the instrument level of the policy mix, Germany has many laws and plans to accelerate the heat transition. However, even though the emission reduction targets in the HC sector are ambitious, policy instruments do not fully align with the goal, so the consistency of elements is low. This is partly because existing laws have not been changed accordingly and in time, while new laws that do align are now being introduced or announced.

In the next chapter, we will examine the stakeholder's opinions on the German policy mix regarding renewable heating and cooling.

6 Stakeholder analysis

This chapter will introduce the stakeholders in the German heat transition and expand on their aims and roles in the heat transition, answering research question 2. This stakeholder analysis refers mainly to the formation and composition of the REDI4Heat national stakeholder group (NSG). Each stakeholder's role in the heat transition is described, after which their points put forward in the NSG and interviews are discussed. The following stakeholder (groups) have been identified: government bodies (including the Federal Ministry of Economic Affairs and Climate Action), heat suppliers, district heating networks (grid operators), industrial users, consumers, scientific institutes, environmental NGOs, and experts (for example from an energy agency such as dena). All these stakeholders are essential for reaching the heat transition goals. Figure 9 shows which stakeholders were included in the NSG and which have not. For the ones that have not been included, there are several reasons. In the case of government bodies, the municipality of Berlin has been included in the group. However, it was not yet possible to include a representative of the ministry, which would have been better. The environmental NGOs were not in the stakeholder group but were selected for an interview to include a critical view from an environmental position. The experts represent the consumers, which is possible because they have a clear enough position: access to reliable, affordable, and if possible renewable heating. Lastly, some stakeholder groups were represented by individuals or individual companies, whereas others were represented by lobbying or interest associations representing that group.

6.1 Description of the stakeholders

The idea of the NSG workshop and interviews is also to see which roles the stakeholders have in the German heat transition. Furthermore, their opinions on which policy instruments need to be changed, and what challenges are present in the heat transition also express what the stakeholders need to fulfill their role better. For a quick overview, Figure 9 shows all the stakeholders' main roles, raised points, challenges, and suggested policy changes. Each stakeholder group is discussed in more detail below. After this section, the statements by each stakeholder (from either the group or the interviews) are discussed in turn.

Government bodies

Government bodies include municipalities, Bundesländer (regional governments), and the Federal Ministry of Economic Affairs and Climate Action (BMWK). As mentioned, at the time of finalizing this thesis, no representative of the federal ministries participated in the NSG, but a representative from the city of Berlin *(Senatsverwaltung Berlin)*, which is a Bundesland and a municipality. On various levels, a government has the responsibility to implement the EU goals for renewable heating and cooling. Depending on the political situation, they may have incentives to do this faster or slower. The government body in the National Stakeholder Group, the municipality of Berlin, has created a renewable heating strategy to provide a 100% renewable heating supply by 2050 (Dunkelberg et al., 2021). They will also have to create a municipal heat plan to identify all potential sources for renewable heating and plan which heating technology should be used at what location.

Heat suppliers

Heat or energy suppliers are utility companies that supply gas, electricity, or heat (but are not the district heating operators). The must adhere to EU goals implemented into national and municipal regulations. It is expected that their position is to remain profitable, but simultaneously work towards company-set goals to decarbonize. Bundesverband der Energie- und Wasserwirtschaft (BDEW) (association of energy and water industries) is included in the NSG to represent the heat suppliers here. The BDEW is a lobbying and interest group for the electricity and energy sector, representing more than 1900 companies among which the big suppliers such as RWE, E.ON and Vattenfall (BDEW, 2023).

District heating networks (grid operators)

District heating network operators are usually municipally owned utility companies that are responsible for the district heating network (and sometimes also electricity, gas, and water supply) for a specific city. The expectation is that they want to remain profitable, in charge of their network, and keep their business. So, they probably want no (complete) transfer of their business into public property and want to decarbonize at a steady rate to become future proof. In the stakeholder group, they are represented by one anonymous East-German utility company and the utility company of Bremen, Stadtwerke Bremen (SWB)/Wesernetz.

Industrial users

Within the topic of heating, we distinguish between home heating and DHW and Industrial (process) heat. Therefore, industrial users of heat are included in the NSG. We expect them to have a demand for high temperature process heat for a competitive price, in order to have a level playing field in international competition, and a strong reliance on natural gas. The industrial users are represented in our stakeholder group by the Bundesverband der Energieabnehmer (VEA) (association of energy consumers), an umbrella organization representing 4500 SMEs with a high energy demand, for example in the glass and ceramic production. Their heat demand ranges from several hundreds to 3000 °C (VEA, 2023).

In the interview, the VEA expressed that the often-thought demand for hydrogen from industries using process heat might be lower than expected. Their estimation is that for a large part of their companies, electrification is possible, and hydrogen is only really needed for a limited part. Furthermore, the VEA restated the three necessary steps in the heat transition: efficiency first, then electrification, and as a third and last option hydrogen.

Consumers

Consumers of home-heating and domestic hot water need a certain comfort level, be able to heat their homes and have access to hot water, for an affordable price. They may or may not have interest in the sustainability level of their heat supply. Consumers may prefer to have a choice of supplier, which is something to consider when discussing district heating as this comes with a monopoly and occasionally higher prices. More on the consumer position is discussed under the experts and environmental NGOs sections.

Scientific institutes

Scientific institutes can provide the necessary knowledge and support to shape and strengthen policy, as a basis to have a good transition. They have an interest in a successful implementation of renewable heating but no direct stake. In the NSG, Agora Energiewende was included, which is a leading think in the German energy transition that provides advice to the government and other actors (Agora Energiewende, 2023b).

Environmental NGOs

Environmental non-governmental organizations (NGOs) have a stake in the heat transition in the sense that they advocate for a quick and socially just decarbonization, usually faster than the national, EU or Paris goal but according to the IPCC recommendations. Their aim is to put forward their opinion on how the heat transition must take shape. Unfortunately, no environmental NGO was included in the NSG, but I was able to interview a representative of Environmental Action Germany *(Deutsche Umwelthilfe, DUH).*

Experts

In order to put the stakeholder opinions in context, two dena-experts were interviewed, one specialized in energy efficiency, district heating, and regulation, and one in climate-neutral buildings and building regulation.

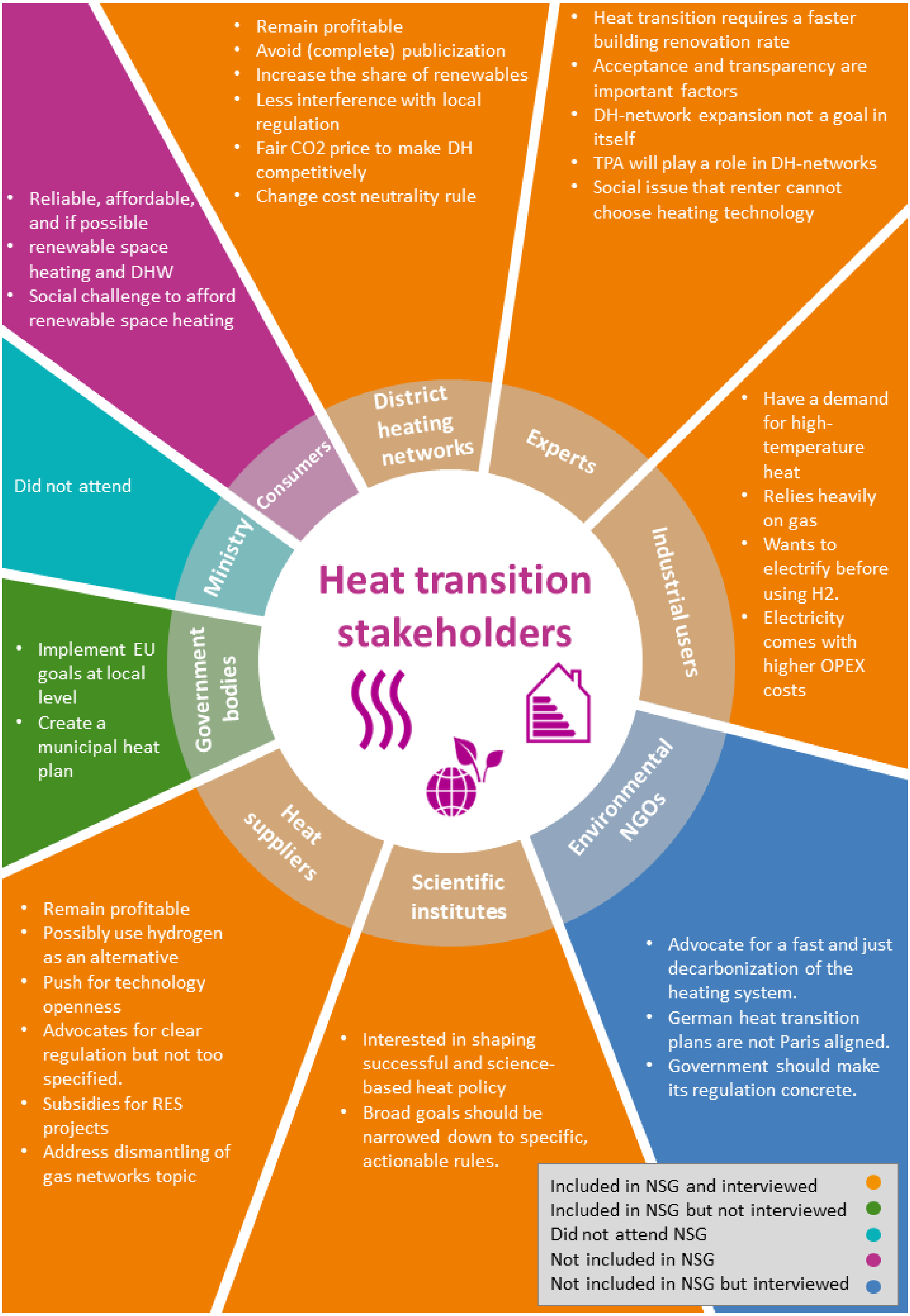

Figure 9. The heat transition stakeholders, their roles, and main points from the interviews.

6.2 Main consensus from the interviews and NSG- workshop

The following points are mentioned by almost all the stakeholders and are therefore accepted as consensus points. These are discussed first, together with the main discussion points, after which the specific points of each stakeholder are discussed in more detail.

To begin with, there is a consensus on the general technological direction of the heating transition. The main decentral technology in the heating transition is the heat pump, and the main central technology is district heating. District heating is mostly going to be used in densely populated areas. For example, this is recognized in scenarios for the future heating supply in the built environment (Maaß, Sandrock, et al., 2021; Thamling & Rau, 2022). However, the stakeholders also agree on several critique points and challenges. Firstly, it is pointed out that regulatory inconsistency and a high bureaucratic burden hampers the energy and heat transition. Secondly, there is a massive deficit of skilled workers, which are needed in many places in the heat transition and energy transition overall, such as: home renovations to increase energy efficiency, installations of renewable, decentral heating equipment such as heat pumps, expanding the district heating networks, decarbonizing district heating networks by adding new solarthermal, geothermal, biomass, industrial waste heat and power-to-heat installations, and expanding the electricity network to cater the increased electricity demand due to (large-scale) heat pumps. Furthermore, it is problematic that, in any case, renewable heating will, for the time being, be more expensive than gas. Therefore, the cost-effectiveness of decarbonizing heating is not as visible and economically feasible as it is for electricity. Lastly, it is mentioned that it is challenging that the heat transition includes many small actors compared to the electricity market. This includes millions of households and many more energy suppliers and networks (several hundred, compared to five electricity network companies).

6.3 Main discussion points arising between stakeholders

Stakeholders do not agree on three big topics in the heat transition. The first is decentral hydrogen use, where the question is whether hydrogen should be used as an alternative to natural gas, using regular, but ‘H2-ready’ gas boilers. The second concerns technology openness, which discusses whether the government should clearly direct which technologies should or should not be used in the heat transition or, on the other hand, offer an open technological road towards a government-set dot on the horizon, thereby stimulating more innovative solutions. Lastly, the issue is raised about who should pay for dismantling the gas network, which becomes increasingly more inefficient and uneconomical once more users switch to more renewable forms of heating. These three discussion points are addressed in more detail in chapter 7.

6.4 Stakeholder positions

In this section, the stakeholder groups are discussed in turn, discussing their specific points and challenges in greater detail. A summarized overview of these positions can be seen in Figure 9. Furthermore, an explanation of the stakeholder positions is provided.

Heat suppliers

During the interview, the federation of heat suppliers BDEW mentioned several important aspects of the heating transition in their sector. Concerning law shaping, they argue that EU law is often inspired by German law, which is then slightly changed and comes back in different form. The BDEW thinks that 37 to 40 thousand industrial companies will need a supply of hydrogen for a successful heat transition. Therefore, they propose using the gas network for hydrogen, or mixing natural gas and hydrogen. Furthermore, they find hydrogen a valid alternative to the 12 electricity 'highways' that are otherwise necessary to transport electricity from the wind parks in the North Sea to southern Germany, which has a high energy demand. Furthermore, the BDEW pushes for technology openness, clear regulation, and subsidies for RES projects. That means that the government should set a clear goal but should not dictate the road to get there. Sub-goals such as the 65% RES in individual heating units distract from the primary goal and complicate the transition, and excluding specific technologies slows the transition down.

This position on hydrogen and technology openness can be explained due to the vested interests of the heat suppliers BDEW represents, who own the gas networks and are interested in a heat transition that uses the gas network instead of an electrification-focused heat transition. However, they realize that the gas network needs to be dismantled too: it is brought up that the utility companies also own the gas networks in their municipalities, the dismantling of which needs to be paid for somehow. This is an essential topic for the companies owning the gas networks because the network becomes increasingly inefficient when more people decide to disconnect.

Lastly, a problem concerning home renovations and changing to heat pumps is addressed: the average German homeowner is 61 years old and cannot get a mortgage for the necessary investments. That is a social problem that needs to be addressed somehow.

District heating operators

The East-German utility company (OSW) and SWB/Wesernetz, both district heating operators, have both developed ambitious decarbonization goals (2035 and 2038), partly due to the municipality being the main shareholder. However, the projects necessary to achieve that (usually in big chunks and not in yearly percentages) and the expansion of the network itself, both necessary for the heat transition, are sometimes hindered by municipal or regional regulations that do not align with the long-term goal. Here, the mention monument preservation laws, road protection, and an area permit that assigns the area to lignite production. This is a sign of incoherence between policy strategy and its instruments.

The district heating companies also address two pricing problems. Firstly, they point out that district heating has to be offered as 'cost-neutral,' which means at the same price as gas heating. However, it is calculated using the gas price of three years ago, which is an uneconomical price for the DHC to offer. Here, the cost-neutrality law and the CO_2-neutral goal for 2035 or 2038 interfere with each other, which is another inconsistency. A second price-related inconsistency is that DHCs are seen as big emitters and pay CO_2 tax under the EU ETS system, which is currently around €80 per ton of CO_2. This is calculated into the price for DH users, which are often renters. On the other hand, homeowners with a gas boiler pay the German CO_2 price which is capped at €35 per ton. This makes it challenging to offer DH competitively and causes poorer (renting) households to contribute to higher CO_2 tax than homeowners, which is a social problem.

Industrial users

The VEA, the association of energy consuming companies, mentions the three biggest push buttons for the heat transition for the industrial sector. Firstly, there is the CO_2-pricing system, which will heavily increase the price of natural gas in the future, rendering it uneconomical to continue using gas-based heating on a long term. Secondly, they mention legal action taken by NGOs. This happens with an increasing success rate and can cause economic and reputational damage to businesses. Third and last, big companies setting own emission goals are mentioned, which ‘weed out’ their supply chain of OEMs (Original Equipment manufacturer) of the biggest emitters. The suppliers will have to keep pace.

Turning to the largest challenges for the industrial consumers, the VEA mentioned the following bottlenecks: different than in the built environment, there is no matured technology to decarbonize high temperature process heat. Both electrification and switching to hydrogen require more research and development. Moreover, the electrification road means an even higher demand for renewable electricity. This opens new challenges, for example the question of own production, the possibility of Power Purchase Agreements (PPAs), and the technical question of high-capacity connections to many industrial users. However, because (renewable) electricity prices are still much higher than gas prices, electrification will cause an increase of OPEX costs that OEMs may not recover in higher prices, as they are in international competition.

What is interesting about the VEA’s position is that it does not align with the heat suppliers’ idea of a hydrogen-based industrial sector. Other than the heat suppliers, the industrial users have no interest in a continued use of the gas network. They are interested in having their processes supplied with renewable heat, at an economical price. If this is technically feasible with direct electrification, there is no reason to prefer hydrogen.

Scientific institutes

According to Agora Energiewende, a leading scientific institute, the following points are important to consider in the heat transition. Firstly, the heat transition consists of many small actors, millions, including everyone who produces their own heat privately, making it diverse and small-scale. They find it necessary to break down a broad goal into specific rules at individual level, to make actions concrete. The 50% overall target for RES in HC does not apply to anyone specific, but the 65% RES in new individual heating units does. This implementation step is necessary, to link individual companies, users or in this case building owners to specific actions. The same applies to the regional heat planning: the conclusion might be that for some areas, a connection to the DH-network becomes mandatory to make it efficient.

On the topic of gas networks, Agora suggested that they might not need to be dismantled, and that it is possible to disconnect them and leave the network safely in the ground (Agora Energiewende, 2023c). Lastly, it is pointed out during the interview that asking if a climate goal is realistic, is a stupid question. We either achieve it, or face the consequences. These positions fit with their role as a scientific institute, making science-based suggestions, and in that way offering solutions to the discussions on, for example, the dismantling of the gas network.

Environmental NGOs

The DUH, (Environmental Action Germany), has a very clear opinion on the heat transition. First, they point out that the goals for the heat transition in Germany are not Paris-aligned, and even worse, we are not achieving them. A clear example of a failing policy instrument in that respect is that new gas CHP plants are installed and subsidized (an example of inconsistency between strategy and instruments), and two thirds of all newly installed home heating equipment are gas boilers, and only one third (300.000 yearly) are heat pumps.

The DUH criticizes the German style of policy making in general. They find it unclear and difficult: instead of concrete rules connected to the long-term rule, such as a prohibition for installing new fossil heating equipment or building new fossil-based energy plants, imprecise and unclear goals are developed after which it takes time to work out what it means for the market. So, at this point they criticize the technology-open style of policy making. Instead, the DUH suggest stronger policy instruments, which are discussed later.

The position of the DUH is unsurprising but is rightfully critical as they identify similar inconsistencies as other stakeholders. Furthermore, it is understandable that the DUH advocates a more technology-closed path, as they have no vested interests in the system as it is but aim for a fast and efficient heat transition. On the other hand, they miss the regulatory inconsistencies at the implementation level, which are more important to the DHCs, for example, who face the practical challenges of the heat transition.

Experts

The experts are discussed here as the last of the stakeholder groups. They have no vested interests in that sense but point out relevant issues that have not been discussed yet. One point is that changes may occur when new EU regulation is being discussed, which can take a long time. Therefore, governments tend to wait with implementation into national law. Furthermore, policy instruments that subsidize industries take more time to install, because it is not allowed to subsidize national industries under EU law unless it serves a political goal such as the energy transition.

In the field of space heating, it is pointed out that the heat transition requires many building renovations, and the rate at which that is happening is also not approach its goal of 1.3-1.4% yearly. Furthermore, there are still subsidies for fossil home heating units, but these are being phased out.

Acceptance, and therefore transparency, is an important factor in increasing support for district heating. While the electricity and gas sectors are fully regulated, district heating is not. Therefore, regulating transparency will increase acceptance of the technology, which is necessary to accelerate the expansion of the DH-networks. However, DH-network expansion is not a necessary goal in the heat transition; decarbonization is. Moreover, they point out that Third-party access (TPA) will play a role in district heating networks to address the natural monopolies.

Lastly, they point out that people renting a house cannot choose which heating technology is installed in their house, which is a social issue.

6.5 Answer to RQ2: the relevant stakeholder groups and their role in the heat transition

The discussed stakeholder groups are: heat suppliers and district heating network operators, who are both responsible for the supply of heat and are challenged with the implementation of the heating transition; consumers and industrial users, who have a demand for reliable, affordable, and renewable heat, the latter with a specific demand for high temperatures; government bodies, including the ministry, who have to regulate the market and steer towards a higher share of RES; and lastly experts, scientific institutes and environmental NGO’s, who want to shape the heat transition science-based and climate-conscious.

The stakeholders agree on several topics, such as the need for clear and coherent regulation, and the general path of the heat transition focusing on heat pumps and district heating. Moreover, they acknowledge the same challenges such as bureaucracy, the deficit in skilled workers, lacking cost-effectiveness of the heat transition and the enormous numbers of actors that need to cooperate. The next chapter turns to the mentioned discussion points and further explores the challenges highlighted by the stakeholders.

7 Action fields: discussion points & bottlenecks

This chapter is about the principal bottlenecks addressed by the stakeholders, both concerning policy (instruments) as societal problems raised that are related to the heat transition. This forms an answer to RQ3. The solutions the form of policy instruments that have been suggested by the stakeholders are discussed in chapter 8. To begin with, the stakeholder positions on the mentioned three discussion points hydrogen, technology openness, and dismantling of the gas network are explained.

7.1 Discussion points in the heat transition

7.1.1 The role of decentral hydrogen use

Hydrogen is a highly versatile energy carrier that can function as a ‘joker’ in the energy transition. Applications that are difficult to electrify, such as high-temperature industrial process heat, aviation, and freight shipping could benefit from the flexibility offered by hydrogen due to its energy-dense storage capacity, which also makes it suitable for energy storage. However, hydrogen is also suggested for sectors where electrification or other solutions are technically feasible, such as transport, and the discussion topic here: building heating. The problem is that the supply of renewable hydrogen is limited, and demand by sectors that cannot decarbonize is likely to be high. Therefore, choices must be made in which sectors hydrogen will play a role, and in which it, despite technological possibility, should not. In the case of space heating, it is widely accepted that hydrogen is wasted on that sector because several feasible technologies can be applied instead. However, it is pushed by gas-suppliers and network owners in order to keep their market (Gabbatiss, 2023). Looking at our stakeholder group, the opinions on decentral hydrogen are as follows:

- Most stakeholders agree that using the scarce hydrogen supply for decentral heating is extremely unhelpful. Especially environmental and scientific organizations stress this point.
- Incumbents, especially gas providers want to continue using their network, so they argue that this is necessary for industry, possibly mixed with natural gas in the current network. The claim is that hydrogen can bridge the electricity-transmission-bottleneck between the supply from wind parks in the North of Germany and the demand in the south, for which currently ‘electricity highways’ are being planned.
- Interestingly, as seen in the VEA interview, also part of the industrial users think that the role of hydrogen is overestimated and more can be electrified than previously thought.

A derivation from the knowledge gained in the interviews would be that experts and users have a consensus that the use of hydrogen is exaggerated and mostly lobby-work form gas companies. Renewable hydrogen in space heating would be more expensive (2-3 times according to Gabbatiss (2023) and would mean an even greater demand for renewable electricity due to the inefficient conversion steps during generation and in the fuel cell. Hydrogen might play a role in transporting energy from north to south – where it is used by industry – however, this does not mean it should also be used to supply individual homes. Studies exist that see a role for hydrogen in plants supplying DH and in the industry (Thomsen et al., 2022), but several other sources clearly describe the drawback of a widespread application of hydrogen (or other green-gas-based) space heating (Öko-Institut & Fraunhofer ISE, 2022; Rosenow, 2022; Thomas et al., 2022).

7.1.2 Technology openness vs. a government directed transition

This discussion revolves around the two possible roads in which the government can create policy instruments that align with a strategic goal.

One option, a technology-open road, means only goal setting and taking a liberal market approach: as long as the industries work towards the goal, any technology that is used is allowed. This liberal path only sets a climate goal, e.g., climate neutrality 2045, as a dot on the horizon, and then freedom for all companies and technologies to achieve that, regardless of the method. This is argued by incumbent heat providers but also by some experts.

On the other hand, the government-directed transition means that the government can create many policy instruments in the form of sub-goals for specific sectors. The transition is technology closed in the sense that the climate goal is combined with a technology specification by the government to increase the speed, increase clarity, and avoid lock-in on technologies that hamper the transition (e.g., new 'efficient' gas boilers or hydrogen in decentral heating). This might include the prohibition of several technologies, a mandatory connection to the district heating network, or a mandatory disconnection from the gas network. In this option, there can still be a mix of different technologies. This is desired, as the heat transition needs a diverse mix of renewable heating technologies to replace the large CHP plants with several smaller units.

Currently, advocates and opponents of full technology openness are not served as no coherent strategy exists. Technology openness is mentioned, but, as argued by BDEW, not fully implemented as for example the 65%-rule is a hidden prohibition of several technologies. However, the main strategy is more than evident, both from stakeholders and from literature (Öko-Institut & Fraunhofer ISE, 2022). Heat pumps will become the leading technology, with decarbonized district heating applied where applicable in dense urban environments, all according to municipal heat planning. The government should choose one option decisively. My suggestion here would be a directing government. As Mazzucato (2022) argues in her book 'Mission Economy', governments should take the lead in big societal transitions and tilt the playing field in the right direction, instead of leveling it (Mazzucato, 2022).

7.1.3 Dismantling of the gas network

Moving to a climate neutral heat supply will mean that the gas network will become unused over time (Rosenow, 2022). The question is: how to dismantle this network, or is it possible to find another use or let it in the ground? A mandatory dismantling comes at a high cost for the owners (and gas suppliers), who might transfer these on the last remaining customers. Discussion points are: is it necessary to remove the network? Who will pay for it? The topic is linked to the hydrogen discussion, as energy companies want to use the network to supply hydrogen instead of decommissioning it.

7.2 Bottlenecks in the heat transition

7.2.1 Fix bureaucratic hurdles and regulatory inconsistencies

The stakeholders mention regulatory inconsistencies, especially at the local level. Examples of local or regional rules interfering with the expansion or decarbonization of district heating networks include a rule prohibiting damaging new roads for seven years, monument protection hindering individual Solara-PV or solarthermal installations or big solarthermal plants, and old land use plans destining plots to lignite mining, hindering a district heating pipe being installed. Moreover, monument protection can cause delays in building renovations necessary to achieve efficiency in space heating.

7.2.2 Deficit of skilled workers

A bottleneck universally addressed by the stakeholder was the deficit of skilled workers to deliver the heat transition. The bottleneck is also fully recognized in the literature: craftsmen are needed to install heat pumps, renovate buildings, expand the district heating network, and much more. It is especially pressing the heat transition (Agora Energiewende, 2022). Up to 240.000 workplaces could lack a specialized employee by 2026, with the most in-demand specializations being energy technology, heating and air-conditioning technology, electrical engineering, and building services. The development of Germany's demographics, with more specialists reaching retirement age, is a complicating factor during a changing demand for skilled work (dena, 2022a).

7.2.3 Social concerns and affordability

Renewable heating is more expensive than fossil heating, and a hard truth is that this is expected to remain in the near future. Therefore, switching to renewable heating is a less attractive business case as switching to renewable power. Moreover, it is a challenge to provide clean and affordable heating also to people that rent their apartment and to homeowners who cannot afford the renovation and heat-appliance change.

7.3 Answer to RQ3: the most critical action points and bottlenecks

The discussion around hydrogen and the option of technology openness, with sub-optimal outcomes, obscure a clear technological path. On the strategic level, the choice must be made to exclude hydrogen from space heating and to tilt the playing field towards heat pumps (combined with locally available heat sources) and district heating. On policy instrument level, coherence issues, especially in relation with the local level, must be addressed. Then deficit of skilled work and social concerns remain. Of this, social concerns seem relatively addressable: with enough targeted subsidies and appropriate compensation mechanisms to relieve the burden on socially disadvantaged households, renewable heating is affordable for everyone. Skilled work force however, is a societal problem affecting every, both renewable and conventional sector and needs its own policy mix to address.

8 New strategies and instruments

In this chapter, policy suggestions made by stakeholders made during the interviews or the NSG-workshop are discussed. This is not an exhaustive overview, but an overview of the most important suggestions. Many suggestions have been made during the interviews and the NSG-workshop, in varying degrees of concreteness. Topic flagging ranges from: *"at some point in the future, building back the gas network will be an issue – we don't want to pay for it – and someone should look into that"* (OSW) or: *"65% renewable energy in new heating appliances from January 1st 2024 is not concrete enough. We want a complete prohibition on installing new fossil-fueled heating appliances and a gradual prohibition of existing appliances starting from 30 year old appliances, with steps of 2 years."* (DUH).

8.1 Instruments suggested by stakeholders

The following tables list the policy instrument suggestions, divided into instrument suggestions for regulations and for subsidies. The regulation table also lists supporting stakeholders or different options, if applicable. It must be noted that no stakeholder suggested a relaxation of the 2030 or 2045 strategic goals, so this section focuses on instrument suggestions. Moreover, policy mix issues – the interplay between instruments and strategy – have been addressed as well and will be discussed here. For clarity, Table 7 lists the stakeholders' abbreviations mentioned in the tables below.

Abbreviation	Organization	Stakeholder category
OSW	Ostdeutsches Stadtwerk *Anonymised*	District Heating Network
SWB	Stadtwerke Bremen/Wesernetz	District Heating Network
BDEW	Bundesverband der Energie- und Wasserwirtschaft (Federation of energy and water companies)	Heat Suppliers
DUH	Deutsche Umwelthilfe (Environment action Germany)	Environmental NGOs
Agora	Agora Energiewende	Scientific institutes
VEA	Verband Energieabnehmender Unternehmen (Association of energy consuming companies)	Industrial users

Table 7. Abbreviations of organizations mentioned below.

Suggestions for regulation changes and raised issues	Suggested/supported or option 1	Opposed or option 2
Adjust CO_2-accounting method for waste heat and share of CO_2 accounted to heat and electricity in CHP	Industrial waste heat should be calculated towards industry, making the heat CO_2-neutral OSW (A district heating network)	Change GEG and KWKG so that for CHP, waste heat is not CO_2-neutral while the emissions are accounted for in the electricity part. DUH (Environmental NGO)
Cost neutrality should apply to current or expected prices and include ecological costs	OSW	
Overcoming local hurdles: e.g. 7 years protection of new	OSW, SWB	

streets, regional planning for old goals (lignite mining), monument protection		
Align national & EU CO_2 price	BDEW, SWB	Currently no political will because of energy crisis – aligning will cause prices to rise. SWB: reduce the price only for social sector.
Removal of gas network and disconnecting remaining gas	BDEW, SWB	Solution for mandatory disconnection: DUH Complete removal possibly unnecessary: Agora
Political framework for biomethane and hydrogen	BDEW	DUH, Agora, dena: no role for hydrogen as a source for space heating
Technology openness	Political goal setting only & technology open: BDEW	Goal setting and regulate towards specific actions and technologies: Agora, DUH
Mandatory 65% Renewable Heating in new appliances	Agora, DUH: actionable dena: with stricter GEG (mandatory renovation, with subsidy). However: tough law, would need a good balance.	BDEW: too specific DUH: not concrete enough. Alternative: heat exchange law. Prohibition of new fossil appliances, gradually prohibiting fossil appliances starting by everything older than 30 years.
Municipal heat planning	Agora, DUH, dena	
Mandatory DH-connections if planned in municipal heat planning	Agora: mandatory, not necessarily state owned, price regulated DUH	
Regulation similar to gas and electricity market, sectoral goal for DH	Agora, dena	
Overcome regulatory difficulties when acquiring new energy projects for industry, PPAs or when generating own electricity	VEA (industrial users)	

Table 8. Policy instruments and instrument changes suggested by stakeholders.

Subsidy suggestions	Suggested/supported by
Seasonal storage	OSW
Risk insurance and investment support for geothermal projects	OSW
Decarbonization electricity price (difference between gas and renewable energy price)	VEA
Subsidies only for renovations and actual renewables, not for gas, biomass, CHP, etc.	DUH
Consider EU recovery and resilience fund	DUH

Table 9. Subsidy suggestions by stakeholders.

8.1.1 CO_2 accounting, difference between national and EU CO_2-price

DH-network operators stress that waste heat should remain being treated as carbon neutral, as the emissions are accounted for by the industry. Similarly, environmental organizations argue that CO_2 emitted from CHP should also be accounted for the in the 'waste heat' from CHP. Currently, the CO_2 is calculated to the electricity part of the CHP, while the heat is CO_2-neutral. This skews the carbon intensity of both DH and heat pumps: DH get 'carbon neutral' heat, while heat pumps work with an artificially inflated carbon intensity of electricity.

Next to this CO_2-accounting topic, there is the difference between the German national and the EU ETS CO_2-price (€30 in Germany, opposed to 80-90 under the ETS (Steiger, 2022)). At first instance, one would argue to align these two prices, at the higher (EU) CO_2 price. However, no stakeholder suggests this policy instrument now: the reason is that this would increase the current energy prices for individuals (and not for large companies), which would have no political and societal support considering the energy crisis due the Ukraine war. Plans to align the prices exist for 2026 and 2028.

8.1.2 Cost-neutrality

According to the OSW, offering to switch from gas to district heating must be cost-neutral, compared to the gas price of three years ago. As the gas prices have spiked recently, there is no economic way to do that. Furthermore, the ecological benefit of switching is not accounted for. Therefore, the cost neutrality rule can be changed to a comparison with current or expected gas prices.

8.1.3 Overcoming local hurdles

A direct solution is not suggested, but a hierarchy in the importance of strategic goals would be a discussion point: when is climate protection more important than a monument? And when does national strategy overrule local laws?

8.1.4 Removal of gas network (mandatory disconnections)

Mandatory disconnection is suggested by both environment organizations because of the increased efficiency, and by network operators and energy suppliers, because gas networks become uneconomical when most customers have disconnected. A good subsidy and alternative renewable heating source should then be available to facilitate the mandatory switch. As for the removal of gas networks, the question remains who pays – the last customers, the energy company that has profited from the network, or society as a whole?

8.1.5 65% RE rule in new heating appliances

The new rule making 65% renewable energy in new heating appliances from 2024 onwards mandatory is both criticized and supported. On the one hand, it is a concrete measure that causes house owners and building to act when changing or installing new heating appliances. On the other hand: BDEW finds the rule too concrete and wishes more political goal setting and less meddling with the road towards that goal, while environmental organizations find “65% renewable” vague, as a heating appliance is either renewable, or not. They argue for an explicit prohibition of fossil-fueled heating appliances.

8.1.6 Mandatory DH connections

Similar to the gas disconnections, mandatory DH connections (with price regulation) increase the speed of the heat transition. It is advocated for by Agora and the DUH.

8.1.7 Regulating of DH similar to the gas and electricity market

The district heating market is currently much less regulated than gas and electricity. The suggestion is here to have similar price regulation, transparency, and climate goals as in the gas and electricity sectors.

8.2 Instruments deemed sensible

CO_2 accounting: proper accounting so CHP must be divided over heat and power. Regarding industrial waste heat, I agree that the industry should pay the CO_2 price to maximize the incentive to decarbonize. The difference is that a CHP plant is designed to produce both heat and power, while industrial waste heat is an actual byproduct.

Cost neutrality: a straightforward solution seems offering anything compatible with current prices. Expected prices can be used because people use heating appliances for 20 years.

Overcoming local hurdles: this needs a political debate on when climate goals receive priority over local regulations. My opinion would be that any old regulation must be open for review when it clearly interferes with climate action.

Removal of the gas network: as Agora pointed out, complete removal might not be necessary everywhere. This needs further research. Mandatory disconnection, when offered a competitive and renewable alternative, is a valid option to remove network inefficiencies.

The 65%-RE rule: the rule is clear and concrete, but a faster option would indeed mean a complete prohibition on the installation on for example gas & oil boilers, as suggested by the DUH.

Mandatory DH connections: the municipal heat planning should make heat usage and production more efficient. It would make sense that, if it is agreed that a specific street is provided with district heating, the residents should use it. However, this also means that heat prices must be regulated.

Regulating DH similar to gas and electricity market: this is suggested by several stakeholders and should be included in the recommendations. DH is supposed to increase in market size, and it is logical that its users receive the same protection as gas- and power users in terms of prices, transparency, and market supervision.

8.3 Answer to RQ4: policy strategy and instruments to support stakeholders

Many specific instrument changes have been suggested under this topic. No stakeholders questioned the strategic goal (except criticism from the Environmental NGO), but still there are strategic choices to consider. One option is to pave the way completely with regulations organizing a mandatory disconnection from the gas network, mandatory change of fossil-fueled heating appliances and possibly mandatory DH-connection, which might come across as very limiting, or alternatively technology-open with an increased risk of strategic goals being missed. Now, existing policies choose neither, but lean towards technology openness: for example, the 65%-rule allows for hydrogen, and hybrid boilers. However, my preference would be to set clearer rules, but this should be a complete and comprehensive plan, with no interference of with other instruments. For example, a ban on new gas boilers and removing subsidies for gas CHP, should be consistent to enable local authorities to set local incentives, and make the right decisions in a consistent and straightforward way, e.g. plan and enforce priority areas for phasing out gas supply and switching to DH or individual solutions. Once the strategic point has been decided politically, the instrument changes can be filled in, such as mandatory implementation of a municipal heat plan. These could include the suggested instruments or instrument changes on CO_2-accounting, cost-neutrality, interaction with local regulation, dismantling of the gas network, the 65-% RES in space-heating rule, mandatory DH-connections and regulation of the DH-market.

9 Conclusion

Germany needs to align and reinforce policy instruments to build towards the goal set out in the policy goal. The national strategy already aligns with the EU goal on heating and cooling, so the amendments to the REDII do not require a strategic policy change from Germany. However, a binding target of 0.8%-points yearly for the increase of renewable energy sources in heating and cooling means that Germany must find a way to overcome its implementation challenges. As we have seen in previous chapters, these concern: (1) Economic and regulatory barriers, such as the difference in CO_2 price, difference between the electricity and the gas price, and counterproductive subsidies for CHP; (2) bureaucratic hurdles, such as local regulations obstructing DH-expansion and decarbonization; and (3) the skilled work force deficit. A beginning to a solution would require the following three aspects as a minimum (4) social challenges.

An improved policy plan to support the strategic goal.

The NECP can be improved to support the goal of 50% climate neutral heat 2030 more. It should define at which points policies in the Renewable HC field may override regulation on lower government levels. This should improve the consistency of the policy mix. Furthermore, the government should make stronger choices regarding technology-openness. Even though heat-supplying companies encourage technology-open policy, it is probably faster and more effective to support specific renewable heat technologies and prohibit fossil ones. It must be possible to shape policy instruments in a way that excludes technologies to avoid lock-in or instruct specific technologies to be used in certain sectors.

The plan must include answers to the pricing problems

Pricing needs to be addressed at several levels. First, the national and EU CO_2-prices must be brought together – even though it is politically impossible now due to the energy crisis. Second, the difference between a renewable electricity price and the gas price must be bridged, most notably for industrial users. Third, a level playing field is necessary for district heating, so cost-neutrality should be applied to current prices, not historic gas prices. It would be even better to compare expected future prices as well.

Social aspects should play a greater role

It has been pointed out that a considerable part of the heat transition will affect people and their homes. Moreover, we have discussed the inconvenient fact that renewable heating is, unlike renewable electricity, uneconomical at present. Therefore, a social solution must be found for house-owners *and* renters to afford the renovation, heating system exchange, and most importantly, the higher operational costs of renewable heating.

Lastly, it is evident that a national approach is needed to improve the amount of skilled work. For the heat transition, these include mechanics, technicians, and construction workers. However, there is a nation-wide deficit in so many sectors (such as healthcare and education) that listing it as a heat transition policy option only seems unreasonable. It is a problem that affects the heat transition, but the solution should be broader.

Addressing these aspects in an improved national energy and climate plan should increase German's changes to adhere to the new EU goals for the increase of RES in heating and cooling.

10 Discussion

This thesis reviewed the German policy mix on Renewable heating and cooling and provided a detailed overview of stakeholder positions in the heat transition. It contributed to the field by describing stakeholder positions and listing possible policy instrument changes. However, many unanswered questions remain on how society should rise to the challenge of transforming our heating system. As stated in the introduction, it has been relatively neglected compared to the electricity transition in research, policy and business and is now slowly gaining interest. The research field 'heat transition' still requires many elaborations in different research fields. These should include technological and economic issues, policy and planning topics, and social issues such as acceptance and affordability.

This thesis used the policy mix framework by Rogge and Reichardt (2016) as a lens to categorize policy. This proved very helpful, especially when analyzing actual and planned policy instruments at different government levels. For the parts based on stakeholder analysis, the framework was less helpful in categorizing the aspects brought forward by the stakeholders, which tend to be fuzzier, but it still proved convenient to use its terminology. Therefore, I can recommend using this framework to understand complicated policy situations involving different levels and a complex interplay of strategic goals, rules, and subsidies.

10.1 Limitations

Some limitations of my research need to be addressed. Firstly, an expected point of criticism would be the scope of the research. Even though the research might be on a highly relevant societal topic, it addresses the complete scope of policy on German heating and cooling, a topic on which scientific organizations and consultancy firms publish big reports. So, it was a bit ambitious for one master student to answer such an immense societal question. However, it is an exciting topic and contributes to a larger project with more specific sub-tasks. So, on the one hand, it gives a comprehensive assessment of the entire complex of the heat transition topic and embraces the overall view across the very diverse stakeholder landscape. This makes the findings very relevant to the REDI4HEAT EU project. However, on the other hand, it provides specific and concrete approaches for specific, current issues, such as the question around the gas dismantling.

The REDI4HEAT project was executed during the trilog negotiations on the content of the REDII amendments, meaning that the precise EU goal on HC was not known until the conclusion of the trilog on March 30th. Moreover, Germany's policy mix is continuously changing during the timespan of the research, with new instruments (such as the 65% rule) being discussed and proposed in the news. Therefore, this research is limited by the knowledge available today and can only cover the status quo and expectations of the future. A better policy mix analysis would have to be conducted ex-post. On the other hand, the social relevance of such research would be limited. Research on a highly relevant topic today might be fuzzier, but analyzing it more precisely ex-post cannot help to shape the policy that is necessary now to achieve societal goals.

Aspects that specifically limited the research concern the availability of stakeholders. Most relevant stakeholders could be included in the NSG. However, no ministry representative was found available to join it yet. This is a limitation to both my research and the REDI4HEAT project. Furthermore, while a local and municipal government representative was in the NSG (From the city and Bundesland Berlin), it was not possible to interview that stakeholder, so their views were only put forward in the NSG workshop.

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Annex I: Interview guides and analyzed interview transcripts

Annex II: REDI4HEAT NSG Agenda and Conceptboard

Annex III: dena Internship report