Faculty of Technology, Policy and Management

Understanding forest biomass energy policy mix impact on energy poverty

A Case Study of Sofia, Bulgaria

EPA Master Thesis

Mihail Deligrozev
Student Number: 5217652

Graduation Committee

Committee Chair:	Dr. Thomas Hoppe
First Supervisor:	Dr. Nihit Goyal
Second Supervisor:	Dr.ir. Els van Daalen

Delft, Tuesday 23rd August, 2022

Summary

Energy transition has become the lead focus of the European Union (EU) agenda. The introduction of European Green Deal (EGD) has further raised the targets regarding greenhouse gas emissions, Renewable Energy (RE) and Energy Efficiency (EE) and strengthened legislation concerning the circular economy and biodiversity. Forest biomass energy has been at the forefront of the EU policy-making. The energy from sustainably harvested biomass is regarded as a RE. Moreover, forest bio-energy represents a major share of the RE produced in the EU. At the same time, forests play a vital role in protecting biodiversity and reducing the carbon dioxide in the atmosphere. Hence, the forest bio-energy has been impacted by policy instrument developed to addresses various goals (RE, EE, Air Quality (AQ), biodiversity).

In Central and Eastern Europe (CEE), where the forest biomass is mainly used for domestic heating in the form of round-wood, the issue of AQ has a significant role in the energy transition agenda. The burning of round-wood in old low-efficiency stoves cannot produce sufficient energy while exposing people to indoor and outdoor pollution. Moreover, the Particulate Matter (PM) from wood burning is associated with multiple health conditions. Thus, the Energy Poverty (EP) literature focused on developing countries emphasises the access to safe and modern energy sources as EP indicator. However, in the context of EU, the access to safe and modern energy aspect of EP is largely neglected.

The issue of forest bio-energy is a subject of several policy instruments on a national and local level, resulting in various policy instruments with the same or different goals. The interaction of policy instruments and policy processes is referred to in the academic literature as policy mix. The interaction between the policy instruments can result in either conflict or synergies, enhancing or mitigating the effects of the policy mix. In addition, in the context of forest bio-energy, the policy mix interactions can result in unintended impacts on other policy areas such as EP. Hence, understanding the policy mix interaction can provide insight into how the energy transition policies can be improved and how to reduce its negative effects.

Nevertheless, the policy mix research tends to focus on conceptualising the framework rather than testing it on real-world issues. Moreover, the most common use of the policy mix framework is in the context of innovation studies, in developed countries, and on the national level. Thus the policy mix framework is unutilised in the context of multi-governance, multiple policy areas and less developed countries.

One of the countries associated with a high rate of energy poverty, regardless of how it is measured, is Bulgaria. Bulgaria, similarly to the other countries in the CEE has a high share of traditional fuels use, like round-wood and coal, especially in the poorer rural regions. However, in Sofia, the largest municipality and capital of Bulgaria, the use of traditional fuels is minimal but dominated by the most impoverished communities with limited access to alternatives. Moreover, the municipal administration is responsible for improving the city's AQ.

The research aims to understand the impact of the forest bio-energy policy mix on EP; hence the following research question is formulated: How is the forest biomass energy policy mix affecting energy poverty alleviation in Sofia, Bulgaria? The case study approach is suited to answer the main research question. Furthermore, the case study approach allows for in-depth exploration of complex issues and uses multiple research methods.

The theoretical framework of the research is based on the policy mix conceptualisation proposed by Rogge and Reichardt (2016). Rogge and Reichardt define three building blocks of the policy mixes: elements, process and characteristics. This research focuses on the policy instruments, one of the elements of the policy mix, and more specific policy instruments and characteristics. Operationalisation of the framework is based on the criteria set by Rogge and Reichardt, subsequent case studies based on the same framework, and the taxonomy of the policy instruments proposed by Howlett and Rayner (2007).

The definition of EP is based on four indicators: "Energy affordability", "Use of modern and safe energy", "Ability to keep home adequately warm", "Dwelling with a leaking roof, damp walls, floors or foundation, or rot in window frames or floors". All four indicators could be measured and provide insight into critical vulnerabilities.

The research process starts with data collection from two sources, desk research and semi-structured exploratory interviews. Both types of data are systemically treated using content analysis tools. Following the data treatment, stakeholder analysis is used to understand the objectives and perceptions of the different actors involved in the system. Next, the policy mix elements are identified based on policy documents and interview data. The causal relations are explored by constructing Causal Loop Diagram (CLD) and validated by additional interviews. Next, the policy mix framework is applied to the identified policy elements and the CLD, recognising the policy mix characteristics. Finally, the impact of the policy mix on the EP in Sofia is evaluated by exploring the effect of the characteristics on the EP indicators.

The forest bio-energy policy mix in Sofia Municipality is centralised around two appliance change programs designed to improve Air Quality in the municipality by replacing old appliances burning wood and cold with more sustainable alternatives. On the national level, the Ministry of Agriculture and Ministry of Labor and Social Assistance focus on reducing the cost of round-wood for the poorest households. In contrast, policy instrument developed on EU are increase EE and stimulate the use of RE.

The national level policy instruments reduce the cost of traditional energy but reduce the participation in the municipal appliance change program. On the other hand, the appliance change programs have restricting conditions for participation, and there are no policy instruments designed to assist the household with increased energy costs participating in the program. Finally, the EU instruments reduce energy consumption and thus stimulate the positive effects of the appliance change program, but the various sustainability and EE requirements put restrictions on the types of alternatives that the programs can offer.

The conflicts existing between the national level policy instruments and the rest of the policy mix result in vertical and horizontal inconsistency. Nevertheless, synergies between the EU instruments and the appliance change programs result in synergies. The lack of capability of the local and national institutions and the perceptions conflict indicate a lack of policy mix coherence. At the same time, the policy mix does not have any instruments to cover market failures exposing households to higher energy cost and include policy instruments outside the national energy plans indicating a lack of comprehensiveness.

While the lack of consistency, coherence and comprehensiveness have some positive impact on energy cost, thus reducing energy poverty, the conflicts in the policy mix are sustaining the use of traditional fuels. Overall, in the situation of surging energy prices, the forest bio-energy policy mix is sustaining the EP in Sofia, Bulgaria.

The evaluation of the impact of the policy mix on energy poverty in Sofia shows that the lack of constancy, coherence and comprehensiveness and credibility does not always lead to adverse effects on the energy poverty indicators. Nevertheless, the results support the findings of other articles focusing on the impact of the energy transition on energy poverty and that the way to achieve energy poverty alleviation is to strive for consistent, coherent and comprehensive energy transition policies. In terms of the policy mix concept, the study shows the need for further empirical research on the multi-dimensional policy mixes and more emphasis on the instrument's design features. In line with other research in the context of CEE, the appliance change should follow the building energy efficiency increase.

The analysis findings show that the continued national support for traditional fuel use slows the participation in the municipal appliance change programs and exposes households to harmful pollution. The first step in reducing the conflicts in the policy mix and reducing EP is the abolition of energy benefits for wood and coal and the end of the direct wood supply policy. The results also show the importance of EE instruments in enhancing the effect and participation in the appliance change program. Hence, there is a need for a policy that addresses housing EE. Finally, the energy benefits of sustainable energy should be expanded to cover a larger group of households; to ensure that households that can afford to transition are not suffering from higher energy costs.

The main limitations of this study are connected to its approach and data collection. Finally, the research explores more closely the policy instruments and characteristics. Future research on EP should expand on the access to modern energy aspect.

Preface

This research was developed as a thesis for the Master of Science Engineering and Policy Analysis program at Delft University of Technology. This work would not be possible without the help of the people responding to my interview requests. I am gratefully for the guidance and advice of my first supervisor, Dr. Nihit Goyal. I would like to express my gratitude to Dr.ir. Els van Daalen and Dr. Thomas Hoppe for their extensive feedback. Finally, I would like to mention the contribution of Dr.ir. Bert Enserink, who is no longer with us.

Mihail Deligrozev

Contents

List of Figures

List of Tables

Acronyms

AQ Air Quality. 2, 33, 35, 40, 42, 54, 55, 58

AQD Air Quality Directive. 45, 50, 58

ASA Agency for Social Assistance. 42

CEE Central and Eastern Europe. 2, 13, 32, 33, 63

CLD Causal Loop Diagram. 14, 29, 31–33, 45, 46, 49–51, 58, 63

EC European Commission. 34, 42, 91, 93

EE Energy Efficiency. 2, 3, 16, 33, 35, 42, 45, 50, 54, 58, 59, 93–96

EE Act Energy Efficiency Act. 39, 42

EEA European Environmental Agency. 91, 94

EED Energy Efficiency Directive. 22, 40, 42, 45, 50, 58

EFA Executive Forest Agency. 39, 40, 91, 96

EGD European Green Deal. 2, 13, 40

EP Energy Poverty. 2, 3, 12–17, 23–25, 31–35, 38–40, 44, 51–53, 55, 57–61, 63, 91, 94

EPOV Energy Poverty Observatory. 13, 35, 91, 95

ERSA Energy from Renewable Sources Act. 42

EU European Union. 2, 3, 12–14, 16, 17, 24, 25, 29, 32, 34, 35, 37, 38, 40, 42–44, 46, 49, 53–55, 57–59, 91, 94

EU-SILC European Union Statistics on Income and Living Conditions. 16, 37

ExEA Executive Environment Agency. 91, 96

GHG Greenhouse gases. 12, 13, 45, 93, 94

HBS Household budget survey. 16

LULUCF Land Use, Land-Use Change and Forestry. 35

MA Ministry of Agriculture. 39, 43, 44, 49, 55, 58, 59, 91, 95

ME Ministry of Energy. 39, 40, 58, 59, 91, 95

MEW Ministry of Environment and Waters. 39, 40, 43, 58, 91, 96

MFF Multiannual Financial Framework. 34

MLSA Ministry of Labour and Social Assistance. 39, 42, 55, 58, 59, 91, 96

MRDI Ministry of Regional Development and Infrastructure. 58, 91, 95

NECP National Energy and Climate Plan. 39

NGOs Non-government organisations. 39, 42, 92, 95, 96

NSI National Statistical Institute. 36

NUTS Nomenclature of territorial units for statistics. 35

PM Particulate Matter. 2, 42, 45

RE Renewable Energy. 2, 3, 17, 33, 35, 42, 45, 54, 93–96

RED Renewable Energy Directive. 40, 42, 45, 50, 58

SAMTS State agency for metrological and technical surveillance. 39, 54

SEDA Sustainable Energy Development Agency. 91, 95

SM Sofia Municipality. 91, 96

SQ Sub-questions. 14, 15, 58

1 Introduction

With the introduction of the European Green Deal, EU has pledged to cut 55% of the greenhouse gas emissions by 2030 from the 1990 levels, becoming climate neutral by 2050 (EC, 2019b). In its nature, the European Green Deal is a strategic vision that sets a transformation which triggers overall economic, political and social-technological change (Bassi et al., 2021). Making that transformation reality could not be done with a single policy instrument; it requires implementing different types of policy instruments across multiple policy fields (Kern & Rogge, 2018).

The European Green Deal stretches over various policy domains: energy production, energy markets, air quality, biodiversity, housing quality, etc. The EU shares authority with the member states and local governments (Bahn-Walkowiak & Wilts, 2017), depending on lower levels of government to achieve its goals (Ehnert et al., 2018). In addition to the EU policy, the national governments and regional or local authorities are introducing various policy instruments addressing energy transition or impacting it in some other way.

As a result, the multiple decision-making centres and differences in beliefs on EU, national, regional or local levels lead to the implementation of interacting policy instruments. In the literature, such a combination of interacting policy instruments are referred to as policy mixes, policy packages or policy portfolios (Rogge et al., 2017; Kern et al., 2019). The complexity of the policy mixes can be further increased depending on the governing structure (Howlett et al., 2015). The conflicts and synergies emerging from the interaction between the policy instruments determine not only the effectiveness of the policy mix but its impact on the other outcomes in the socio-technical system (Edmondson et al., 2019).

In order to understand the impact of the energy transition policy mix on the EP this research will look at a case that is connected to multiple policy instruments and multiple objectives in the context of a municipality that is suffering from a high rate of EP. The policy concerning forest biomass energy is developed across various policy areas and at multiple governmental levels. At the same time, Bulgaria is one of the countries in the EU with the highest energy poverty (Bouzarovski & Tirado Herrero, 2015). Hence, the case of forest biomass energy use in Sofia, Bulgaria, provides policy complexity in the context of eminent social problems.

This chapter provides a background of the forest biomass energy and EP with respect to the energy transition framework of the EU in Section 1.1. Next, Section 1.2 identifies the research problem and presents the policy mix concepts as a way to address it. Section 1.2 also elaborates the gap in the academic literature this research addresses. Section 1.3 formulates the main research question, the sub-question deriving from it and presents the study's research approach. The EPA relevance of the thesis is presented in Section 1.4. Finally, Section 1.5 depicts the outline of the research.

1.1 Background

1.1.1 Forest Biomass Energy

Forest biomass energy or forest bio-energy plays an essential role in the EU energy transition. First and foremost, forest bio-energy represents a large share of the renewable energy in the EU. Almost 60% of the renewable energy produced is bio-energy (Scarlat et al., 2019), and most of the bio-energy is produced from forest biomass (Andersen et al., 2021). Second, the use of forest bio-energy is increasing, and it is used throughout the EU. The share of forest bio-energy has increased from 6% in 2000 to 18% in 2019 (*Odyssee-Mure*, 2021). In addition, the forest bio-energy is regarded as a carbon neutral substitution for fossil fuels (Aguilar et al., 2018). Each harvested tree is replaced with a new one; hence, burning the forest biomass does not contribute to the Greenhouse gases (GHG). Furthermore, the forest biomass contributes to the EU's energy security since it is harvested in the EU. Finally, forests are instrumental in carbon caption and biodiversity.

The European Green Deal emphasises the need for the use of "sustainable" biomass for the production of energy (EC, 2019b). When it comes to forest biomass, the sustainability requirements

refer to what biomass is used for the production of energy and how this biomass is harvested. The source of forest biomass can be either primary, harvested round-wood and logging residuals or secondary, waste-wood products such as wood pellets (Commission et al., 2021). The use of round-wood has a negative impact on biodiversity and people's health. In contrast to the round-wood, the secondary wood products (pellets) have a lower level of moisture, making them more energy efficient and producing less GHG and PM emissions (Andersen et al., 2021).

The objective of the EU is to reduce the energy use of round-wood and promote the use of logging residuals and waste-wood from industry to produce secondary wood products, which can then be used for the generation of bio-energy (Andersen et al., 2021). However, the round-wood is still a common source of heating energy all over Europe, especially in domestic settings in the CEE (Bouzarovski & Tirado Herrero, 2015; Vlahinic Lenz & Grgurev, 2017). It is predominately used for heating in the poorer rural areas (Bajomi et al., 2021; Karpinska & Śmiech, 2021), where round-wood is a traditional way of heating, and the alternatives are costly or unavailable. The transition from traditional fuels to other energy sources for heating could improve the health and well-being of the poorest part of EU's population.

1.1.2 Energy poverty

Alongside the environmental consequences of energy transition policy mixes, there are other social-technological and economic outcomes (Bouzarovski & Tirado Herrero, 2015; Bartiaux et al., 2019; Dong et al., 2021; Feenstra et al., 2021; Karpinska & Śmiech, 2021; Mastropietro, 2019; Yadav et al., 2019). Evaluating the energy transition policy mix through its environmental goals is insufficient for understanding its overall socio-technical impacts. The EU recognises this outcome and underlines the importance of addressing social issues as EP within the EGD. EP has been connected to respiratory health conditions and other chronic illnesses (Castaño-Rosa & Okushima, 2021). Furthermore, it can lead to social exclusion and mental health issues (Guzowski et al., 2021). When it comes to the vulnerable groups, it disproportionately affects the poorest members of society as well as women and children (Jiang et al., 2020; Dong et al., 2021; Karpinska & Śmiech, 2021). However, EP drivers can differ quite significantly (Kahouli & Okushima, 2021), as well as the levels of EP across the EU (Barroco Fontes Cunha et al., 2021; Bouzarovski & Tirado Herrero, 2015). The EU recognises this and does not have a single purpose policy framework but rather monitors and provides recommendations according to the country-specific needs through the EU Energy Poverty Observatory (EPOV).

1.2 Problem Identification

1.2.1 Policy Interactions

The existent energy transition policy mix results from continued policy development on different levels of government and across different policy domains leading to the coexistence of multiple policy instruments and policy objectives. The interaction can occur between policy instruments with similar goals or targeting the same actors or processes (Flanagan et al., 2011). Moreover, the policy instruments' interaction can be a consequence of the choice and design of the instrument, its implementation, and actors' perceptions or rationals (Rogge & Reichardt, 2016). The interactions within a policy mix can reduce policy effectiveness and lead to undesired consequences in one policy area in favour of another. For example, the appliance change programs developed throughout CEE are designed to assist households transitioning from the use of inefficient and hazardous traditional fuels to sustainable alternatives. However, policy instruments that reduce the price of traditional fuels or increase the cost of the alternatives can slow the transition to modern and safe energy.

Understanding the policy mix interaction is critical for creating policy instruments that complement each other and work in synergy (del Río, 2014). Furthermore, the policy mix framework can be used to identify which part of the policy mix contributes more to the success and effectiveness of the policy mix and the impact on the socio-technical system. Thus, the Policy mix concept can be used to evaluate the performance of the policy instrument and underline the critical issues in the policy mix and help the decision-makers address them.

1.2.2 Knowledge Gap

This research is intended to contribute to policy mix literature, specifically, the research concerning the framework developed by (Rogge & Reichardt, 2016). Based on the literature review presented in Appendix A, it can be concluded that the policy mix research has been primarily conceptual and characterised by multiple definitions (Rogge et al., 2017). While more empirical research has been undertaken in the last few years, few articles are focused outside the innovation studies domain (Kern et al., 2019). Furthermore, the policy mix framework is not thoroughly utilised in the impact evaluation of the energy transition on the social outcomes as it mainly focuses on the success and effectiveness of the policy mixes (Table 1.2.2, Appendix A). Finally, the current research on the topic underlines the need for a better understanding of the vertical dimension of the policy mix, with emphasis on the regional and local levels (Rogge et al., 2017; Nguyen et al., 2019).

1.3 Research Objective and Research Approach

This research aims to understand how the forest bio-energy policy mix affects EP in the context of multilevel governance. Several studies exploring EP across the EU have found that Bulgaria is the country with the highest rate of EP in EU (Bouzarovski & Tirado Herrero, 2017; Vondung & Thema, 2019; Bartiaux et al., 2019). At the same time, the Sofia Municipality, the biggest municipality in the country, is trying to reduce the round-wood burning in the poorest municipal regions (*Sofiaplan*, 2021). Hence, the case of Sofia, Bulgaria, represents a suitable case with respect to the research objective.

The following research question is formulated based on the research objective:

How is the forest biomass energy policy mix affecting energy poverty alleviation in Sofia, Bulgaria?

Additionally, six Sub-questions (SQ) (Figure 1) assist in answering the main research question. Each SQ represents a step in the research process. There are multiple ways of measuring EP depending on the case context. Therefore, the first SQ should present an understanding of the context in which the different EP indicators are used. Next, the second SQ provides information about the stakeholders involved in the problem. The third SQ explores the policy instruments and strategies of the policy mix. SQ 4 refers to the existing relations and. The fifth SQ is used to understand the interaction and conflicts in the system in the context of the policy mix concept. Lastly, SQ 6 is introduced to formulate a recommendation for the decision-makers.

The primary research approach of this study represents a case study approach. The case study approach is used for an in-depth analysis in the context of single or multiple cases (Yin, 2011). The research methods combined with this approach can be qualitative, quantitative or mixed (Harrison et al., 2017). The versatility and the depth of the case study approach make it suitable for exploring very complex problems. The case study approach has its limitations; the repeatability and validity of the research are not guaranteed and should be thoroughly addressed during the research process (Flyvbjerg, 2006).

1.4 EPA Relevance

This thesis addresses several issues related to the EPA program. First, it examines the impact of the energy transition on EP, both of which are formidable Grand Challenges. Second, the research looks into multilevel governance, considering the policy developed on the various levels of government. The use of the policy mix framework allows for identifying problems in the existing policy and formulating recommendations to address them. Next, the research uses Causal Loop Diagram (CLD) to explore causal relations; the CLD method is part of the EPA program curriculum and is a key research method in policy analysis. Finally, the research formulates recommendations for the decision-makers based on the findings of the analysis.

SQ 1	*In what context the indicators measuring energy poverty formulated in the existing research are applied?*
SQ 2	*What are the objectives and perceptions of the stakeholders involved in the context of energy poverty and forest biomass energy?*
SQ 3	*What is the existing policy mix developed at the different levels of government affecting the forest biomass energy in Sofia, Bulgaria?*
SQ 4	*What do the factors and their relations in the context of forest bio-energy and energy poverty in Sofia explain?*
SQ 5	*What are the policy mix interactions, when implemented, with respect to energy poverty in Sofia?*
SQ 6	*How could the negative effects of the policy mix on energy poverty in Sofia be mitigated and the positive ones amplified?*

Figure 1: Sub-questions

1.5 Outline

The research is structured in five chapters: Theoretical Framework, Methods, Case Description, Results and Conclusion. First, Chapter 2 presents the various way of measuring EP and the context in which they are used. The theoretical framework of the research is established in Chapter 3, presenting the evolution of the policy mix definition as it is used in the literature. Chapter 4 presents the research approach, its merits and shortcomings, followed by argumentation of the case study choice and policy scope. In addition, the chapter provides operations of the study's theoretical concepts and a description of the overall research process. At the end of Chapter 4, the replicability and validity issues of the research are addressed by underlining the risk, and the steps are taken to mitigate them. The institutional structure and roles of the stakeholders involved in the issues are explained in Chapter 5, in addition to the demographic structure, state of EP in Sofia Municipality and the main policy instruments regarding the forest bio-energy use. Chapter 6 presents the analysis finding by establishing the causal relations in the system, the policy mix interactions and the impact on EP in Sofia, Bulgaria. Finally, the conclusion Chapter depicts the answer to the main research question and the SQ and recommendations, discussion and limitations of the study.

2 Energy Poverty

This Chapter proves the answer to the first Sub-question defined in Section 1.3 by conducting a literature review. First, the literature search and overview on the EP definition are presented in section 2.1. Second, Section 2.2 shows the various indicators for measuring EP and the context in which they are used, based on the selected literature.

2.1 Literature Review

The literature search is conducted in the Scopus database, and the search query and the selected articles are presented in Appendix B. The articles are selected based on their focus on EP measurement. The literature analysis is executed based on the Wee and Banister (2016) framework. The results are presented in Figures 9, 10 and 11.

The EU does not have a single definition of EP due to the specifics of each country or region (Bouzarovski & Tirado Herrero, 2017; Primc et al., 2021; Lowans et al., 2021), the role of the definition in the policy process (Kerr et al., 2019; Siksnelyte-Butkiene et al., 2022) and the available data and data quality (Streimikiene et al., 2020). Nevertheless, there are several studies focusing on EP and its metrics (Appendix B Table 9) within the context of the whole EU: Bouzarovski and Tirado Herrero (2017), Vondung and Thema (2019) Streimikiene et al. (2020) and Siksnelyte-Butkiene et al. (2022). All four studies argue for using multiple metrics to explore and assess the level of EP in the EU. That argument is supported by other case studies focusing on one or multiple EU countries (Bajomi et al., 2021; Feenstra et al., 2021; Kerr et al., 2019).

2.2 Energy Poverty Indicators

While there is a consensus among the authors of the (presented) articles about the multi-dimensional nature of EP there are several proposals on what that definition should be. For example, Bouzarovski and Tirado Herrero (2017) proposes three metrics based on the European Union Statistics on Income and Living Conditions (EU-SILC): "percentages of people who have been unable to keep their homes adequately warm", "percentages of people who have had arrears in utility bills", and "percentages of people who have lived in a home with a leaking roof, or the presence of damp and rot". This conceptualisation has several strengths since this is data collected by all member states. First, it provides an understanding of households' perceptions regarding adequate heating, in contrast to the existing objective indicators, which are not helpful due to the difference in people's perceptions. Second, the housing dimension provides insight into the EE of the dwelling without the need to measure it. However, it does not provide a complete picture of the EP issue. The most significant disadvantage of this way of measuring EP is that it excludes all households that are spending a high share of their income on utility bills but are not late with their payments.

All three indicators proposed by Bouzarovski and Tirado Herrero (2017) are "consensual-based" according to the classification made by Vondung and Thema (2019). According to Vondung and Thema (2019), the other indicator types are "expenditure-based", which shows what share of household income is spent on energy bills. "Direct measurement" indicates the energy needs of the households compared to their actual energy use. Finally, the "outcome-based" metric is connected to mortality due to cold exposure, grid disconnections and others. Similar to Bouzarovski and Tirado Herrero (2017), Vondung and Thema (2019) uses EU-SILC for the "consensual-based" indicators and Household budget survey (HBS) data for the "expenditure-based". Overall, both types of research are beneficial for measuring the levels of EP using the available data. However, this approach to EP does not provide insight into how to address it.

The issue of how to alleviate EP is undertaken by Siksnelyte-Butkiene et al. (2022), bridging the gap between policy development and EP monitoring. Siksnelyte-Butkiene et al. (2022) proposes three dimensions: economic, social and environmental; the economic and social dimensions align with the "expenditure-based" and "consensual-based" indicators proposed by Vondung and Thema (2019). The three dimensions are used for evaluating the fitness of a policy to achieve the energy transition and sustainability objectives. Overall, the framework proposed by Siksnelyte-Butkiene

et al. (2022) underlines the need for policies that enhance the use of RE, increase the living standard and save energy for the people.

Bouzarovski and Tirado Herrero (2015) define six vulnerability factors: "availability of energy supply"; "high energy prices and low income of households"; "restrictions of choice of energy supply options"; "high energy losses"; "discrepancies between energy needs and available energy services"; "lack of knowledge and awareness". These factors are used by Streimikiene et al. (2020) and Bajomi et al. (2021) to explore the EP concept in order to use it for policy development. While Streimikiene et al. (2020) explore these vulnerabilities as drivers of EP in the context of energy transitions policy development, Bajomi et al. (2021) focuses on solid fuel use in Hungary. This approach underlines the issues facing the policymakers but ignores the monitoring of the progress of these policies.

The empirical research reviewed in this literature review (Appendix B) regarding the EP in the EU and other developed countries utilises expenditure and consensual-based indicators. However, as Bajomi et al. (2021) stresses, these indicators do not address the EP among solid fuel consumers. Moreover, the access and use of quality energy sources have been neglected by the EU level due to focusing on the comparison and progress monitoring (Vondung & Thema, 2019).

Nevertheless, the access and quality of the energy sources have been the focus of the literature regarding developing regions (Calvo et al., 2022; Guzowski et al., 2021; Herington & Malakar, 2016). Guzowski et al. (2021) differentiate four approaches to measuring EP based on: expenditure; energy services; perception; and multi-dimensional. The expenditure and perception approaches correspond to the economic and social dimension proposed by Siksnelyte-Butkiene et al. (2022) and the expenditure and consensual-based indicators proposed by Vondung and Thema (2019). At the same time, energy services are generally ignored in developed countries due to the high level of energy connectivity, use of modern energy sources, and high-efficiency appliances (Guzowski et al., 2021). However, that is not always the case as many parts of Europe have relied on heat or cooking energy by wood or coal-burning with dire health consequences (Korteland et al., 2022). The addition of the energy services indicator guarantees that using hazardous energy sources would not be sacrificed in the name of cheap and affordable energy.

3 Theoretical Framework

This Chapter establishes the theoretical framework of the research by exploring the literature on policy mixes and in the energy transition context. First, Section 3.1 depicts the literature search and the findings of the literature reviews. Next, the evolution of the policy mix concept is explained in Section 3.2, elaborating on the change in the definition over the years and across study areas. Finally, the choice of the theoretical framework is argued in Section 3.3.

3.1 Literature Review

The literature selected for this analysis was acquired using a two-step process. First, a search query was formulated in the Scopus database (Appendix C, Table 12). Second, after reviewing the first batch of literature, the second group of studies were selected based on the cross-references.

Using the searches described above and cross-referencing 28 policy mix papers were reviewed (Appendix C, Table 13). While this represents a substantial number of studies, as Kern et al. (2019) find, the number of authors concerning policy mix research is also limited. Despite the limited number of authors, the policy mix concept is associated with a substantial variety of terminology and definitions (Rogge et al., 2017). Furthermore, there are several conceptualisations of the policy mic framework (Appendix C, Table 14) which are used in different research areas (Kern et al., 2019). Consequently, while intended to explore real-world phenomena, the policy mix research is characterised by the various theoretical frameworks and a few empirical studies in which they are applied.

The difference in policy mix definitions could be explained by their purpose and study field (Rogge et al., 2017). Rogge et al. (2017) underline three research fields that have developed distinct understandings of the policy mix concept; Environmental Economics, Policy Studies and Innovation studies. The environmental economics studies define the policy mix as a combination of instruments that target the same goal. That is the most narrow concept of policy mix of three, and it is not helpful for the purposes of this study. Policy science studies focus on evaluating and designing the policy mix based on the coherence of goals and consistency of the instruments through the processes from which they are developed (Howlett, 2005; Howlett & Rayner, 2007; Howlett et al., 2015, 2017). Finally, the innovation studies (Flanagan et al., 2011; Rogge & Reichardt, 2016; Edmondson et al., 2019; Huang, 2019; Gomel & Rogge, 2020) are focused on instrument interaction and evaluating the outcome of these interactions. The definition developed by Rogge and Reichardt (2016) despite being part of the innovation studies incorporates features from the policy and innovation studies. Hence it can be used for both studying the policy mix's outcomes and the policy mix's design. Nonetheless, in the research field or purpose of the study, all of the policy mix concepts are based on the instruments interactions that determine the effectiveness of the policy mix (Rogge et al., 2017).

The studies can be classified not just by the research field but based on the part of policy mix or dimension they are addressing (Appendix C, Table 15). The earlier research has a more narrow focus (Figure 2) whether it is instrument mix and instrument change (Howlett & Rayner, 2007) or instrument interactions (Flanagan et al., 2011; del Río, 2014). On the other hand, the later conceptual studies have a more complex viewpoint of the concept (Howlett et al., 2015; Rogge & Reichardt, 2016; Schmidt & Sewerin, 2019). Nevertheless, the empirical studies based on the broader concepts are still limited to one part of the policy mix or single dimension (Huang, 2019).

3.2 Evolution of the policy mix concept

The evolution of the policy mix concept is depicted in Figure 2 by showing some critical articles. While there are other definitions of the policy mix concept, these represent the different types of policy mix frameworks. Moreover, this selection represents the key authors contributing to this topic. As mentioned earlier, the policy mix concept has been used in different research fields. Hence, different definitions and terminologies have emerged over the years. Nonetheless, the

most recent studies are introducing broader definitions bridging the gap between the policy and innovation studies (Rogge et al., 2017).

Within the realm of policy studies Howlett (2005) first define a policy (instrument) mix as a combination of policy instruments targeting a particular objective. The introduction of the instrument mix by Howlett (2005) raises the question of how the instruments composing the mix interact and whether these interactions lead to conflicting or complementing results. While the point is made that the processes behind the policy instrument's design are as important as the instrument itself, this framework does not provide tools for understanding the policy processes. This gap is, to some extent, addressed by Howlett and Rayner (2007), taking into account the policy design and the decision-making process behind it. The authors propose an evaluation framework that classifies the instrument mixes as consistent or inconsistent and the policy goals as coherent or incoherent. This classification is based on the choice of instruments in the context of policy change and policy learning Howlett and Rayner (2007). Focusing on instrument choice, the study distinguishes two categories of instruments (Table 1): substantive and procedural. This definition is based on the purpose for which the instrument is used. The "substantive" instrument is designed to influence a targeted goal directly; on the other hand, the "procedural" instrument is intended to influence social behaviour to achieve support for the policy (Howlett, 2000). According to the same taxonomy, the other way of categorising policy instruments is based on the governing resources used (Table 1).

Table 1: Instrument Types according to Howlett and Rayner (2007) p.5 Figure 1

		Principal Governing Resource Used			
		Nodality	**Authority**	**Treasure**	**Organization**
Principal Governing Resources Used	**Substantive**	Advice Training Reporting Registration	Regulation Self-Regulation Licences Census-taking	Grants User User Charges Loans Tax Credits Polling	Administration Public Enterprises Policing Consultants Record Keeping
	Procedural	Information provision/ withdrawal	Treaties Advisory committees commissions	Interest group funding/ creation	Conferences Commissions of Inquiry Government Reorganization

Flanagan et al. (2011) propose a different way of looking at the policy mix concept. The framework is developed in the context of innovation studies, focusing on the outcomes of the interactions but is not useful in designing a policy mix. Where Howlett and Rayner (2007) discusses coherence and consistency, Flanagan et al. (2011) refer to instrument interactions and conflicts. According to this understanding of policy mixes, conflicts emerge due to contesting policy rationals, goals and implementation approaches. Moreover, while Howlett (2005) mentions the different policy areas of the policy mixes and their complexity, Flanagan et al. (2011) explicitly states the multidimensional nature of the policy mix by defining different spaces where the interactions occur: policy space, governance space, geographical space and time. The policy space represents the different policy areas that can be addressed or impacted by a policy mix. The government space represents the existence of policy instruments developed on a different level of government. The scope of the policy mix can be limited based on geographical boundaries or time restraints. The temporal dimension plays a significant role in which the dynamics of the policy change and policy learning are considered (Edmondson et al., 2019; Gomel & Rogge, 2020).

Another conceptualisation of the policy mix framework is proposed by del Río (2014). The author studies instrument interactions, focusing on conflicts and synergies based on the outcome of a policy. In addition, the article distinguishes between strong conflicts, weak conflicts, entirely complementary instruments and synergies. This approach underlines the complexity of the policy mixes coming from the instruments having the same goals but originating from different levels of

government (vertical dimension) or policy field (horizontal dimension). This approach to identifying conflicts and synergies resulting from policy interactions is easily applicable because it looks into the outcome of the interactions. Moreover, it can pinpoint which part of the policy mix should be improved and within which level of government or policy area the conflict emerges.

The "vertical" and "horizontal" dimension of the policy mix are further explored by Howlett et al. (2015) and later Howlett et al. (2017). The authors argue that the space where interaction occurs should be properly identified to design an effective policy mix. Furthermore, the more complex the issue addressed by the policy mix is, the more complex the policy mix needs to be. Hence, the involvement in the policy process of a variety of stakeholders is important because each of them has different perceptions of the problem and different tools to address it (Howlett et al., 2015). The empirical research of Howlett et al. (2017) shows that to minimise the conflicts within the policy mix, the focus of the policy-makers should shift from incorporating substantive instruments to procedural ones. As conflicts exist due to differences in perception, the way to mitigate that rational conflict is to incorporate procedural instruments.

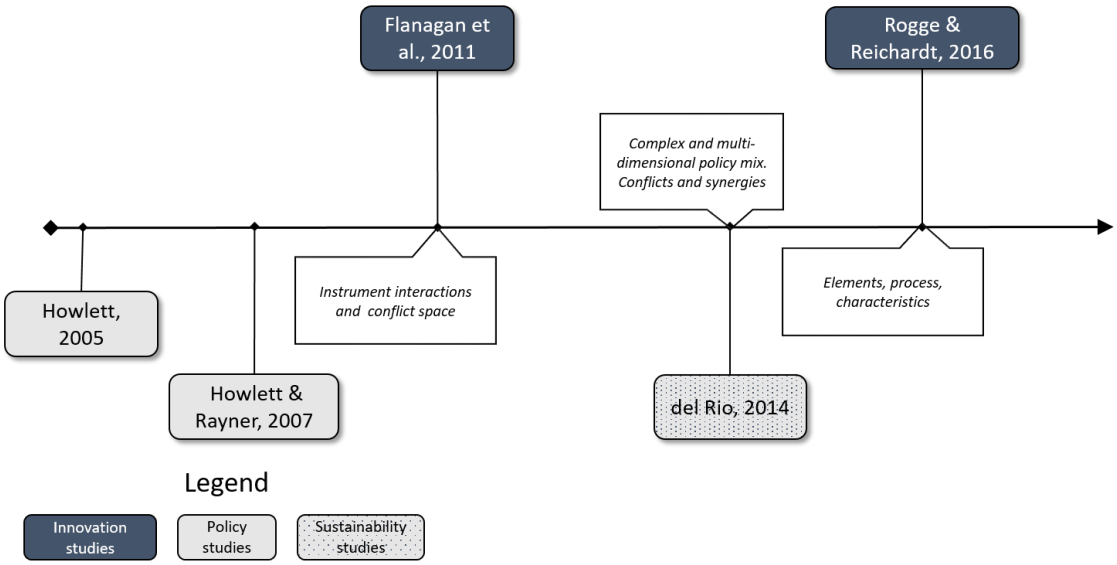

Figure 2: evolution of policy mix concept. Own understanding.

Adopting aspects from previous definitions Rogge and Reichardt (2016) identify three building blocks of the policy mix (Figure 3). Combining the elements' interactions, policy processes and their characteristics. The elements consist of the strategy and instrument mix. The processes building block combines policy design processes and implementation processes. The characteristics include instrument consistency, process coherence, comprehensiveness and credibility. Finally, the policy mix is analysed considering the dimensions of time, geography, government level, and policy fields.

According to Rogge and Reichardt (2016), a policy strategy consists of objectives and principal plans, which underline the long-term perspective of the policy mix. The principal plans map the policy instruments used in achieving the strategic objectives. While the strategies that represent the base of the policy mix with a long turn perspective, they are only an intention, thus easy to change or disregard (Rogge & Reichardt, 2016). On the other hand, the instruments are the tools implemented to achieve the objective. Therefore, they are affiliated with goals rather than objectives.

Like Howlett and Rayner (2007), Rogge and Reichardt (2016) categorise the instruments by type and purpose. However, here the types are Economic, Regulation and Information. At the same time, the purpose can be Technology push, Demand-pull and Systemic. The different categorisation comes from the focus of both studies; the earlier research focuses on broader policy

development while the latter one on the narrower realm of innovation.

Furthermore, Rogge and Reichardt (2016) associates the policy instrument with its design features. The design feature could be descriptive or abstract. The design features represent a description of the policy instrument, its legal form or targeted group. On the other hand, the abstract design features are "stringency, level of support, predictability, flexibility, differentiation and depth" (Rogge & Reichardt, 2016, p. 1624). Overall the design features capture the magnitude of a policy instrument. The last part of the policy mix elements is the instrument mix. Rogge and Reichardt (2016) makes a distinction between instrument mix and policy mix. However, they emphasise that the instrument mix's foundation is the interactions that align with the conceptualisations of Flanagan et al. (2011) and Howlett et al. (2015).

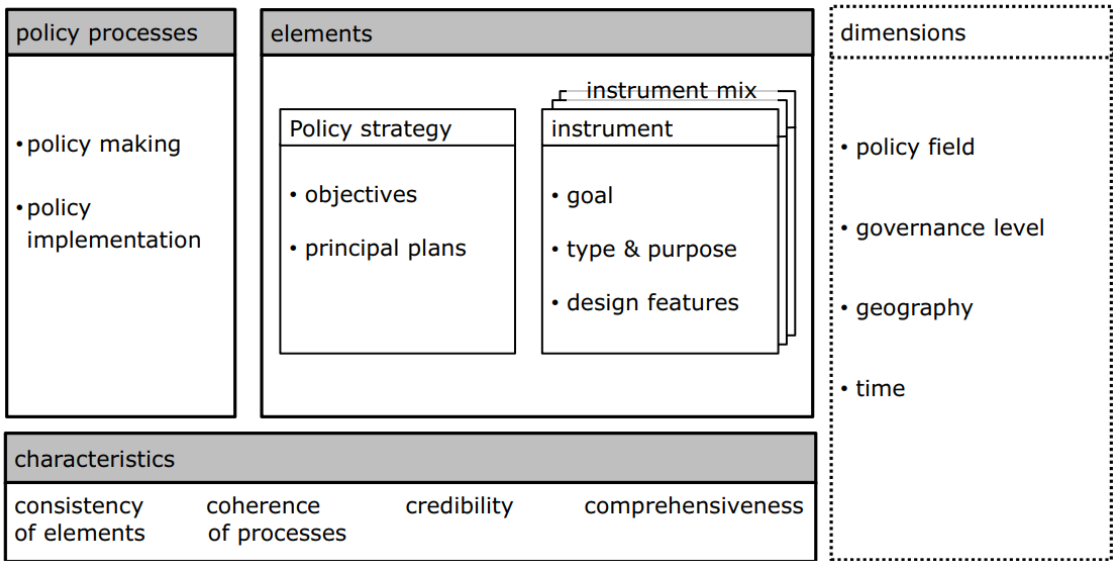

Figure 3: Policy mix framework proposed by Rogge and Reichardt (2016), p.1629 fig. 12

Earlier studies address the process part of the policy mix by focusing on policy learning, instrument change and implementation. Rogge and Reichardt (2016) expand the definition by adding the actor's perceptions and capabilities. Moreover, the authors recognise two types of policy processes: policy-making and policy implementation.

The third building block of the policy mix concept is the characteristics. While the framework discusses coherence and consistency, similar to the Howlett and Rayner (2007), these terms have different meanings. Here consistency refers to the lack of conflicts between the policy mix elements and goals. On the other hand, coherence is associated with policy processes. Furthermore, there are two more characteristics: comprehensiveness and credibility. Both can be referred to as elements and processes, as well as the policy mix as a whole. The comprehensiveness shows the thoroughness of the policy process and whether the policy mix addresses all the market failures. The credibility can be influenced by the elements and the other characteristics (Rogge & Dütschke, 2018)

The biggest strength of the framework proposed by Rogge and Reichardt (2016) is its extensive nature, allowing exploration of the elements' interactions, as well as policy processes, actors' involvement, and characteristics. The framework's applicability is illustrated by Magro and Wilson (2019) by applying it to cases outside the energy transition and innovation space. However, this complexity is its biggest weakness as well. Ossenbrink et al. (2019) argue that with the increase of frameworks complexity, the operationalisation becomes more challenging. Therefore, the studies based on this framework are exploring only one aspect of the policy mix: vertical dimension (Huang, 2019), temporal dimension (Edmondson et al., 2019), processes (Gomel & Rogge, 2020), characteristics (Rosenow et al., 2017; Rogge & Dütschke, 2018; Braungardt et al., 2021).

3.3 Analytical Framework

The literature review and the analysis of the evolution of the policy mix concept (Section 3.2) show that the framework developed by Rogge and Reichardt (2016) represents the most comprehensive understanding of the policy mix concept. This framework is helpful in research outside the space of innovation studies (Magro & Wilson, 2019). Furthermore, it provides an opportunity to evaluate the policy mix's performance and address the design and implementation processes. Finally, several studies underline the complexity emerging from the energy (sustainable) transition and the need to address them (Flanagan et al., 2011; Howlett et al., 2017; del Río, 2017). Thus, this study adopts Rogge and Reichardt (2016) conceptualisation of the policy mixes.

Nevertheless, aspects of the Rogge and Reichardt (2016) could be improved. The types and purposes of the policy instruments proposed by Rogge and Reichardt (2016) could not be applied universally. For example, Rosenow et al. (2017) explores the comprehensiveness of the policy mix by utilising the Rogge and Reichardt (2016) framework in the context of technology innovation and energy efficiency. In this case, Rosenow et al. (2017) classify the policy instruments based on the Energy Efficiency Directive (EED). At the same time, in the case of tobacco control in Switzerland Mavrot et al. (2019) propose different taxonomy based on instruments being carrots or sticks. Both studies classify the policy instruments based on the context of the research, underlining the narrow classification proposed by Rogge and Reichardt (2016). Therefore, a broader policy instruments classification is required.

At the same time, the taxonomy proposed by Howlett and Rayner (2007) and shown in Table 1 represents a general and comprehensive classification of the policy mix instruments. Thus, the research draws from Howlett and Rayner (2007), utilising the policy instrument classification made by Howlett and Rayner (2007) in combination with the overall framework developed by Rogge and Reichardt (2016).

4 Methods

The main research question defined in Chapter 1 is explored using a single case study research approach. The characteristics of the case study approach and its strengths and weaknesses are described in Section 4.1. Focusing on the case of Sofia, Bulgaria and the forest biomass energy policy realm. Following the pragmatic constructive perspective, underlining the existence of different viewpoints within the area of energy transition and energy poverty but providing systematic evidence-based analysis.

The case selection justification is presented in Section 4.2, followed by the selection of energy poverty indicators in Section 4.3. Next, the criteria for policy mix operationalisation are presented in Section 4.4. The research process starts with data collection (Section 4.5). Then a description of the data treatment processes (Section 4.6) and data analysis methods (Section 4.7) is presented. The replicability and validity issues following the choice of the research approach and methods are addressed in Section 4.10 and Section 4.11 respectively. Finally, Section 4.12 presents a summary of the research methodology.

4.1 Approach

The case study approach represents a qualitative or quantitative exploration of an issue in the real-world context within set boundaries (Yin, 2011; Crowe et al., 2011). Moreover, it allows in-depth research in a wide range of study areas, utilising various research methods (Harrison et al., 2017). At the same time, the EP is a complex phenomenon depending on the specific context of a region. Hence, the case study approach is suitable for answering the Research Question of this study.

Harrison et al. (2017) defines seven elements that describe the case study research: Case; Bounded system; Studied in context; In-depth study; Selecting the case; Multiple sources of evidence, and Case study design. The case definition includes selecting the unit of analysis and the study's objective. The unit of analysis can be a political, geographical, social or economic entity.

A case study research can be descriptive or explanatory based on the researched questions; this distinction exists based on the proposed research question (Yin, 2011). Research questions starting with "what" is associated with descriptive case studies, while the explanatory answers research questions starting with "how" or "why".

The bounded system underlies the scope of the research based on time, space or activity. The bounding of the system sets the space where the context variables can interact. In some cases, the bounding of the system and the context can coexist. Nevertheless, the context refers to the viewpoint by which the phenomenon is studied: economic, political, social, environmental, historical, etc.

The analysis' intensiveness and the choice of the philosophical orientation of the research determine the depth of the case study. The philosophical orientations of the case study research, according to Harrison et al. (2017), are realist, relativist and pragmatic constructive perspectives. The realist perspective refers to a single reality that can be studied independently and objectively. On the other hand, the relativist perspective accepts the existence of multiple realities. Finally, pragmatic constructive research embraces that "reality is constructed inter-subjectively through meanings and understandings developed socially and experiential" (Harrison et al., 2017, p.10). The adoption of one or other perspective predetermines the depth, research methods and research design. Hence, the pragmatic constructive study represents the middle ground between the realist and the relativist perspective, accepting the subjective nature of reality of the real-world problems but providing a systematic and objective examination of the problem at hand.

The selection of a case under research according to the Harrison et al. (2017) is made based on the purpose, scope, broadness, methods and replication logic. The scope of the study refers to whether single or multiple cases are explored and whether a single (holistic) or multiple units (embedded) are analysed (Yin, 2011). Furthermore, data sources can vary based on the research methods. Nonetheless, to guarantee the in-depth nature of the study, multiple data sources and

a systematic, exhaustive description of data collecting and data analysis are required. Finally, the design of the case study relates to the choices made by the researcher regarding the purpose, scope, perspective and methods.

The characteristics underlined by Harrison et al. (2017) show the strengths of the case study approach: versatility of methods, applicability, data sources and purposes. However, strengths can only be utilised if the researcher applies rigorous, transparent and systematic techniques in collecting, analysing and interpreting the available data (Flyvbjerg, 2006); otherwise, the strengths become a weakness. For example, if qualitative data is collected from a source with only one perspective, this could result in invalid or unreliable results. Likewise, the use of quantitative data can also have its problems, depending on how the data is collected and what its quality is. The choice of case and analysing methods should not be disregarded. A common criticism of the case study approach is its inability to generalisation (Crowe et al., 2011). At the same time, the vast number of analysing and imperative tools may result in an unsuitable choice of methods. Nonetheless, Flyvbjerg (2006) argues that the generalisation and methods selection issue can be mitigated with proper case selection and context elaboration.

4.2 Case selection

Following Harrison et al. (2017) characterisation of the case study approach, the first step in the case definition is the choice of unit. For the purpose of this study, the unit of analysis will be a municipality. The Municipality represents the lowest level of governing structure in the most EU countries (Ehnert et al., 2018). Thus, they are the subject of all policies developed at the upper level of government. At the same time, they are closest to the communities, putting them at the centre of the energy transition process (Kona et al., 2019).

Flyvbjerg (2006) makes the argument that case selection is critical in treating the problem of generalisation, proposing several strategies to choose the most suitable case. Flyvbjerg (2006) recommends the selection of extreme cases in order to emphasise the research problem. Bulgaria is the country with the highest rate of energy poverty in EU according to several studies (Bouzarovski & Tirado Herrero, 2017; Vondung & Thema, 2019; Bartiaux et al., 2019). Moreover, the Municipality of Sofia is the biggest in Bulgaria and has the most complex administrative structure and stakeholder intensity. Regarding forest biomass energy, only 5% of the population uses forest biomass for heating; however, in several neighbourhoods, that share is above 60% (*Sofiaplan*, 2021) more than the country average of 54% (*NSI*, 2021). Therefore, the Sofia Municipality is a good example of an extreme case, with a high level of energy poverty and high policy complexity, for exploring the impact of the forest biomass energy policy mix on EP.

Policy areas and temporal boundaries need to be established in line with the case study approach and the theoretical framework. Therefore, the time dimension of the research is bounded in the period 2020-2022, looking into all implemented policies that impact forest biomass energy use and all factors related to those policies and the EP. The chosen period represents the transition of the EU, national and local policy framework from the 2012-2020 planning period to 2021-2030. At the same time, there are few implemented local policies before 2020. Thus, the examined issues are relevant, and the recommendations following the analysis can be helpful for the design and implementation of the emerging policy instruments.

4.3 Energy poverty indicators selection

The literature review in Section 2 emphasises that the definition of EP is associated with the indicators that are measuring EP and that it depends on the context of each country or region. Therefore, this section identifies four indicators of EP in the context of Sofia, Bulgaria. Table 2 presents the four metrics used in this study to evaluate the impact of energy transition policy mix on the EP. This research does not look at who is energy poor but how policy mix interactions affect the indicators used to evaluate EP. Hence, the indicators' choice is based on their usability for policy-making and progress monitoring, covering all vulnerabilities underlined by Bouzarovski and Tirado Herrero (2015).

The multidimensional approach to EP is established to be the most suited for policy development and progress monitoring. However, considering which indicators are a more contested issue among the reviewed literature. Two types of indicators should be included since they are dominant in the literature: expenditure (economic) and perception (consensual-based). The energy expenditure will be measured through "Energy affordability". Two indicators represent the perception dimension: "Ability to keep home adequately warm" and "Dwelling with a leaking roof, damp walls, floors or foundation, or rot in window frames or floors".

These three indicators could be monitored since all EU member states collect data about them. The three indicators provide knowledge about affordability (expenditure) and energy efficiency (adequate heating and dwelling quality). However, these indicators do not address the other three vulnerabilities: access, flexibility and practice. These drivers could only be addressed by utilising the energy services dimension, which has been used in developing countries contexts. Thus, the last indicator selected for this research will be: "Use of modern and safe energy". This indicator implies that using energy sources such as round-wood and coal represents health and environmental risk and that the households using them have either no alternative or this alternative is not affordable.

Table 2: Energy Poverty Indicators

Indicator	**Description**
Energy affordability	Percentage of households paying less than 10% of their income for energy
Ability to keep home adequately warm	Percentage of households said to feel adequately warm
Dwelling with a leaking roof, damp walls, floors or foundation, or rot in window frames or floors	Percentage of households said to live in poor conditions
Use of modern and safe energy	Percentage of households using solid fuels for heating

4.4 Operationalisation of policy mix theoretical concepts

The operationalisation of the policy mix framework becomes more challenging with the increase of its complexity, as shown in Chapter 3. Table 3 presents operational criteria for all components of the policy mix concept as defined by (Rogge & Reichardt, 2016). The operationalisation of the policy mix is provided in Table 3. For each building block of the policy mix, operationalisation criteria will be used to identify the policy mix elements and characteristics. In contrast, the policy mix processes would not be a focus of the research.

Table 3: Operationalization of the Policy mix

Component	**Operationalization**	**Source**
Policy strategy	Impact domain. Any policy strategy that affects the share of biomass energy.	Ossenbrink et al. (2019)
Policy instrument	Impact domain. Any policy instrument that affects the share of biomass energy.	Ossenbrink et al. (2019)
Instrument mix	Combination of policy instruments that have shared goal and complement each other.	Rogge and Reichardt (2016)
Instrument goals	Designed effect of the policy instrument	Rogge and Reichardt (2016)

Instrument types	Nodality, Authority, Treasury, Organization (Table 1)	Howlett and Rayner (2007)
Instrument purpose	Substantive, Procedural (Table 1)	Howlett and Rayner (2007)
Design features	Descriptive, abstract	Rogge and Reichardt (2016)
Policy design processes	Initiations of policy change Process of stakeholders involvement Formulating policy objectives Adoption of policy strategy Formulation of instrument goal Adopting of policy instrument Policy legislation	Rogge and Reichardt (2016)
Implementation processes	Resource allocating Gathering public support	Rogge and Reichardt (2016)
Consistency of the policy strategy	The principal plans on the different levels of government or policy domains are setting conflicting objectives.	Rogge and Reichardt (2016)
Consistency of the instrument mix	There are no conflicting instruments' goals and the nature of the impacts on a goal is the same for all instruments.	Rogge and Reichardt (2016)
Consistency of the instrument mix with the policy strategy	Both strategy and the instrument mix should be consistent and adequately address the problem to reach the set target.	Rogge and Reichardt (2016)
Coherence of policy processes	There is alignment between the beliefs and perceptions of the policymakers on the different levels of government. Existence of a coordination procedure between the different levels of government. Existence of information flow. The elements should be designed taking the capabilities and capacities of the relevant institutions. The existing policies should be taken into account in the policy-making process. All the relevant information should be utilized. Inclusion of the relevant stakeholders.	Rogge and Reichardt (2016)
The credibility of the policy mix	Addressing vulnerable groups. Participation in the decision making, transparency, existence of a public support	Rogge and Reichardt (2016)
The comprehensiveness of the policy processes	Stakeholders' involvement, type of decision-making process.	Rogge and Reichardt (2016)
The comprehensiveness of the policy elements	Does the policy mix address all the market and system failures?	Rogge and Reichardt (2016)

4.4.1 Identifying the elements of the policy mix

Ossenbrink et al. (2019) propose two approaches to identify the elements of policy mix: top-down and bottom-up. The top-down approach is based on strategic intent. On the other hand, the bottom-up approach considers the "impact domain" if a policy strategy or policy instrument is impacting the domain of interest but is not necessarily designed with that intent. If the top-down approach is used, the policy mix elements will be principal plans and instruments specifically

targeting biomass energy use. On the other hand, if the bottom-up approach is chosen, the policy mix elements will include a policy impacting biomass energy use. However, their strategic intent is to reduce air pollution or diversify energy sources. Thus, the bottom-up approach will generate a large set of policy instruments, and principal plans cross more policy fields.

The bottom-up approach proposed by Ossenbrink et al. (2019) for identifying the policy mix elements is useful in exploring the problem of this research. This study aims to understand the impact of policy mix on alleviating energy poverty, which is influenced by more factors than forest bio-energy use. Moreover, local and national government authorities have not focused on biomass energy for domestic use. In addition, another policy domain, such as air quality, has drawn more public and government attention.

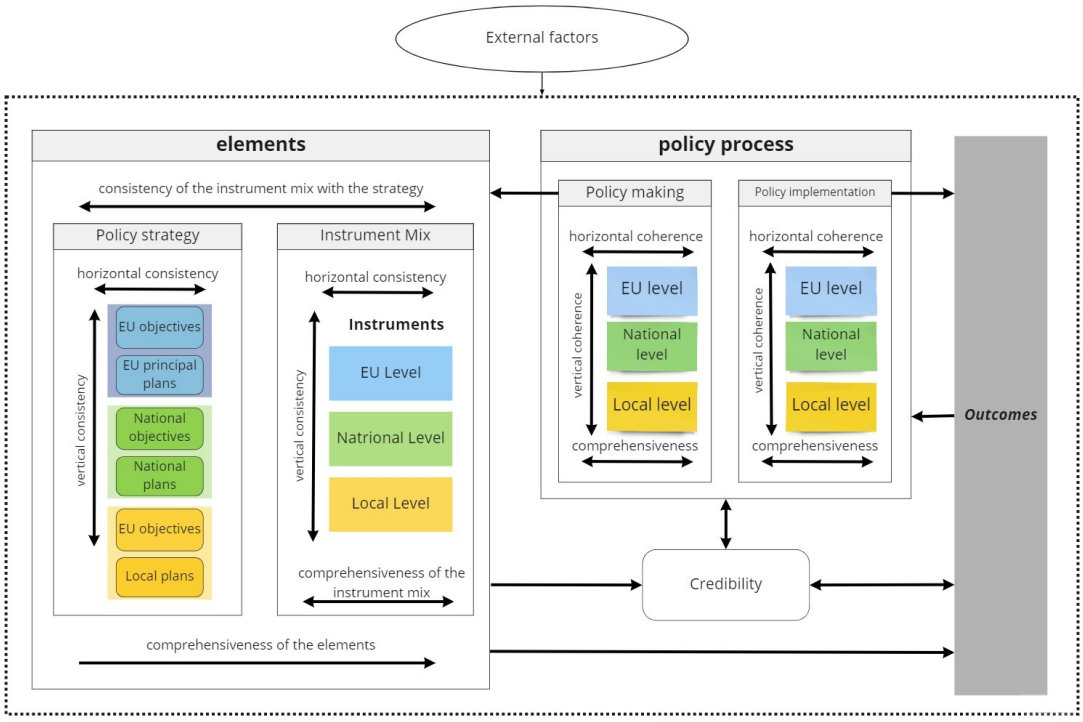

Figure 4: Elements, Processes, Characteristics and relations to the outcomes based on Rogge and Reichardt (2016) in the context of multilevel governance.

4.4.2 Policy instruments

Rogge and Reichardt (2016) associate the policy instruments with goals, type and purposes and design features. The goals represent the policy instruments' expected impact and are specified when the instrument is designed. Furthermore, the type and purposes of the policy mix are identified according to the taxonomy developed by (Howlett & Rayner, 2007). Finally, the design features have mainly been ignored by the studies using the Rogge and Reichardt (2016) framework; nevertheless, the framework has two types of design features: descriptive and abstract.

The descriptive design features refer to the legal form of the instrument, whether they are compulsory or voluntary, the period in which it is active, and the groups it targets. On the other hand, Rogge and Reichardt (2016) proposes six abstract design features: stringency, level of support, predictability, flexibility, differentiation, and depth.

4.4.3 Characteristics

The characteristics determine the effectiveness and success of the policy mix as well as the overall policy mix impact. Figure 4 visualises the framework developed by Rogge and Reichardt (2016); emphasising the multi-dimensionality of the policy mixes and visualising the operationalisation of the characteristics. For example, constancy and coherence have both horizontal and vertical dimensions. Vertical consistency refers to the conflicts and synergies existing between the instruments across the governmental level. On the other hand, horizontal consistency represents the interaction between policy instruments addressing different policy domains on the same level of government.

Concerning the coherence, vertical coherence is embedded in the policy-makers perceptions and capabilities on the different governance levels. In contrast, horizontal coherence refers to policy areas of the policy-maker. There is no vertical or horizontal aspect of comprehensiveness and credibility. However, the comprehensives can refer to the existence of a balanced and comprehensive instrument mix, addressing all market failures and adverse outcomes, or the existence of policy objectives, strategic plans, goals and instruments that address them. At the same time, the policy mix's credibility can be determined by other characteristics, policy instruments, and processes.

4.5 Data collection

The data for this analysis was acquired in two ways: desk research and semi-structured qualitative interviews. First, the desk research includes a review of policy documents (strategies and action plans), legislative documents (law, directives, regulations and by-laws), academic literature, policy reports (from governmental and non-governmental sources) and media publications. The academic literature is gathered through a Scopus query based on a combination of the following keywords: EU, Bulgaria, Sofia, energy poverty, and biomass energy. The rest of the documents were collected through Google search using the same keywords. The selected documents are used for identifying the stakeholders involved in the issue, their objectives and perception of the problem using the actor analysis framework conceptualised by Enserink et al. (2010). Second, the desk research data was used to identify the elements of the policy mix base on the criteria described in Section 4.4.

The second data source consists of five semi-structured interviews. Four interviews are conducted with NGO representatives and one with a representative of the Executive Forest Agency (I2, Appendix E). The NGO representatives included an NGO working on energy efficiency and renewable energy with knowledge of Sofia Municipality's projects (I1 and I2 Appendix E); a representative of an organisation involved in energy efficiency project coordination and monitoring on a local level (I4 Appendix E), and an environmental NGO representative with more knowledge on the national level decision making (I5, Appendix E). All interviews were conducted and transcribed in Bulgarian and later translated into English. The interviews were conducted based on interview protocols presented in Appendix E. The interview protocols were designed not to include leading questions which can point the answers in pre-set direction, avoiding "yes" or "no" questions. For example, "Is A having a negative influence on B?" or "Does the A designed to increase B?" are unacceptable questions; instead, the more proper formulation will be: "What factors are causing B?" and follow-up questions, "How are these factors influencing B?". Besides the predefined questions, the respondents were asked various other questions depending on their shared information and field of expertise.

4.6 Data treatment

The documents collected by the desk research and the transcripts of the interviews were analysed using NVivo software. For each step of the research, a different technique for the content analysis was used. First, for the stakeholder analysis, the stakeholders are identified based on the authors of the various documents and manually looking through the documents for identified stakeholders. The stakeholders' role, dependencies and interests are acquired through the laws and information from the official web pages. Their objectives and perspectives are explored through the proposed

policy strategies, instruments and insight from the interviews. Second, the policy mix strategy and action plans are identified based on the desk research. At the same time, the policy instruments are discovered by searching all policy documents and reports with the keywords; biomass, wood, and pellets (and their Bulgarian translations). Finally, the content of the interview transcripts was analysed, and a CLD was constructed following the Kim and Andersen (2012) framework.

The framework proposed by Kim and Andersen (2012) provides a systematic path to generate a System Dynamics model from qualitative data to create a valid and reliable model. Kim and Andersen (2012) defines five steps processes for mapping the system relations: discovering themes; identification of variables and relations; transformation of text to diagram; generalising structural representation; linking the maps to the data.

4.7 Data Analysis

4.7.1 Stakeholder analysis

In order to identify and establish the dependencies between the various actors involved in the case, stakeholder analysis will be performed. The stakeholder analysis is conducted following the six steps defined by Enserink et al. (2010):

1. formulation of a problem as a point of departure;
2. inventory of the actors involved;
3. exhibiting the formal chart: the formal tasks, authorities, and relations of actors and the current legislation;
4. determining the interests, objectives and problem perceptions of actors;
5. mapping out the interdependencies between actors by making inventories of resources and the subjective involvement of actors with the problem;
6. determining the consequences of these findings about the problem formulation.

The actors included in the analysis are government bodies on the EU, national and local levels, NGOs, companies and impact groups. The aggregation of the stakeholders will be done based on their organisational structure. For example, the Sofia Municipality will be represented by the municipal council and the mayor. The Municipality has a vertical structure, and all departments are directly responsible under the mayor. Hence a high level of coordination could be assumed. On the other hand, in the national government, the ministries have a horizontal structure. Hence each ministry is acting under its agenda.

4.7.2 Causal Loop Diagram

The policy mix concept underlines the existing complexity and interaction between the policy mix instruments. At the same time, the CLD is a system thinking method which is used to understand the dynamics and relations of complex systems through feedback mechanisms (Saeri et al., 2019). For example, the CLD can explain how variable A impacts variable B without having a direct relation, emphasising the interconnections and dependencies in the system. Hence, the CLD represent an appropriate tool for capturing the relation in the system.

The most important part of the CLD is the system factors and their relations. These relations represent a causal connection that can be positive or negative. The positive causality meant the increase of Factor A led to an increase of Factor B, or a decrease in Factor A leads to a decrease in Factor B. On the other hand, the negative causality means that an increase in Factor A leads to a decrease in Factor B. A closed causal link in the CLD forms a feedback loop. The feedback loop can be re-inforcing (R) or balancing (B). The balancing loop has an overall negative effect, while the re-inforcing loop is positive.

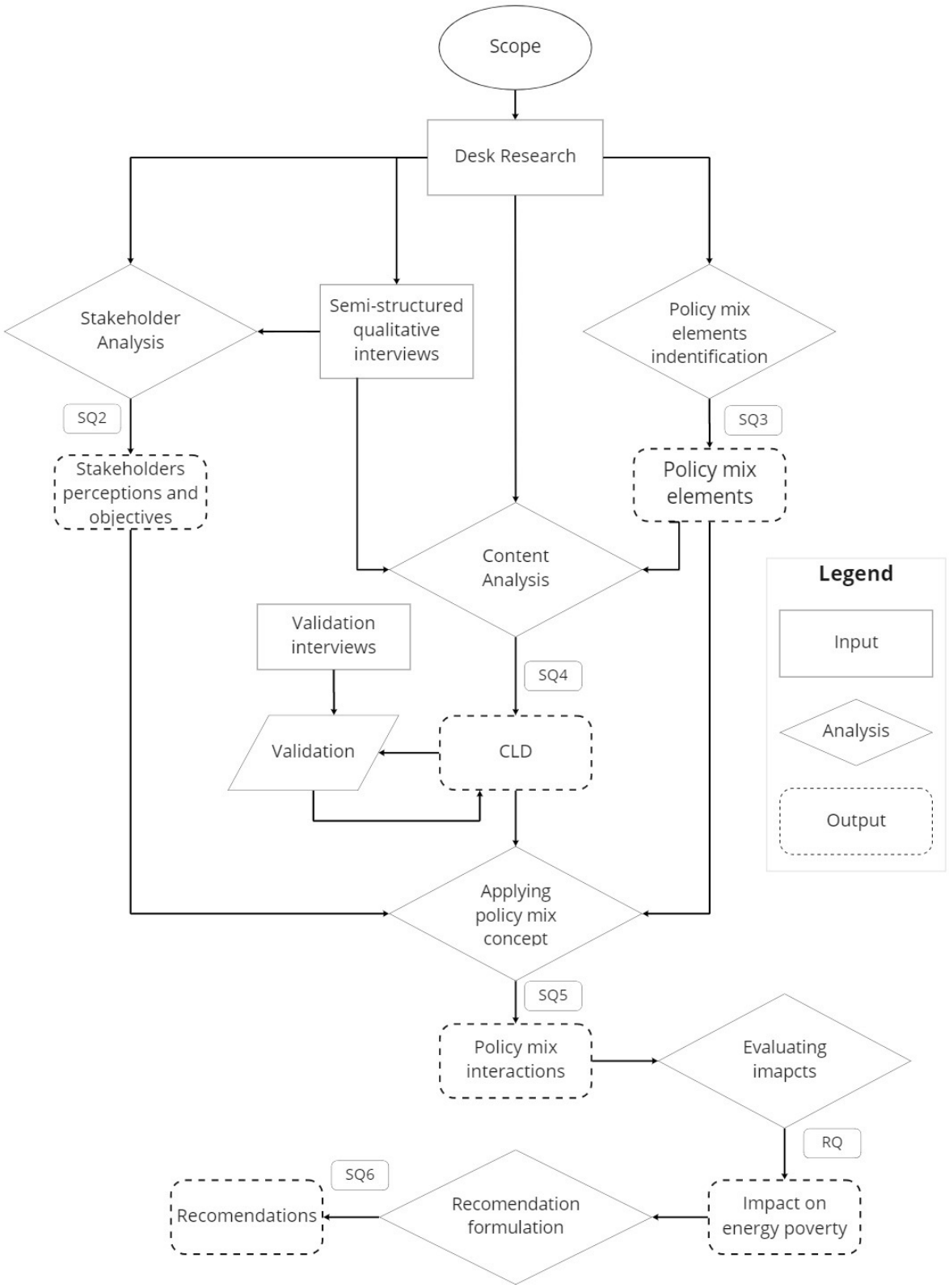

Figure 5: Research Flow Diagram

The CLD is formed based on content analysis of the interview transcripts and the documents acquired through desk research and conducted in NVivo. The framework developed by Kim and Andersen (2012) is followed for the construction of the CLD. First, key themes are searched using the auto coding feature of NVivo through the documents and transcripts. Next, the common themes are combined and coded. Based on the context of each citation, a relation is assigned between themes in one paragraph. Next, these relations are transferred in a CLD using Venisim software. For the variables' names, the System Dynamics conventions are followed (Auping et al., 2014). The causal relations are indicated with "+" (positive) or "-" (negative).

4.8 Applying and reflecting on the theoretical policy mix framework

The operationalisation of the policy mix presented in Table 3 as well as the results of the stakeholder analysis and the identification of the elements will be used to apply the policy mix framework to the CLD. The elements of the policy mix are already present on the causal map. However, the causal map should also assign their government level, goal, type and purpose. The policy instruments' design features represent a causal map factor. For example, the consistency of the policy mix depends on whether there are conflicting goals; that information can be obtained through analysis of the CLD and determines the overall consequence of this conflict.

4.9 Impact evaluation

After applying the operationalisation criteria to the CLD the impact on the energy poverty indicator should be evaluated. The EP indicators are added to the system, and the causal relation to them is based on the definitions of the indicators elaborated in Section 4.3. The expenditures indicator depends on the cost of energy and the household income. The adequate heating indicator is a function of the energy consumption and energy need. At the same time, access to modern and safe energy sources depends on the type of appliances (old or new) and the quality of the traditional fuels. Finally, the model does not include the dwelling quality indicator because the instrument mix does not affect it. The evaluation of the impacts is made on the effect of the policy mix characteristics on the EP indicators based on the CLD.

4.10 Reliability of the research

This research's contextual and qualitative nature requires addressing the replicability issue at each step of the research process: energy poverty indicators selection, data collection, stakeholder analysis, policy mix identification, CLD formulation and validation.

4.10.1 Operationalisation of the theoretical concepts

The research operationalises two theoretical concepts: EP and policy mix. The operationalisation of the EP refers to the EP indicators choice. In contrast, the policy mix operationalisation represents the utilisation of the Rogge and Reichardt (2016) framework in the study context. The replicability of the operationalisation of the policy mix theoretical concept is ensured by applying criteria proposed by Rogge and Reichardt (2016); or studies based on their framework. However, due to its broader nature, the instruments type and purpose taxonomy is based on the framework of Howlett and Rayner (2007). Therefore, regardless of what criteria are used, their source is reported.

The replicability issues that can occur with selecting the energy poverty indicators are connected to the literature on which the literature review is based, the results of the literature review and finally, the criteria by which the indicators are formulated. All these issues are addressed in the following way. First, the parameters of the search query conducted in Scopus are described in Appendix B. The query is defined as broad as possible. Next, articles are selected based on their abstracts and clear criteria to address the energy poverty measurement and inclusion of various regions and research approaches. The last two criteria are included in the literature review to

represent the whole variety of studies as possible. The literature analysis follows the framework developed by (Wee & Banister, 2016). The indicators of energy poverty were selected based on the literature review considering the context of the CEE. The challenge for repeatability in this step is that if the literature review is conducted again, the same indicators will be selected. The process described beforehand should ensure that happens.

4.10.2 Data collection

The data is collected in two ways: desk research and semi-structured interviews. The repeatability requirement, in this case, is to structure the collecting process in a way that always leads to data that, when analysed, will lead to the same results. Hence, the following steps are undertaken. First, all web searches and sources of all documents are formulated and documented. It ensured the documents included various sources on different levels of government, NGOs and academics. Second, the interviewees are contacted based on the stakeholder analysis so they can represent all stakeholders.

4.10.3 Stakeholder analysis

To ensure replicability of stakeholder analysis, it is conducted based on the framework proposed by Enserink et al. (2010). It used data obtained through desk research and interviews. First, the stakeholders are identified based on the documents authors or specific listing in some of the reports conserving energy poverty or forest biomass energy, as well as the normative acts concerning these two topics, which is a broad but not exhaustive list of possible sources. Next, the perception and objective were determined based on a direct search of the stakeholder name within the documents and interview transcripts.

4.10.4 Policy mix identification

The policy mix identification is conducted by analysing all documents and looking for policies that impact the energy produced by forest biomass for the residential sector. The analysis is conducted in the keyword search in NVivo. The policy instruments and plans are identified and operationalised based on the methodology in Section 4.4. The risks for replicability emerge mainly from the data sources and the inclusion of all possible synonyms of the searched keywords.

4.10.5 CLD

The structure of the CLD directly affects the study's results. In order to ensure repeatability of the causal map, several steps are taken. First, the data sources are reported, followed by a description of the documents. Second, the generation of the CLD is based on a clear framework drawn from the existing literature. Finally, each step of the construction of the CLD is reported.

4.11 Research Validity

The validity of the study concerns whether the insight drawn from the results can be used in respect of the policy mix concept. This issue is addressed by choice of case selection. The case of Sofia municipality provides a look into the policy mix developed in the context of the country that is a member of the EU but has multiple policy implementation and administrative issues similar to countries that are characterised as developed. Applying the policy mix framework by Rogge and Reichardt (2016) to the case of Sofia can provide insight into the strengths and weaknesses of the framework.

The choice of a single case study approach creates a risk for the research results to apply only to the case of Sofia or to the case or the context of forest bio-energy. Both of these risks are addressed through the motivation of the case study choice (Section 4.2). The case selection is based on the criteria drawn from the case study literature. Sofia Municipality represents extreme cases in terms of EP and policy complexity. The scope of forest bio-energy use is common across

CEE. At the same time, the issue of forest bio-energy use in Sofia touches multiple policy areas: AQ, RE, EE, biodiversity.

The other aspect of the study's validity relates to applying the framework to the specific case. This research utilises operationalisation criteria already established in the policy mix literature. Thus, when the insights for the operationalisation are drawn, they can be compared to the existing literature.

The validity of the results is addressed by reporting each step of the research process, using multiple evidence from various data sources, and validating the established causal relations. The validation process aims to establish an understanding of the causal relations between the different factors. The interview transcript and document source support each causal relation. The two sources should mitigate relying upon a limited number of interviews and types of stakeholders. Most of the responders who agreed to interview were representatives of the NGO sector.

Nevertheless, they represent different policy areas, energy efficiency, environment, and renewable energy. Hence they can provide a different perspective to some extent. Next, the interview is conducted based on interview protocol (Appendix E).

In addition, two interviews with experts that have not been interviewed before were conducted in order to increase confidence in the model. The validation interviews intend to conform to the unidentified causal relation and nature. The first validation interview was conducted with an expert monitoring one of the municipal appliance chaining programs. The second interview was conducted with a representative of an NGO familiar with the forest biomass sector in Bulgaria. Nevertheless, the two interviewees again come from the NGO sector, which does not eliminate the bias issues.

4.12 Summary

The research methodology described in this chapter is based on a single case study approach. The methodology is visualised in Figure 5, starting with data collection and data analysis. Next, the key stakeholders and their relations and perceptions are identified. Following the stakeholder analysis, the policy mix plans and instruments are identified. A CLD is drawn and based on the interview transcripts and policy documents, establishing the causal relations in the system. Then, the policy mix framework is applied to the identified policy elements and the CLD. The answer to the main research question is provided, evaluating the impact of the policy mix characteristics on the EP based on the CLD. Finally, recommendations are formulated based on the finding of the impact evaluation.

5 Case Description

This Chapter will establish the existing relationships and dependencies between the different levels of government by describing the administrative structure of Bulgaria and dividing competence between, EU, national and local government institutions in Section 5.1. Next, Section 5.2 describes the socio-demographic structure of Sofia Municipality, followed by a depiction of the EP state in Sofia (Section 5.3). The EU, national and local institutions involvement and responsibilities regarding forest bio-energy use and EP is elaborated in Section 5.4. The main policies regarding the forest bio-energy are discussed in Section 5.5. Finally, Section 5.6 summarises the ramifications for the research arising based on the context of Sofia, Bulgaria.

5.1 Institutional structure and governance

5.1.1 EU institutions and competences

According to the founding documents of the EU there are three main institutions involved into decision-making process (European Union, 2002): European Parliament; European Commission (EC); Council of the EU. European Parliament is the only directly elected body of the EU. It stands for the interest of the EU citizens. The Council of the EU consists of representatives of the member states' governments. Thus it represents the interests of the EU governments. Finally, the EC represents the interests of the EU itself. All three institutions have a role in both agenda setting and legislative processes. The EC and Council of the EU can put forward priorities; however, for them to become strategic documents of the EU, the proposals need to be approved by all three institutions (European Union, 2002). Once the three bodies approve the strategic objective, it needs to be implemented in the form of legal acts. Regarding the legislative process, the EC has the sole power to propose legislation; however, both the Parliament and the Council have the power to amend or reject it completely.

The EU has multiple policy instruments available to achieve its strategic agenda. There are five forms of legal acts accessible to the EU: Regulations; Directives; Decisions; Recommendations; and Opinions (EC, 2019c). The regulations, directives and decisions are binding, while the recommendations and opinions are not. First, the regulations represent legislation obligatory for all in the EU and enforced throughout the EU as it is. At the same time, the second obligatory acts of the EU, directives set common objectives but leave the exact form in which they will be reached in the hands of the member states. The last binding legal acts are the decisions that target specific public or private institutions and are obligatory only for that entity. Finally, the recommendations and opinions are used to express not mandatory advice and assessments.

Alongside the legislative instruments, the EU can rely on its budget to realise its strategic objectives. There are two aspects of the EU budget: the Multiannual Financial Framework (MFF) and the annual budget. The MFF is the long-term budget of the EU for 7 years. The MFF is proposed by the EC and needs unanimous approval from the Council and the Parliament's consent. The budget spending can be managed by the EC directly or with national institutions and indirectly by other government or non-government organisations. Direct funding takes the form of grants and subsidies to organisations inside and outside the EU. In addition, the direct funding goes to support the various EU institutions and agencies. The part of the budget managed by the EC and the national authorities includes regional, agricultural, cohesion and other funds intended to reduce the inequality between the EU regions and stimulate sustainable economic growth.

While all EU law is superior to the national legal acts, there are policy areas that are exclusively a prerogative of the EU and other domains in which the EU is sharing competence with the member states. For example, according to the Lisbon Treaty (European Union, 2002), the competition rules, the customs union, common commercial policy and monetary policy are exclusively the competence of the EU. On the other hand, policy areas such as energy, agriculture, environment, transport and some aspect of the social and economic policy are under shared responsibilities. In the end, the EU plays coordination and advisory role in all other policy realms.

The EU plays a very prominent role when it come to RE, EE, AQ and Land Use, Land-Use Change and Forestry (LULUCF) (Figure 12); all of this areas have impact on forest bio-energy. On the other hand, the EU leaves the domain of EP in the hands of the member states and limits its role to three aspects: monitoring the progress of EP alleviation through EPOV; creating regulations and requirements for member states to addresses EP in other to have access to EU financing, and directly financing the EP research and awareness projects. Nevertheless, the definition and the exact way of addressing EP are entirely in the competence of the national and local authorities.

5.1.2 Administrative structure of Bulgaria

Bulgaria is a centralised unitary state, which means that most resources and competencies are concentrated on the national level (Ehnert et al., 2018). The country is a parliamentary republic with a unicameral National Assembly holding all legislative power. The National Assembly is elected every four years and elects the Council of Ministers. The Council of Ministers represents the executive branch of the government, and Prime Minister heads it. A minister can be responsible for a ministry or be without a portfolio; in the latter case, the minister is a task with more coordinating functions. The Ministers are also directly responsible for the agencies under the respective Ministry's authority.

The main administrative divisions in the country are 28 districts and 265 municipalities. According to the Nomenclature of territorial units for statistics (NUTS) classification, the districts represents the NUTS III regions. NUTS I and NUTS II regions also exist; however, as Ganev and Primatarova (2007) point, these regions are used only for planning purposes. With NUTS I regions increasing importance since Bulgaria joined the EU; due to their role in the EU funds planning. On the other hand, the municipalities have been established as the main operational sub-national authority (Ganev & Primatarova, 2007). While the districts have more of a coordinating function without legal powers or financial resources.

Each district has a regional administration headed by a District Governor appointed by the Council of Ministers. The District Governor represent the national government's interest on the regional and local level and can overturn the decisions made by the Municipal Council. Municipal Councils are the main decision-making body of a municipality. At the same time, the Mayor is responsible for the implementation of the decision of the Municipal Council. In contrast to the Districts, the municipalities can only collect local taxis but have limited financial independence (Ganev & Primatarova, 2007). For example, the waste tax can only be spent on municipal waste collection and treatment.

The areas where the municipalities have sole competence are very few. The state's unitary nature determines the municipalities' role as executors of the national government policy. The municipalities have sole competence in two issues: problems of local importance that are not explicitly in the national government's competence and issues related to municipal ownership. However, the actions of the municipalities regarding both areas are limited by the municipality's ability to finance them.

5.2 Sofia Municipality

The Sofia municipality is the biggest in Bulgaria based on its population and territory. Its territory co-exists with one of Bulgaria's 28 Districts - Sofia-city. Similarly to other municipalities, the governmental structure of Sofia consists of Municipal Council and a Mayor. The municipal administration's structure resembles the national government, with separate divisions responsible for environmental, energy and social issues. The divisions are under the supervision of a deputy mayor. However, the municipality's governance is highly centralised, in contrast with the national government, where the ministries have more independence in their actions.

The municipality itself is divided into 23 regions (Figure 6). Despite the strong centralisation of the municipal administration, the problems that each of these regions faces are very different; substantial inequalities exist between the core (central) regions and the periphery. First, the central regions are highly urbanised, with high population density (Figure 7). On the other hand,

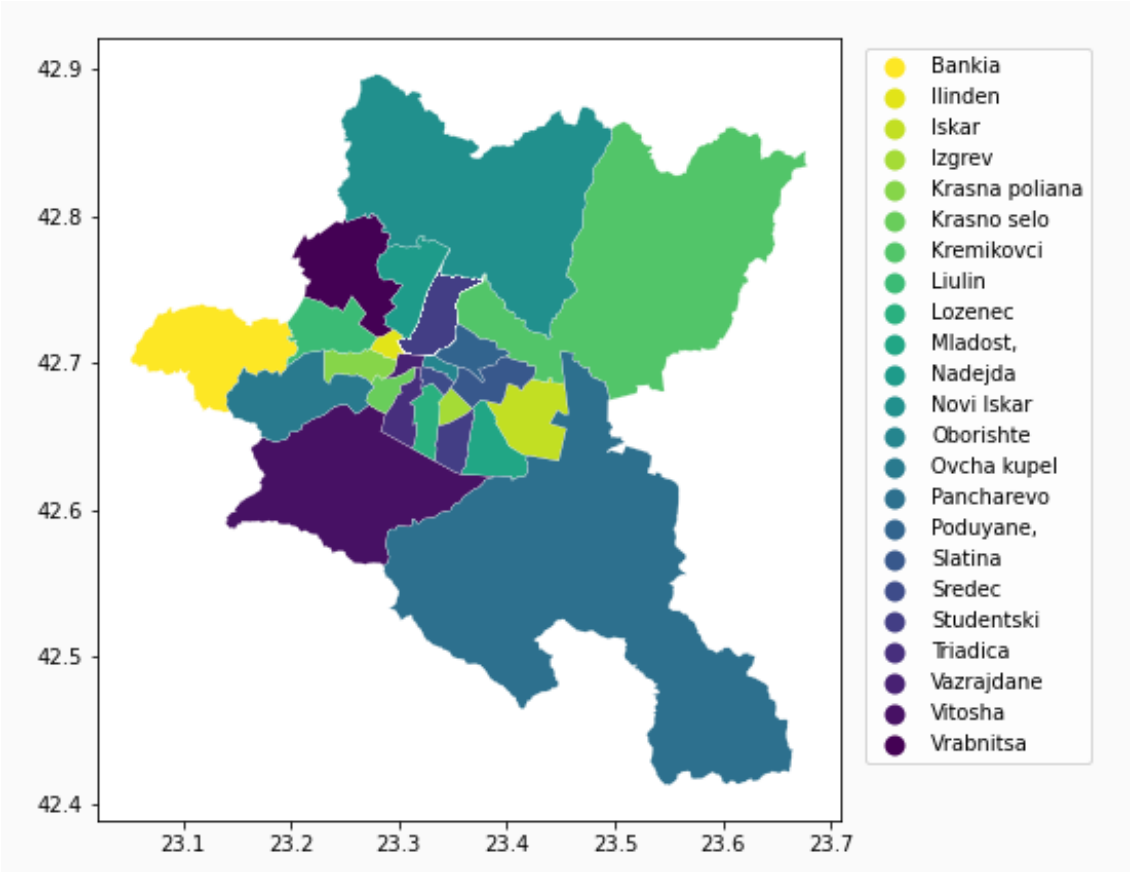

Figure 6: Administrative Districts of Sofia Municipality. Source Sofiaplan

the regions in the North-East and South-East of the municipal core (Pancharevo, Kremikovci and Novi Iskar) can be identified as rural (Figure 6), with low population density. Furthermore, these distinctly rural regions rely predominately on traditional fuels for heating (Figure 9) due to a lack of connectivity to the district heating and natural gas network.

Furthermore, according to *Sofiaplan* (2021), the current district heating network is limited to the core neighbourhoods, and the natural gas network is more developed in the western part of the municipality. Finally, while the average monthly income in Sofia Municipality is one of the highest in the country, according to the *NSI* (2021), there is strong income segregation (Figure 8). The people living in the northern regions of the municipality have significantly lower incomes that those living in the central and southern parts.

5.3 Energy poverty in Sofia

Section 4.3 identified four energy poverty indicators for measuring energy poverty: "Ability to keep home adequately warm"; "Dwelling with a leaking roof, damp walls, floors or foundation, or rot in window frames or floors"; "Energy affordability"; "Use of modern and safe energy". While there is no data on the local level about the first two indicators, parallels can be made with the national level surveys. As a whole, Sofia municipality is quite different from the rest of the country regarding demographic and social parameters. However, as argued in Section 5.2, there are significant differences between the municipalities' regions, with the periphery district having similar living standards to the rest of the country. Concerning "Energy affordability", the price of electricity and natural gas is monitored by the National Statistical Institute (NSI); however, the price of wood and wood pellets is not. Thus, information about the price of wood and wood

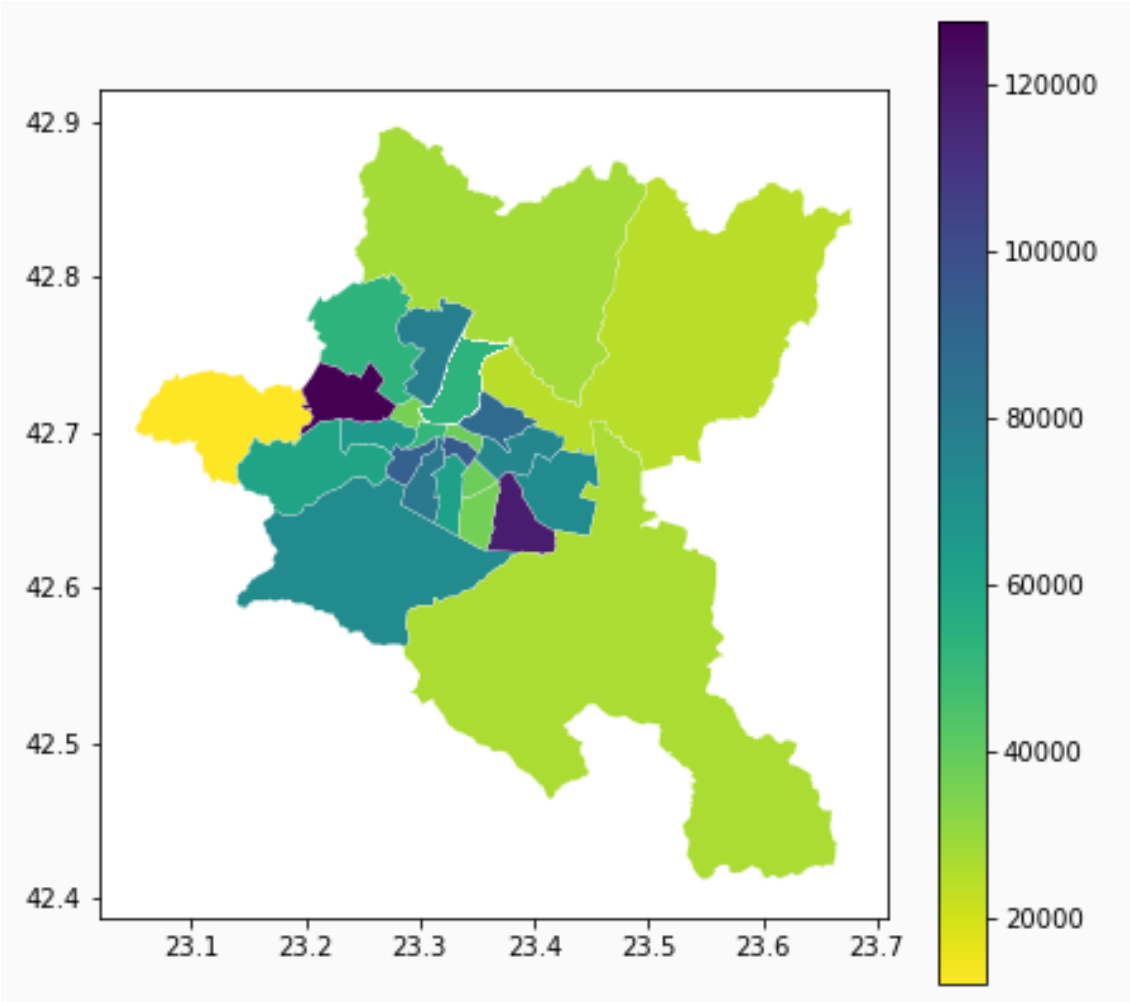

Figure 7: Population of Sofia Municipality per district. Source Sofiaplan

pellets is obtained through exploratory interviews.

According to EU-SILC for 2020, 27.5% of Bulgaria's population is unable to adequately keep their home warm, with an average of 8% for the EU. However, for the same year, 11% of Bulgarians are said to live in a dwelling with a leaking roof, damp walls, floors or foundation, or rot in window frames or floor, which is below the EU's average of 14.8%. Several assumptions can be made regarding Sofia based on EU-SILC data. First, taking the income status of the different regions, the population of the southern parts of the municipality could be assumed to have a higher ability to keep their homes warm and live in better dwellings. On the other hand, the poorer northerner regions are more likely to be close to the national average. Finally, it must be noted that EU-SILC data shows that ability to adequately keep their home warm and dwelling quality had increased in the years after 2010.

In contrast to the first two indicators, "Energy affordability" is not based on people's subjective perception but rather on their actual spending. According to the *NSI* (2021), the households in Sofia pay 12.7% of their income for energy bills in 2020 and 13.8 % in 2021. Again, these figures should be considered in the context of the different income levels between the regions and the different energy sources and energy consumption. According to I1, I3 and I4 (Appendix E), the price of wood and wood pellets has increased due to industrial demand for wood, as well as demand from neighbouring countries and higher price of energy resources needed in the production of pellets. The price of electricity for domestic purposes has not seen an increase (*NSI*, 2021) due

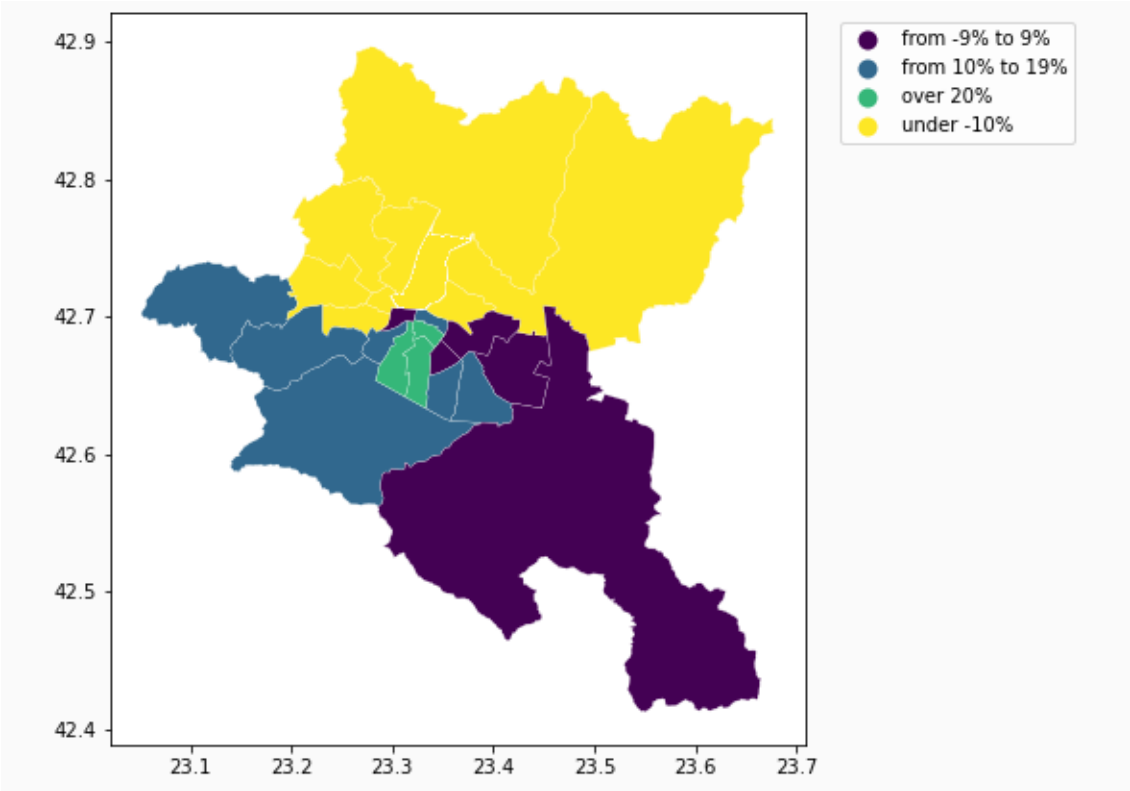

Figure 8: Average monthly income for 2017 as a % over/under the average for the capital of 1,312 BGN (Bulgarian lev) per month. Source Sofiaplan

to the regulation that exists, the price is set by the energy and water regulatory commission, and the ability of the national electricity producers to meet the national needs. However, the natural gas price at the beginning of 2021 has increased by almost 100% compared to the beginning of 2020 (Figure 10). In addition, district heating energy is generated from natural gas; its price has also increased. Thus, households using energy other than electricity for heating are receiving an increase in their heating costs.

The final indicator defined in this research refers to the use of traditional fuels for heating; as Figure 9 shows, there are regions in the municipalities where more than 60% of the population uses traditional fuels for heating. The extensive use of wood and coal in these regions can be explained by the residents' financial state and the lack of access to alternatives such as natural gas and district heating.

Overall, the EP should be looked at through the lens of the different regions in the municipality. The city's core part is wealthier and associated with a higher level of dwelling quality, ability to meet its energy need and access to various energy sources. On the other hand, the periphery of the municipality, specifically the east part, has lower income and few affordable alternatives to traditional fuels.

5.4 Stakeholder roles and relations

There are four types of stakeholders based on the governmental dimension: EU, national, local and non-governmental. The EU stakeholders, largely have same objectives and perception (Table 18, Appendix F) and can be looked as one composite actor regarding the forest biomass energy and EP. In contrast, the national level is associated with a horizontal governmental structure; each Ministry has a different objective and develops policies regarding its objective with little

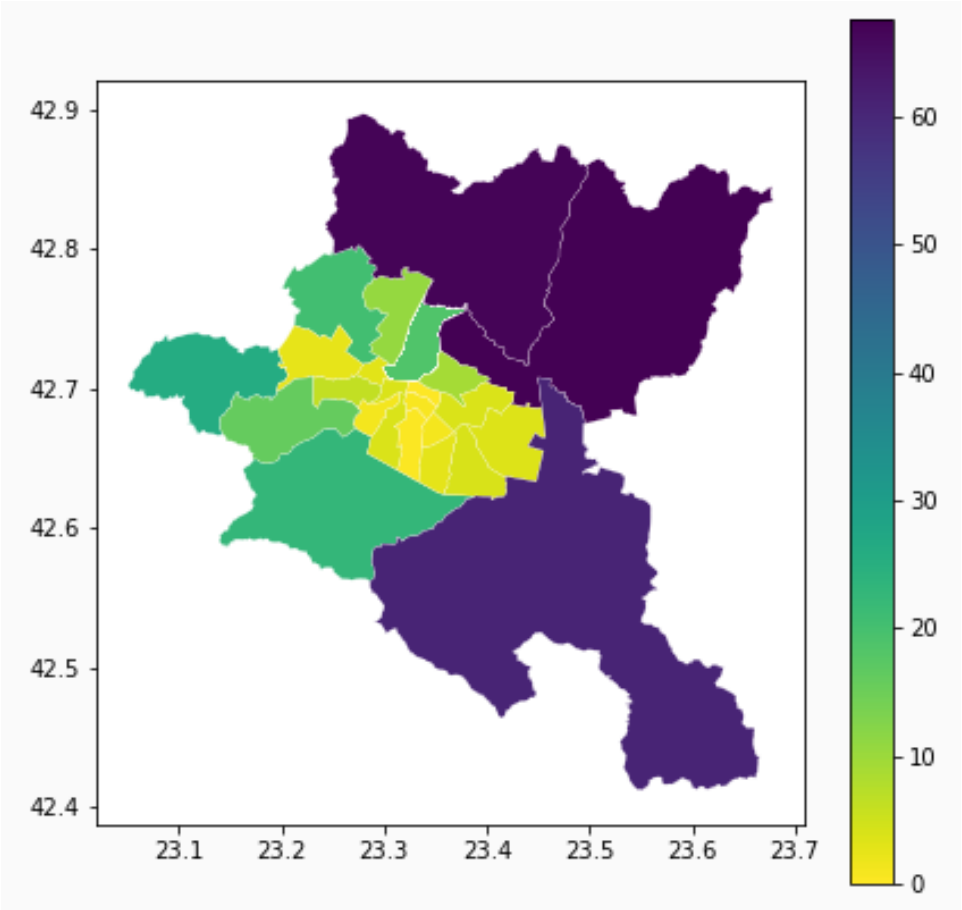

Figure 9: Share of population heating with heat or coal. Source Sofiaplan

cooperation with the other ministries. On a local level, the municipality is regarded as a single stakeholder because all power and responsibility are concentrated in the hands of the Mayor and the municipal Council; currently, both are held by one political party. The fourth stakeholder types include Non-government organisations (NGOs)s, Academic organisations, forest biomass producers, and energy consumers. The NGOs play an important role as a connection between all other stakeholders (I5, Appendix E).

There are two main national-level stakeholders regarding forest biomass energy: Ministry of Agriculture (MA) and Ministry of Environment and Waters (MEW). MA is responsible for managing the national forest through regional state enterprises, and Executive Forest Agency (EFA). On the other hand, MEW monitors air pollution and is involved in developing policy instruments regarding appliance change. At the same time, the EFA responsible for "National Action Plan for Energy Development from Forest Wood Biomass 2018-2027", the MA is not focused on sustainable use of biomass but on making round-wood more affordable for households (I5, Appendix E). Regarding the quality of forest biomass, State agency for metrological and technical surveillance (SAMTS) has the authority to enforce standards and requirements. However, SAMTS do not have the resources to do it effectively since it has a limited budget and multiple responsibilities (I1, Appendix E).

According to the National Energy and Climate Plan (NECP) of Bulgaria, the definition of EP has to be incorporated in the Energy Efficiency Act (EE Act) by the Ministry of Energy (ME). Nevertheless, the ME has not shown interest in the topic of EP. At the same time, the Ministry of Labour and Social Assistance (MLSA) has been operating an energy benefits program, under

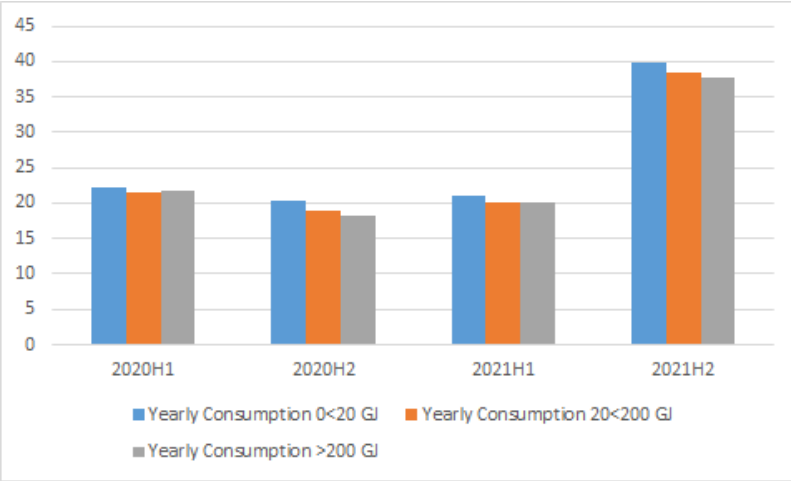

Figure 10: price of natural gas for households, including all taxes, in BGN per GJ. Source NSI

which energy benefits are provided for all types of energy to low-income households.

The main focus of Sofia Municipality regarding the forest bio-energy and EP is the AQ. The municipality operates two appliance change programs and is responsible for ensuring good AQ on its territory. All financing for the AQ policy instruments comes from EU funds.

5.5 Policy addressing forest bio-energy use

In the period 2020-2022, the EU had been transitioning from one planning period to another. As shown in Figure 11, in this 2020-2022 period, the EU introduced a new strategic framework, known as EGD as well as the "Clean energy for all Europeans" plan to replace the expiring 2020 EU climate and energy package. Several other EU strategic documents concerning the forest biomass and the energy produced from it also exist: "Bioeconomy: the European way to use our natural resources" is a continuation of the earlier "Innovating for Sustainable Growth" plan; "A new EU Forest Strategy: for forests and the forest-based sector" and the subsequent "New EU Forest Strategy for 2030".

The EU strategic agenda determines the principal and action plans developed nationally and locally. The overall national climate strategy is set by the "Third National Action Plan on Climate Change for the Period 2013-2020" and the following "Integrated Energy and Climate Plan of the Republic of Bulgaria 2021–2030"; The former plan was developed by the MEW, while the latter is a product of the cooperation between MEW and ME. In addition, there are two more strategic documents concerning climate change: "Energy strategy of the Republic of Bulgaria till 2020 for Reliable, Efficient and Cleaner Energy" introduced by the ME and "National Climate Change Adaptation Strategy and Action Plan" developed by the World Bank. The "National Renewable Energy Action Plan" and "the National Energy Efficiency Action Plan 2014-2020" are introduced as a consequence of the Renewable Energy Directive (RED) and the EED respectively. Both plans originate from the ME, which also developed the strategies concerning building renovation (Figure 11). The domestic burning of wood has been seen as a major air pollutant; hence the "National Program for Improving the Quality of Atmospheric Air (2018-2024)" is proposed by the MEW to map the measures addressing this issue. Finally, the plan that directly affects forest bio-energy use is the "National Action Plan for Energy Development from Forest Wood Biomass 2018-2027", developed by the EFA and is the main document concerning the issue of forest biomass.

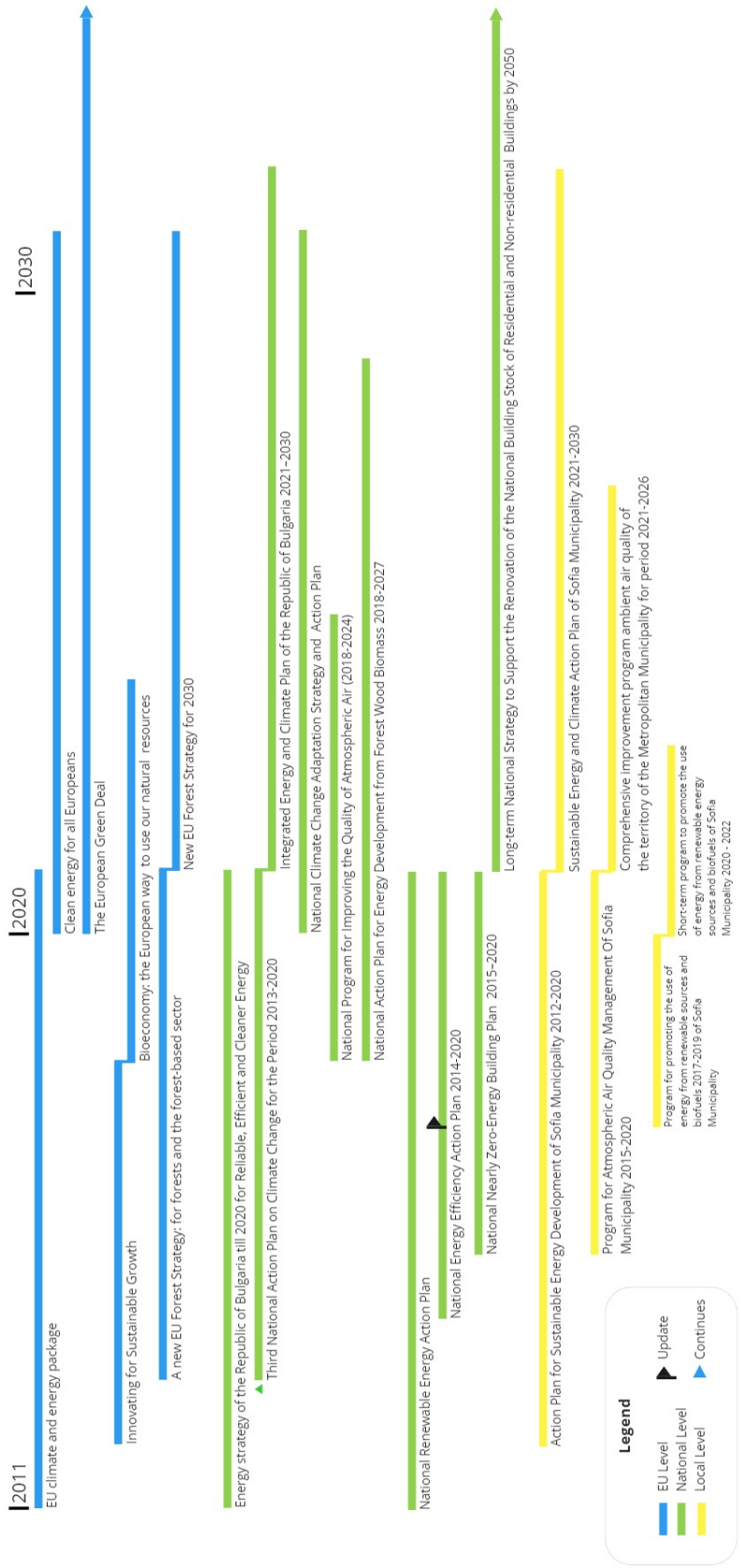

Figure 11: Policy mix Elements: Principal plans

The centralised structure of Sofia Municipality resulted in less variety of policy plans on the local level compared to the national level. The "Action Plan for Sustainable Energy Development of Sofia Municipality 2012-2020" transitions to the "Sustainable Energy and Climate Action Plan of Sofia Municipality 2021-2030". Besides these general action plans, Sofia municipality has proposed short terms plans and programs in the areas of RE and AQ (Figure 11).

While all the plans, strategies and programs have different objectives based on the policy area, they are targeting, when it comes to the forest bio-energy, four main objectives: increase the share of energy produced of sustainably harvested biomass; increase the EE of the forest biomass burners; reduce the PM emissions from forest biomass, and protect biodiversity. The principal plans rely on four categories of instruments based on their goals to reach their strategic objectives. First, instruments that ensure sustainable harvesting of the forest biomass used for energy, only using waste wood and logging residuals, with the goal of protecting forest biodiversity and forest areas that capture the carbon dioxide from the atmosphere. Second, instruments focused on the quality of the forest biomass used for heating; burning appliances that use low moisture products release fewer PM particles. Instruments that are designed to increase the appliances burning efficiency to maximise the heating efficiency of the households. Finally, instruments that stimulate the use of sustainably harvested forest biomass for heating.

5.5.1 EU Level Policy Instruments

The EU has the larger number of policy instruments in respect of the forest bio-energy (Figure 12). Nevertheless, few of the EU's instruments directly impact the EU objectives without the influence of the other governmental level. The four directives listed in Figure 12, the "Governance Regulation on NCEP", and the "EU Taxonomy Regulation" are obligatory for the member state. However, they force the member state to adopt the EU objectives and develop plans without specifying how these objects will be achieved. The "Cohesion and Regional Development Funds" finance the development and implementation of policy instruments but still do not have a direct effect. Since the forest in Bulgaria is almost completely the property of the state and "Regulation on LULUCF" is not consequential for the forest sectors in Bulgaria (I3, Appendix E). Therefore, only the "LIFE program" and "Horizon 2020" have a direct impact on the EU objectives; both instruments provide direct financing to private, academic and NGOs organisations in Bulgaria without the interference of the national or local institutions.

5.5.2 National Level Instruments

The national government has produced a higher number of policy strategies and plans; however, when it comes to actual policy instruments, most of the existing national instruments are a consequence of the EU initiative. First, as a member of the EU, Bulgaria is required to implement the EU directives and enforce the EU regulations. Implementation of the regulation includes the development of action plans and laws. The Energy from Renewable Sources Act (ERSA) and the EE Act as a result of the RED and the EED. Furthermore, while the national government is managing the EU Operation Program "Environment", which is financed through the Cohesion Fund and the Regional Development Fund, thus it shares the management of these resources with the EC. The "Energy Benefits" and "Direct Wood Supply" are the two instruments originating from the national government.

The "Energy Benefits" are a long-running government instrument which provides a subsidy for the heating energy bills for the lowest income households in Bulgaria. The benefits are pay-out by the Agency for Social Assistance (ASA), and the amount is determined by the MLSA. The benefits cover all types of energy, regardless of sustainability and pollution criteria and are based on the Ministry's yearly evaluation of the energy cost per energy type. Around 300 000 people are receiving this type of social assistance, most of which are heated with traditional fuels such as wood and coal (Peneva, 2019).

More than 50% of the people in Bulgaria are heating with wood (Peneva, 2019) due to their affordability and lack of alternatives (I3, Appendix E). Nevertheless, only a minority are receiving

the benefits. At the same time, firewood prices have risen due to demand from neighbouring countries and industrial consumers (I1, Appendix E), leading to higher energy costs for many households. However, the National Government has almost complete control over forest resources in Bulgaria. The country's territory is divided into six regional State Enterprises, under the control of the MA. Each state enterprise is responsible for managing the state forest in its region; it harvests the wood and sells it through public auctions. According to I3 (Appendix E), there is no distinction between wood suitable for industrial purposes and residual wood suitable for domestic heating, with both domestic and industrial suppliers competing in the same market. Hence, the MA is trying to mitigate the wood price increase by selling wood directly to the households using the state enterprise under its control.

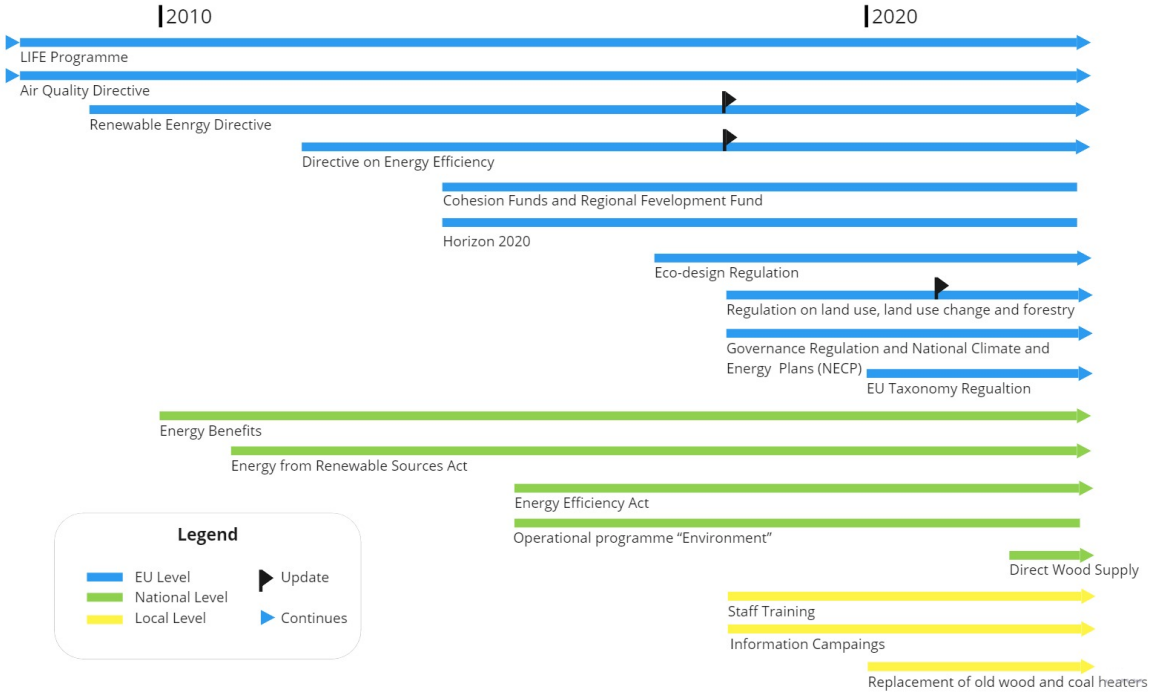

Figure 12: Policy mix Elements: Policy instruments

5.5.3 Local level instruments

There is a municipal program designed to reduce the use of traditional fuels by replacing the old heating appliances to improve the air quality in the municipality. The financing for both programs came from EU and was implemented by the municipality. However, the two programs are developed in different periods and by different institutions. The first program is developed by the MEW as part of the Operation Program "Environment" 2014-2020, and it is financed by the EU Cohesion Fund; hereafter, it will be referred to as the "program environment". The program covers the change of up to 9320 appliances. The type of new appliances covered by the "program environment" are air conditions, wood pellets, natural gas heating systems and district heating, all of which were regarded as sustainable solutions at the time of program design. The program covers the municipality's whole territory.

The second program is financed through the EU "LIFE program", and its designed and managed by Sofia municipality in coordination with other municipalities and NGOs, hereafter will be referred to as "program LIFE". The "program LIFE" could finance the appliance change for up to 5000 households. The appliances covered by the program are wood pellets systems or natural gas systems. The program was designed in late 2019 and has adopted more strict sustainability

criteria regarding the financed appliance. In contrast to the "program environment", the "program LIFE" is applied to only a few rural neighbourhoods in the municipality's eastern regions (Novi Iskar, Iskar, Pancharevo and Kremikovci).

While there are defences between the two appliance change programs, there are many similarities. First, both programs require the participant to own their homes and ensure that their house is connected to the natural gas or district heating grid if this alternative is chosen. The participants should provide a heating plan for the system and agree to use the chosen alternative for a minimum of five years. Moreover, the participants should pay for the connection to the grid; nevertheless, once the households fulfil all requirements, the new appliances are installed by a firm selected by the municipality.

5.6 Summary

Several issues are specific to the case of Sofia municipality and will determine the relations and interactions in the system. First, the difference in objectives and perceptions between the ministers indicates conflict translating into the policy instruments developed by each Ministry. Furthermore, concerning the energy transition, EU has a prominent role in setting the objective and instruments that will be implemented, through the regulation, directive and funding. However, in the forest sector, where the MA has complete authority, the EU has little influence. Moreover, the lack of EU policies concerning EP domain leaves freedom for the national government to act without aligning its policy with the EU objectives. Finally, the impacts on EP in Sofia depend on the income group of the households, the region where they live, and the energy source they transition to.

6 Results

This Chapter presents the analysis results following the methodology described in Chapter 4. First, the policy instruments part of the policy mix with their goals, design features, types and purposes are listed in Section 6.1. Next, section 6.2 elaborates on the factors, relations and feed-backs in each sub-model and the connections between the sub-models. Following the CLD, the forest bio-energy policy mix characteristics are identified in Section 6.3. Next, the impact on the energy poverty indicators is determined in Section 6.4. Finally, the Chapter's content is summarised in Section 6.5.

6.1 Policy Mix Elements

Table 4 shows the policy instruments that have a role in the system. The RED, EED, Air Quality Directive (AQD), ecodesign directive, and the respective national acts have two important roles when it comes to the forest bio-energy. First, they set the EE requirements for all heating appliances; second, they provide sustainability standards for the fuels used for heating. The RED define the criteria each fuel has to fulfil to be sustainable for the environment and be regarded as RE, while the ecodesign directive provides the requirements for the fuel manufacturers and suppliers. At the same time the AQD set what are acceptable levels of PM and GHG. On the other hand, the EE of the appliances are targeted by the ecodesign directive and the EED. Therefore, the variable "Appliance EE requirements" influences the "EE of old appliances" and the "EE of the new appliances", while the "Sustainability requirements" impacts the "Quality of the traditional fuel".

The national instruments, "Energy benefits" and "Direct wood supply", represent policy actions in the system. In contrast, the appliance change programs is associated with its design features in the CLD (Figure 17). Finally, Horizon 2020 and the LIFE program are funding various NGO projects training energy advisors to increase awareness of the energy transition benefits in energy-poor communities.

Table 4: Policy Instruments

Level	Instrument	Goal	Type & Purpose	Design Feature
EU	Air Quality Directive	Air Quality Improvement	Authority & Substantive	Sets mandatory objectives for air pollution.
EU	Renewable Energy Directive (RED)	Increase share of RE	Authority & Substantive	Defines what energy source is RE and sets mandatory objectives for air pollution.
EU	Energy Efficiency Directive (EED)	Increases EE of buildings and appliances	Authority & Substantive	Sets obligatory target for energy consummation reduction and saving energy. Requires member states to developer plans for increasing energy efficiency
EU	Ecodesign Directive	Improve air quality and EE of appliances	Authority & Substantive	Provides modality regiments for the producers of appliances and fuels.
EU	Horizon 2020	Increase research and innovation in climate change solutions	Treasury & Procedural/substantive	Directly manged instrument, provides funding to NGO and academia on a project base. Operational in the period 2014-2020

EU	LIFE Program	Development and innovative solution to the environmental problems	Treasury & Procedural/substantive	Directly manged instrument, provides funding to NGO and academia on a project base. Operational in the period
National	Energy Benefits	Reduce heating cost of the poorest households	Treasury & Substantive	Energy benefits for all types of energy targeting the low income household.
National	Renewable Energy Sources Act	Increase share of RE	Authority & Substantive	Implements RED
National	Energy Efficiency Act	Reduce energy consumption	Authority & Substantive	Implements EED
National	Direct Wood Supply	Reduce heating cost of households heating on round-wood	Treasury & Substantive	Direst supply of wood to households for state enterprises
Local	Appliance Change (program environment)	Improve air quality	Treasury & Substantive	Municipality changes appliance of over 9000 households using wood or coal. The program operates on the period 2019 and 2020
Local	Appliance Change (program LIFE)	Improve air quality	Treasury & Substantive	Municipality changes appliance of over 5000 households using wood or coal in rural neighbourhoods. Alternatives are wood pellets and natural gas.
Local	Information Campaign	Improve air quality	Nodality & Procedural	TV adds and community meetings. The campaign is organised by firm selected through public procurement procedure based on the lowest offer and municipal staff.
Local	Staff Training	Increase staff capability to develop and implement energy transition policies	Nodality & Substantive	Multiple voluntary training of the municipality staff, financed by EU funds. The trainers are choice by public procurement procedure based on the lowest offer, low staff participation.

6.2 CLD

Based on the framework by Kim and Andersen (2012) the causal relations of the system are established (Appendix G), and Figure 17 is constructed; the following section explains the nature of these relations and the consequences of them. The CLD can be looked at in terms of three subsystems: "Appliance Change" (Figure 13); "Traditional Energy Use" (Figure 14); and "Alternative Energy Use" (Figure 15).

6.2.1 Appliance change

Figure 13 depicts the "Appliance change" sub-model; this sub-model represents the factors concerning the municipal appliance change programs implementation and the causal relation between them. At the centre of the sub-model is the reinforcing loop R2. More "Households benefiting from new appliance" increases the "Awareness about benefits", which increases the "Willingness to participate in the municipal program" and finally, leads to a higher "Rate of households switching

from traditional fuels". However, the impact is only positive if the "Cost of alternative energy" is not rising more than it is affordable for the household so they can actually experience the benefits of the change. "Rate of households switching from traditional fuels" is also determined by the "Ability to participate in municipal program"; the more households able to participate higher the rate is.

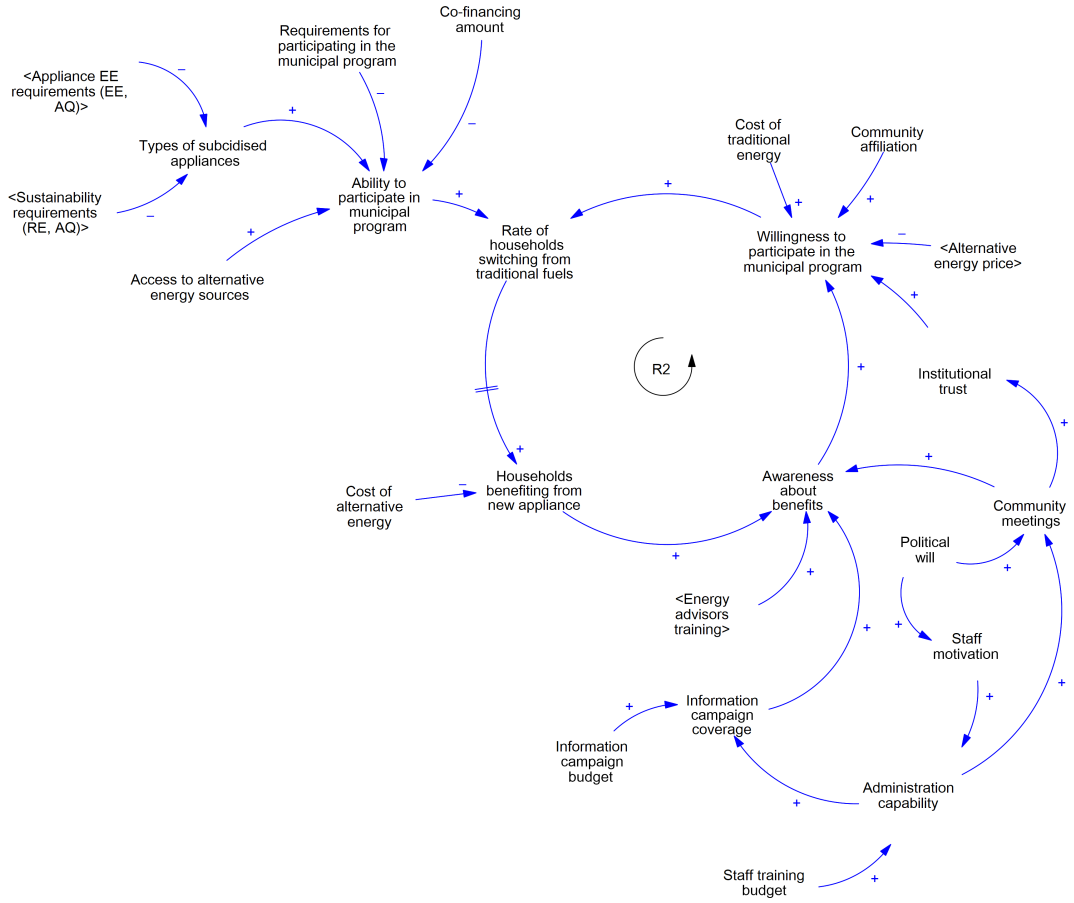

Figure 13: Appliance change sub-model.

The "Ability to participate in municipal program" is reduced by the "Requirements for participating in the municipal program" and the "Co-financing amount". The "Requirements for participating in the municipal program" refer to all the documents and procedures that must be fulfilled for participation in the program. At the same time, the "Co-financing amount" refers to any additional cost when participating in the program. On the other hand, the "Ability to participate in municipal program" is positively influenced by the "Access to alternative energy sources" and "Types of subsidised appliances". "Access to alternative energy sources" represents a physical restriction, whether a building is connected to a natural gas or district heating grid. Both programs offer alternatives for the old appliances, depending on the legislative framework when they were designed. Hence, the "Types of subsidised appliances" depend on the "Sustainability requirements" and the "Appliance EE requirements".

The "Willingness to participate in the municipal program" is enforced by the "Community affiliation" and "Institutional trust" it is more likely for people living in close communities to participate in any government program as well as if they have trust in the institutions (I1, Appendix E). Furthermore, the "Willingness to participate in the municipal program" is increased by the "Cost of traditional energy"; at the same time, "Alternative energy price" has the opposite effect.

Finally, the "Awareness about benefits" increases due to "Energy advisors training" among the energy-poor households, "Community meetings", and "Information campaign coverage". The "Information campaign coverage" is a function of the "Information campaign budget" and the "Administration capability" (I2, Appendix E), while the "Administration capability" depends on the "Staff training budget" and the "Staff motivation". According to I4 (Appendix E), the "Political will" plays a significant role in increasing the "Staff motivation" and initiation of "community meetings".

6.2.2 Traditional fuel use

The next sub-model depicts the "traditional fuels use" in Sofia Municipality. Traditional fuel use connects to the "Appliance change" sub-model through two causal relations. First, the "Rate of households switching from traditional fuels" affects the "Traditional fuel consumption" by reducing the number of households using traditional fuels for heating. Second, the "Cost of traditional energy" is one of the factors determining the "Willingness to participate in the municipal program".

The "Rate of households switching from traditional fuels" negatively influences the "Traditional energy consumption"; the higher the "Rate of households switching from traditional fuels", the more households are switching from the traditional fuels and thus lower the consumption is. However, the "Traditional energy consumption" decline does not occur immediately, only at the beginning of the heating season. On the other hand, the "Cost of traditional energy" rise leads to a reduction in the "Traditional energy consumption". Therefore, a negative feed-back loop B1 (Figure 14) exists between the "Traditional energy consumption" and the "Cost of traditional energy"; any increase in the cost is mitigated by lower consumption.

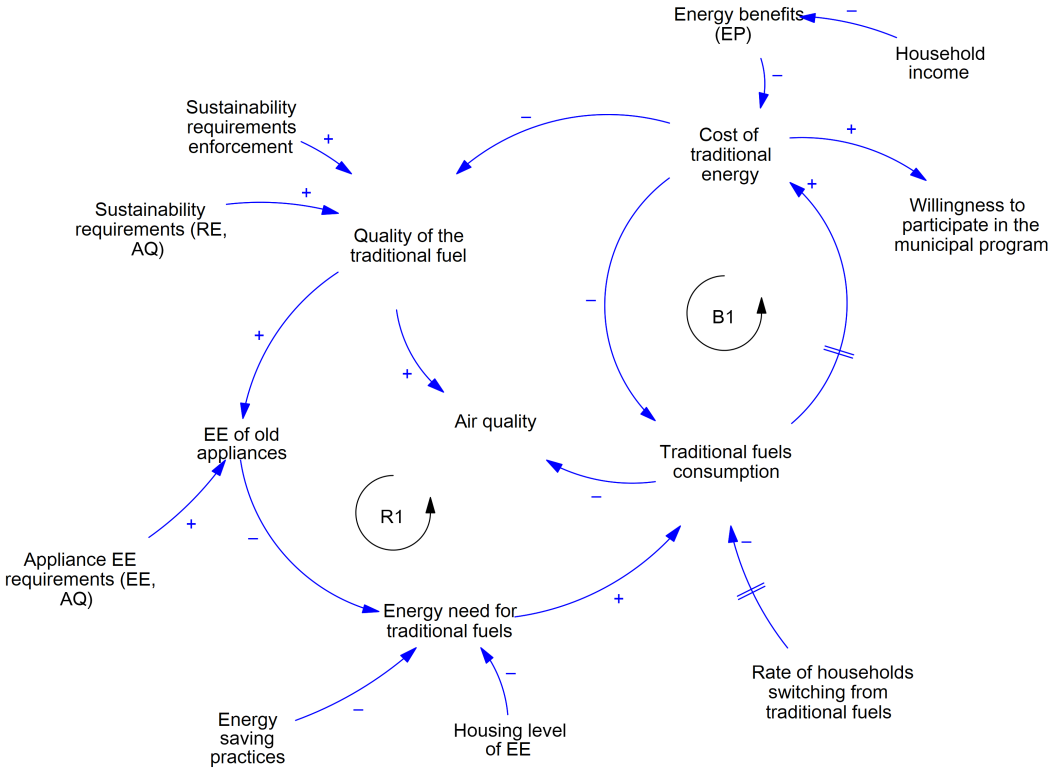

Figure 14: Traditional Energy Use sub-model.

Besides the "Traditional energy consumption", the "Cost of traditional energy" is also impacted by the "Energy benefits" and "Traditional fuel price"; the benefits are reducing the "Cost of

traditional energy", while the rise in the "Traditional energy consumption" leads to cost increase. According to I3 (Appendix E), the price of wood, which is part of the "Traditional fuel price", is mainly influenced by the "External demand" and the "Direct wood supply" initiated by the MA in order to mitigate the impact of the "External demand". The "Energy benefits" depend on the "Households income", with only the lowest income docile could receive them.

With the increase in the "Cost of traditional energy", households are looking for more affordable alternatives, which are either higher moisture round-wood or coal (I4, Appendix E); hence, with the rise in "Cost of traditional energy", the "Quality of the traditional fuel" declines. Nevertheless, the "Sustainability requirements" introduced by the EU in combination with "Sustainability requirements enforcement" by the national authorities are designed to increase the "Quality of the traditional fuel". The "Sustainability requirements" exist because the "Quality of the traditional fuel" has a significant effect on the "Air Quality"; the lower the "Quality of the traditional fuel" is, the lower the "Air Quality" becomes.

The "Quality of the traditional fuel" has one other effect, it impacts the "EE of old appliances"; lower quality fuels do not burn efficiently and do not produce enough heat. Hence, when the "EE of old appliances" drops, the "Energy need for traditional fuels" increases, so households can heat effectively. However, other factors can mitigate the effect of "EE of old appliances" on the "Energy need for traditional fuels"; both "Housing level of EE" and "Energy saving practices" reduce "Energy need for traditional fuels". Alongside the "Quality of the traditional fuel", there is one other factor that determines the "EE of old appliances": "Appliance EE requirement". Finally, the "Energy saving practices" are boosted by the existence of "Energy advisors training".

The reinforcing loop R1 shows the lower "Traditional energy consumption", reduces the "Cost of traditional energy" for households, leading to the use of higher "Quality of the traditional fuel" and eventually lower "Energy need for traditional fuels", which further reduces the "Traditional energy consumption". Therefore, any action to reduce the "Traditional energy consumption" will be reinforced. Nevertheless, the B1 will balance the reinforcing effect, but only if the "Traditional fuel price" stays the same and the "Energy benefit" still exist. Overall, the "Traditional energy consumption" can be minimised by ending the "Energy benefits" for the traditional fuels and ending the "Direct wood supply" in combination with strengthening the policies which are reducing the "Energy need for traditional fuels."

6.2.3 Alternative fuel use

Figure 15 shows the "Alternative fuel use" sub-model; similarly to the "Traditional fuel use", the "Alternative energy consumption" is connected to the "Appliance change" sub-model through the "Rate of households switching from traditional fuels". In this sub-model, the "Rate of households switching from traditional fuels" increases the "Alternative energy consumption", which occurs in the first heating season after the appliance change happens. "Alternative energy consumption" also depends on the "Energy need for alternative energy", which is reduced by "Housing level of EE", "Energy saving practices", and "EE of the new appliances". The "EE of the new appliances" is determined only by the "Appliance EE requirements".

The increase in "Alternative energy consumption" leads to an increase in the "Cost of alternative energy", but the higher "Cost of alternative energy" forces the households to reduce "Alternative energy consumption", creating balancing loop B2 (Figure 15). The "Cost of alternative energy" is affected by the "Alternative energy price" and the "Energy benefits", where the rise in the "Alternative energy price" increases the cost and the rise in the "Energy benefits" decreases it but only for the poorer households. The "Alternative fuel use" sub-model connects to the "Appliance change" sub-model by the relation between the "Cost of alternative energy" and "Households benefiting from new appliances".

6.2.4 Assumptions

A major assumption when the CLD was constructed is the formulation of the energy price factors. While all interviewees said that technically the price of the energy sources is based on supply-

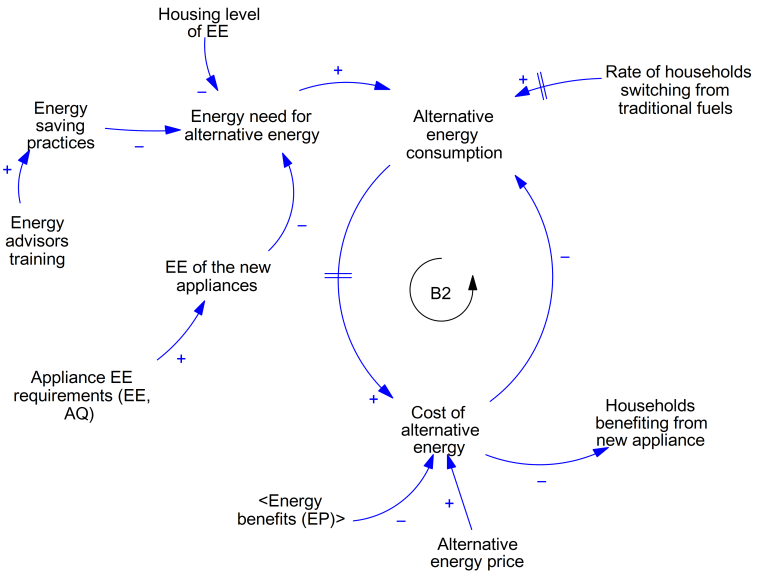

Figure 15: Alternative Energy Use sub-model.

demand factors, they also described the existence of speculators, external demand and the very low impact of the domestic internal demand on the price of energy. Hence, for the purposes of this analysis, the price of energy sources will not be dependent on the energy consumption by the domestic sector. However, not all price factors will be looked at as external factors. For example, while the price of natural gas is influenced by the international market and the district's heating and electricity prices are regulated, the price of wood and all its derivatives is much more dependent on national policy. First, the majority of the forests in the country are state-owned. Second, there are existing regulations for land management on the EU and local levels. Hence, the rise of wood and the price of pellets will be considered external factors but not as dependable on domestic sector consumption.

Another assumption derived from the validations interviews is about the role of the quality of the pellets. In theory, the quality of the pellets plays a role in determining the EE of the appliance. However, in practice, that is not the case since low-quality pellets lead to high maintenance costs, and households do not use them (Appendix E)

Finally, several policy actions are combined into one factor because they impact the system similarly. The RED, AQD, as well as the Nation acts co-responding to them, are combined in the factor "Sustainability requirements". At the same time, the Eco-design Regulations and the EED are represented by the "Appliance EE requirements".

6.2.5 Validation

The validation is conducted by the validation interviews with two representatives of the NGO sector, one that monitors the LIFE stove changing program and another familiar with biomass energy. The protocol for the validation interviews is presented in Appendix G, and Figure 23 (Appendix G) shows the CLD that was presented to the interviewees.

The model was presented to the interviews by elaborating the factors and their meaning, the causal relations and the expected behaviour of the outcomes according to the model. The interviewees agreed with the overall depiction of the Appliance change sub-model in the factors determining the "Rate of households switching from traditional fuels". However, they raised issues concerning the "Traditional fuel price" and the "Alternative energy price". According to validation interview 2, the domestic sector demand should influence the energy sources price.

The major change between the CLD shown to the validation experts and the final CLD is the role of the quality of the pellets in the system. According to validation interview 1, the "Cost of alternative energy" does not play a role in the "EE of the new appliances" because switching to low-quality pellets makes the proper function of the appliances impossible. There is a natural barrier to using low-quality pellets. Thus, the loop R3 and R4 on Figure 23 (Appendix E) are not existing.

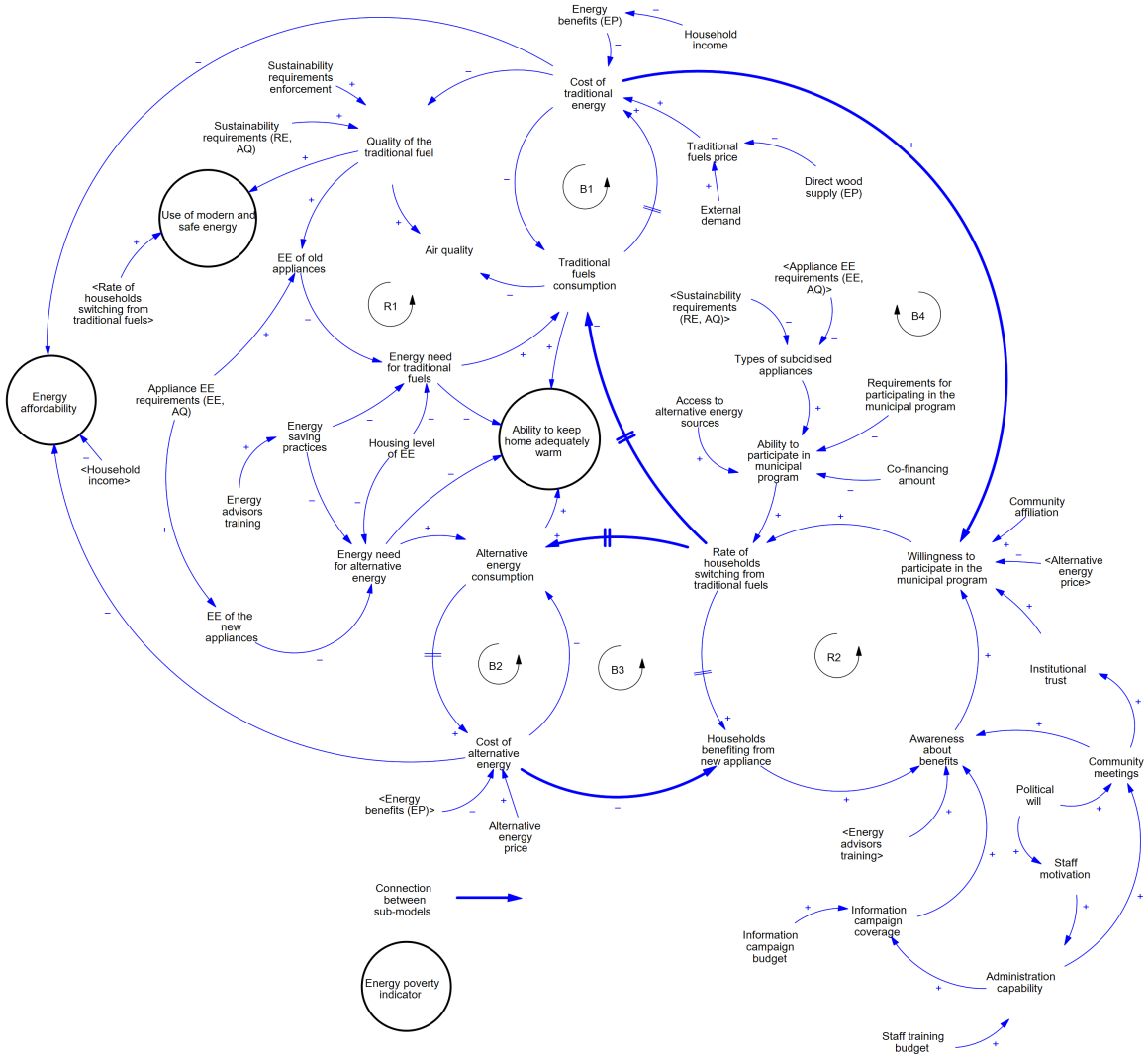

Figure 16: Complete model

6.2.6 Complete model

Figure 16 shows the connections between the sub-models and incorporates the EP indicators. The connection between "Appliance change" and "Traditional fuels use" sub-models represents a negative feed-back loop (B4). B4 shows the dependency between the "Rate of households switching from traditional fuels" and the "Cost of traditional energy", which indicates that in the long run, the "Rate of households switching from traditional fuels" will slow down due to the decrease "Traditional fuels consumption" which will reduce the "Cost of traditional energy"; finally resulting in lower "Willingness to participate in the municipal program". At the same

time, the "Rate of households switching from traditional fuels" can be slowed by the increase in the "Alternative energy consumption" through balancing loop B3. Higher "Alternative energy consumption" leads to higher "Cost of alternative energy" and through it a lower number of "Households benefiting from new appliance".

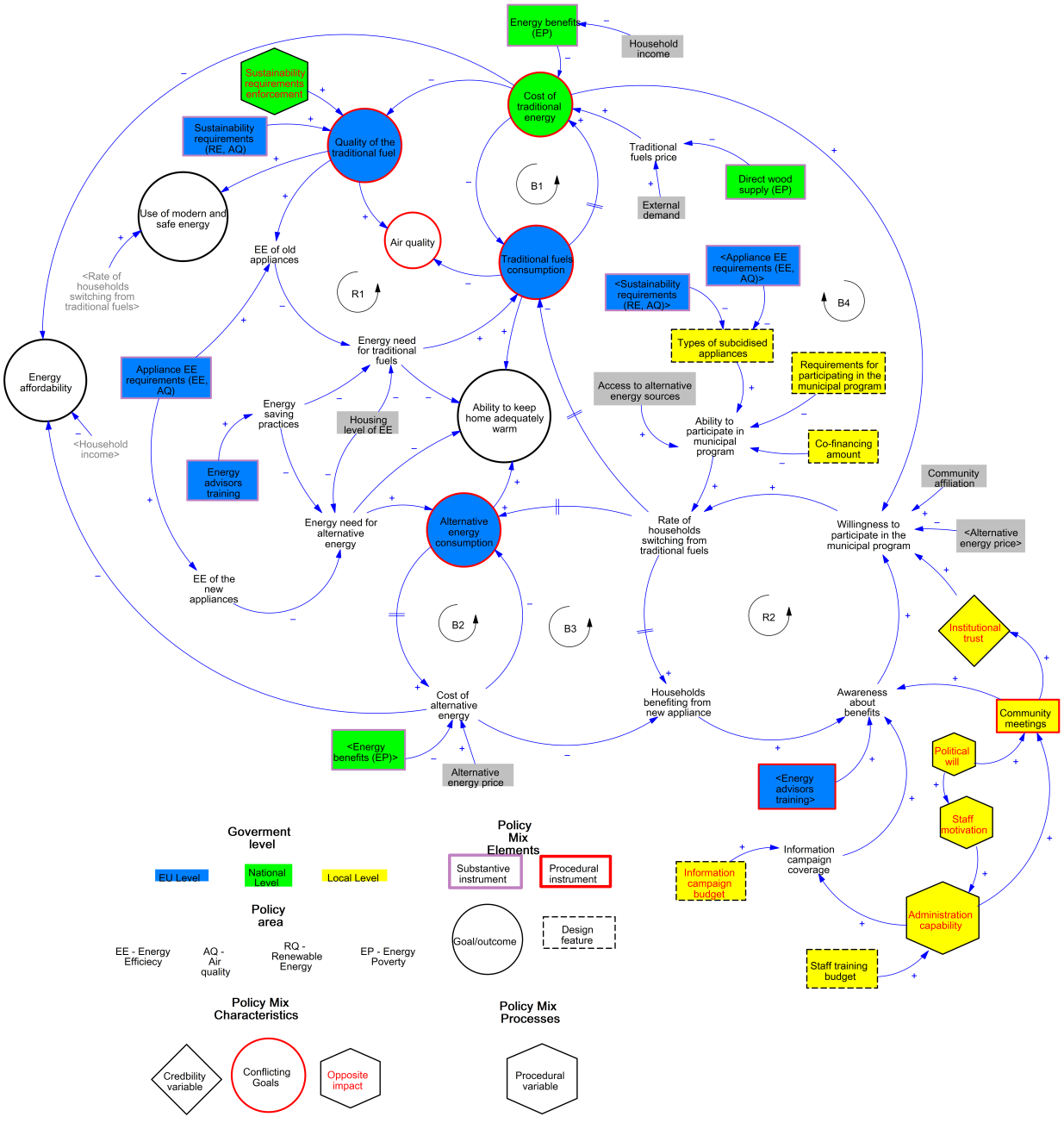

Figure 17: Operationalisation of the policy mix concept.

The EP indicators influenced by the factors in the models are: "Energy affordability", "Use of modern and safe energy", and "Ability to keep home adequately warm". First, based on the definition provided in Table 2 "Energy affordability" is dependable on the "Households income", the "Cost of traditional energy", and the "Cost of alternative energy". An increase in any of the

costs will lead to a decrease in "Energy affordability". In contrast, an increase in "Households income" leads to increasing in "Energy affordability". Second, the "Use of modern and safe energy" is associated with the use of alternative energy or with the use of high-quality traditional fuels; hence it is a function of the "Rate of households switching from traditional fuels" and the "Quality of the traditional fuel". Lastly, "Ability to keep home adequately warm" captures if the household's consumption matches its need. Therefore, it will increase if "Energy need for traditional fuels" and "Energy need for alternative energy" decline or if "Traditional fuels consumption" and "Alternative energy consumption" rise.

6.3 Policy Mix Characteristics

In Figure 17 each factor from Figure 16 is identified based on the operationalisation provided in Section 4.4. The policy instruments are identified by their movement level, policy domain, type, purpose, and design features. Figure 17 is used to identify the characteristics of the forest bio-energy policy mix.

6.3.1 Consistency

Sofia's forest bio-energy policy mix is horizontally and vertically inconsistent, with conflicts emerging due to the EP policy instruments as well as EU and national legislation mitigating the effects of the appliance change programs. First, a conflict exists between the instruments targeting EP and the rest of the policy mix elements. Second, the "Sustainability requirements" and "Appliance EE requirements" are limiting the "Types of subsidised appliances" and therefore are mitigating the effects of the appliance change program. Nevertheless, there are policy instruments that enhance each other. Figures 18, 19 and 20 are derived from the model (Figure 17) and depict the causal chains by which the constancy of the policy mix is determined.

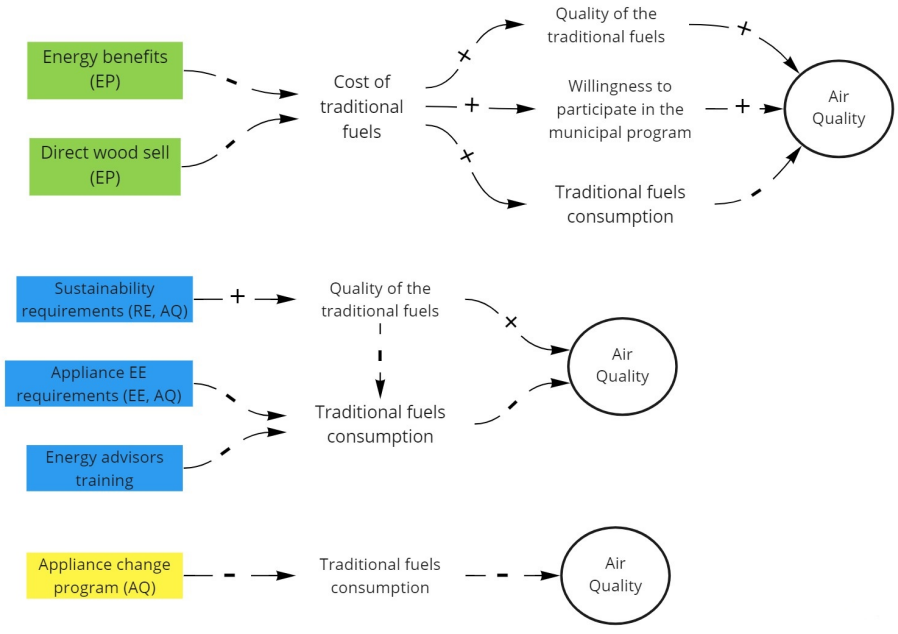

Figure 18: Vertical and horizontal inconsistency with respect to the "Air Quality"

The "Energy benefits" and "Direct wood sell" have the objective to reduce the cost of heating energy for the lowest income households; in the case of the "Direct wood sell", that is the "Cost of traditional fuels", while the "Energy benefits" targets "Cost of alternative energy" as well. However, the decrease in the cost has three effects, as shown in Figure 18. First, it increases the

"Traditional fuels consumption"; second, it increases the "Quality of the traditional fuels"; finally, it increases the "Willingness to participate in the municipal program". Thus, the decrease in "Cost of traditional fuels" has both positive and negative effects on "Air Quality". However, the "Air Quality" increase is the goal of the appliance change program and all EU national sustainability and appliance EE instruments (Figure 18). The impact of "Air Quality" represents a goal conflict that classifies as vertical and horizontal inconsistency.

A vertical inconsistency also exists between the EU and the local level as depicted on Figure 19. "Sustainability requirements" and "Appliance EE requirements" include all EU and national legislation that determines which type of energy should be subsidised and which should not be encouraged, based on RE, EE and AQ criteria. At the same time, the municipality's appliance change programs are financed by the EU. Hence, they should apply all EU requirements when choosing the types of appliances subsidised by the program. Therefore, while the "Sustainability requirements" and "Appliance EE requirements" increase the "Air Quality" and the overall energy consumption, they limit the "Ability to participate in municipal programs" and thus reduce the positive impacts of the appliance change programs.

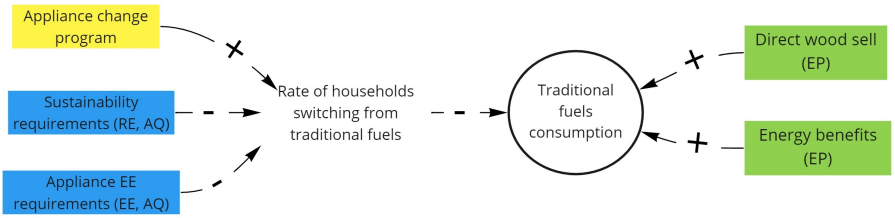

Figure 19: Vertical inconsistency with respect to the "Traditional fuels consumption"

Alongside the inconsistencies, there is evidence for synergy as well. The "Energy advisors training" finance by the LIFE program and Horizon 2020 increases "Awareness about benefits" and reduce energy consumption, thus increasing the "Rate of households switching from traditional fuels" (Figure 20). At the same time, the "Appliance EE requirements" guarantees the new appliance will have high EE increasing "Households benefiting from new appliance". Hence both the "Energy advisors training" and "Appliance EE requirements" enhance the effects of the Municipal Appliance change program as shown in Figure 20

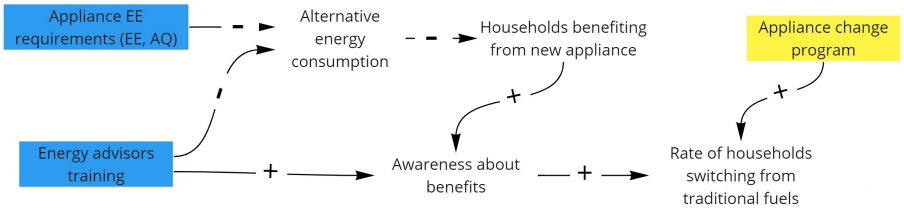

Figure 20: Synergy between municipal Appliance change program and the EE instruments.

6.3.2 Coherence

Based on the coherence capability criteria, the policy mix lacks vertical coherence. First, the EU "Sustainability requirements" set a high standard for heating fuels. However, the national institution (SAMTS) responsible for enforcing the requirements are incapable of enforcing the fuel quality standards due to limited resources (Figure 17). Second, the most considerable responsibility for the transition from wood and coal heating energy falls to the municipal administration. While the appliance change programs and the information campaigns are financed with EU funds, the administration expense is still part of the municipal budget. However, the municipality lacks

resources, resulting in low "Administration capability". Therefore, AQ objective of the EU is in the hands of institutions that do not have the full potential to achieve it. Moreover, the lack of "Administration capability" is enforced by the low "staff motivation" and "political will".

The other aspect of the coherence characteristic refers to the policy-makers perceptions. In this case, the policy-makers that have different perceptions are the MA and MLSA; both stakeholders have developed policy instruments that are contradictory to the EU and national energy transition policies. Furthermore, through the state enterprises, the MA continues to supply round-wood for the domestic heating market and with the introduction of the "Direct wood supply" is sustaining the domestic use of round-wood. At the same time, the MLSA continues its long-run "energy benefits" program supporting low-income households' wood and coal consumption. The difference in perceptions between the MA and MLSA with the rest of the stakeholders represents horizontal incoherence.

6.3.3 Comprehensiveness

The lack of comprehensiveness of the policy mix is established based on two components. First, the policy mix does not comprehensively cover all market failures and side effects of the policy instruments. Second, there are policy instruments that are not part of any strategic documents. Many policy instruments are listed in the various national and local plans but are not implemented.

The appliance change programs are central policy instruments for Sofia's forest bio-energy policy mix. The programs do not have specific income groups. However, the additional cost for the participants restricts the participation of low-income households. At the same time, the transition to a new energy source is increasing the cost of heating, either because of more consumption (more rooms are heated) or because the price of the alternative energy is higher. Nevertheless, the "energy benefits" are not designed to assist the income groups most likely to participate in the appliance change programs. Thus, while the government institutions are encouraging people to switch from cheaper wood and coal, there is no provision for financial help if energy prices increase.

Next, the multiple policy instruments are proposed by the various activities and strategic plans of the Nation and local movements; these are a continuation of the EU strategic objectives and activities. However, most of the instruments listed in the strategic documents on the national and local levels never become a reality. Instead, all strategic plans repeat the same policy instruments without ever being implemented (I1, Appendix E). Thus, in theory, the objectives are addressed through action plans setting goals and instruments targeting the goals. However, in reality, this is not the case. Furthermore, "energy benefits" for wood and coal and the "Direct wood supply" are not part of any strategic plan.

6.3.4 Credibility

There is only one factor in Figure 17 that can be associated with policy mix credibility based on the Rogge and Reichardt (2016) framework: "Institutional trust". In this case, the "Institutional trust" influences the "Willingness to participate in the municipal program". According to I1, I2, I4 and I5 (Appendix E), the trust in Sofia municipality is low; due to the lack of communication with the communities. However, "Institutional trust" cannot be conclusive for the credibility of the policy mix as a whole. While credibility has a role in determining the "Rate of households switching from traditional fuels", other variables also influence it.

6.4 Impacts on Energy Poverty

The impact of the forest bio-energy policy mix on the EP in Sofia, Bulgaria, is evaluated based on the influence of the policy mix characteristics identified in Section 6.3 on the EP indicators. There are two conflicts leading to inconstancy if the policy mix: Conflict over "Air Quality" (Figure 18), Conflict over "Traditional fuels consumption" (Figure 19) and Synergy over "Rate of households switching from traditional fuels" (Figure 20). The coherence is associated with:

Conflict of perception, Lack of capability of national institutions and Lack of capability of the local administration staff. Comprehensiveness characteristics include Instruments not part of the strategic framework and a Lack of instruments addressing market failures. Finally, credibility is indicated by the "Institutional trust" factor.

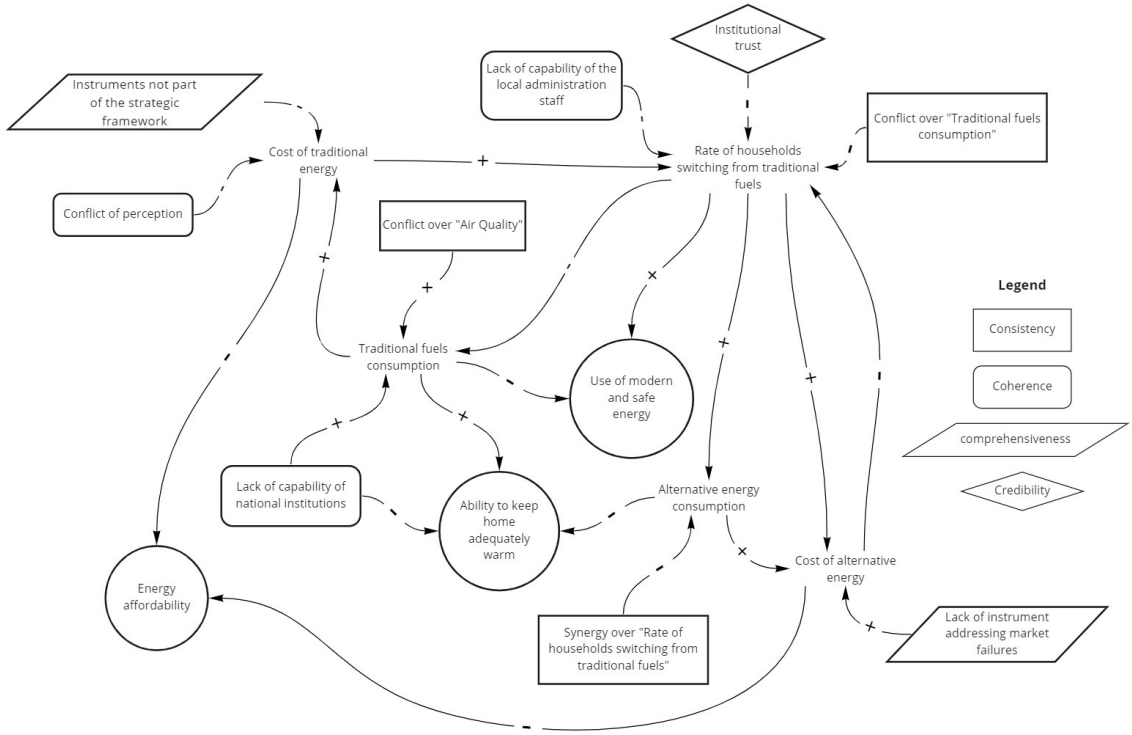

Figure 21: Impacts of Policy mix Characteristics on the Forest Bio-energy policy mix

6.4.1 Energy affordability

As shown in Figure 17 the indicator represents a function of "Household income", "Cost of traditional energy", and "Cost of alternative energy". While the cost of wood and coal has increased, the "Energy benefits" and the "Direct wood supply" have kept the energy cost for the poorest households affordable. At the same time, the conflict between the "Appliance EE requirements" and "Sustainability requirements" on one side and the Appliance change program leads to a reduction of participation in the program. A lower "Rate of households switching from traditional fuels" means fewer people have increased energy bills due to the rise in the "Cost of alternative energy". Hence, the conflicts over "Air quality" and "Traditional energy consumption" have a positive impact on "Energy affordability" (Figure 21).

Synergy over the "Rate of households switching from traditional fuels" also positively impacts the "Energy affordability". The "Energy advisors training" and "Appliance EE requirements (EE, AQ)" reduce the "Alternative energy consumption" for the households that have switched from traditional energy and thus have decreased the "Cost of alternative energy" (Figure 21).

The conflict of perceptions keeps the energy expenditure low for the poorest families. They would be unable to afford to switch to alternative energy if the energy benefits for wood and coal are ended. Thus, resulting in a positive effect on "Energy affordability". Furthermore, the lack of capability of the local administration staff is restricting the "information campaign coverage" and the "community meetings", thus slowing the "Rate of households switching from traditional fuels", again exposing fewer people to the higher "Cost of alternative energy" and decrease in "Energy affordability". Finally, the "Lack of capability of national institutions" increases "Energy consumption", and that negatively impacts "Energy affordability".

"Lack of instruments addressing market failures" leads to the absence of policy instruments addressing the possibility of an increase in "Alternative energy price", exposing the households participating in the appliance change program to a lower "Energy affordability". In contrast, the existence of "Instruments not part of the strategic framework" reduce the "Cost of traditional energy" and increase the "energy affordability". Finally, the lack of "institutional trust" reduces the "Rate of households switching from traditional fuels" and thus has a positive impact on the indicator.

6.4.2 Use of modern and safe energy

The positive effects on the "Use of modern and safe energy" are limited due to the lack of comprehensiveness of the policy mix elements, lack of coherence represented by the low capabilities of national and local governments and conflicting stakeholders' perspectives, poorly designed policy instruments, absence of an effective procedural instrument, and credibility issues.

The "Use of modern and safe energy" is defined by the "Rate of households switching from traditional fuels" and the "Quality of the traditional fuel". Hence, the "Use of modern and safe energy" is negatively impacted by all interactions that reduce the impact of the two variables, and the synergies positively enhance it. For example, the inconsistency between the "Suitability requirements" and "Appliance EE requirements" and the appliance change program regarding the "Rate of households switching from traditional fuels" reduces the number of households switching from traditional fuels. At the same time, the conflict between the national EP policy instruments and the rest of the policy mix is keeping the number of households using traditional fuels high.

The lack of coherence from the lack of capabilities further negatively affects the use of modern energy indicators and the lack of comprehensiveness and credibility. Finally, the synergies between the EU policy instruments enhance the "Use of modern and safe energy".

6.4.3 Ability to keep home adequately warm

The last EP indicator is "Ability to keep home adequately warm" is a function of the energy that a household needs to keep adequately warm and the actual consumption of energy; thus, it is influenced by the "Energy need for traditional fuels", "Energy need for alternative energy", "Traditional fuels consumption" and "Alternative energy consumption". Therefore, the indicator is most directly impacted by the synergy interaction of the policy mix. However, the lack of coherence negatively impacts the "Ability to keep home adequately warm" by keeping the quality of the traditional fuels low.

6.5 Summary

The municipal appliance change programs are central to the forest bio-energy policy mix in Sofia Municipality. Participation in the programs is determined by the willingness and ability of the households. The willingness can be increased by influencing other households that have to change their appliances and the information campaigns. In comparison, the ability to participate is constrained by the proposed alternatives in the programs, the existing energy infrastructure and the households' ability to cover additional costs and requirements. Furthermore, the policy instruments developed on national and EU levels can influence both willingness and ability to participate in the appliance change program. The inconsistency, lack of coherence and lack of comprehensiveness of the policy mix positively impact the "energy affordability" while having a negative impact on the "use of modern and safe energy". At the same time, the impact on the "Ability to keep home adequately warm" is a mixed one.

7 Conclusion and Discussion

This Chapter provides an answer to the main research question and six SQs in Section 7.1. Followed by a discussion on the contribution of the thesis in those two areas (Section 7.2) Policy recommendations based on the results of the analysis are formulated in Section 7.3. The limitation of the study and the possibility of further research are discussed in Section 7.4.

7.1 Conclusion

7.1.1 Objectives and Perceptions

Sub-question 2 is explored using stakeholder analysis based on desk research and interview data (Appendix F). The data is analysed based on Enserink et al. (2010) framework. The issue of forest bio-energy and EP involves a significant number of stakeholders inside and outside the government space. However, the research looks mainly at the stakeholders who are part of the EU, National or local government. Due to the similarity in objectives (Table 18, Appendix F) and the nature of decision making in the EU, all EU level institutions are regarded as one actor. Same assumptions are made regarding the local authorities; the municipal administration is centralised and can be examined as one unit. On the other hand, the national-level stakeholders operate independently; each ministry has its objectives and coordinates its actions to a minimal extent. MA and MLSA want to reduce the heating costs of the poorest households using round-wood. In comparison, the MEW, ME, and Ministry of Regional Development and Infrastructure (MRDI) are developing and implementing policies to reduce energy consumption and use of round-wood and coal for heating in line with the EU and local objectives. Overall there are two groups of stakeholders based on their perceptions and objectives; one (MA and MLSA) which see energy affordability, and the second group that is focused on Air Quality and EE.

7.1.2 Policy Mix Elements

Sub-question 3 is answered based on the framework developed by Ossenbrink et al. (2019). The policy mix elements are identified based on their impact; hence the instruments should impact forest bio-energy use in Sofia, Bulgaria. The two main policy instruments in Sofia's forest bio-energy policy mix are the two appliance change programs operated by the municipality; the programs aim to improve the AQ in the municipality by changing the old wood and coal-burning stoves with the new heating appliances. On the national level, the only two instruments that are not influenced by EU legislation are the "Energy benefits" and "Direct wood supply". The EU level instruments are represented by the RED, AQD, EED, ecodesign directive, "LIFE program" and "Horizon 2020"

The effect of EU policy instruments is in the domain of EE and AQ; however, this impact is mitigated by factors representing the incapability of the national institution to enforce the national and EU legislation. On the other hand, the national policy actions are intended to reduce the cost of energy and increase energy consumption and air pollution. The municipality's role in the system is to install free appliances; however, the design features of the programs and the capability of the administration are slowing the participation rate in the municipal appliance change programs.

7.1.3 Factors and Relations

The factors and their relations in the context of forest bio-energy and energy poverty in Sofia are the focus of Sub-question 4. The answer to to this sub-question is provided by developing CLD model (Figure 16). A key factor in the model is the "Rate of households switching from traditional fuels" it influences both "Traditional fuels consumption" and "Alternative energy consumption", and it is an indicator of the success of the municipal appliance change program. On the other hand, the "Rate of households switching from traditional fuels" is determined by the "Ability to participate in municipal program" and "Willingness to participate in the municipal program". The "Ability to participate in municipal program" is mostly influenced by the design features of the

program and the EU "Authority" instruments. At the same time, the "Willingness to participate in the municipal program" is influenced by multiple external and internal factors. Therefore, the behaviour of "Ability to participate in municipal program" is to a large extent in the control of the municipality, while the "Willingness to participate in the municipal program" is not.

7.1.4 Interactions

Based on the relations represented in Figure 17 the policy mix characteristics are determined. First, the policy mix is dominated by conflicts, with few synergies between the policy instruments. Second, vertical and horizontal inconsistency follows the national instruments' negative impact on the EU, national and local objectives. At the same time, the synergy exists between EU and local instruments. Third, the conflict of perception and lack of capability defines the incoherence of the policy mix. Finally, the lack of comprehensiveness is represented by the existence of policy instruments that are not part of any strategic document, while critical market failures are not addressed.

The conflicts occurring in the policy mix are a consequence of the objectives and perceptions of the two ministries and the lack of capability of the national and local administrations. ME and MLSA have very different responsibilities in the government; however, both see the round-wood as an affordable energy source, while all other stakeholders want to reduce its use. All other national and local institutions are dependable on EU financing for their policies and EU regulations and directives. However, the MA has complete control over the country's forest sector; the current EU legislation does not affect it. At the same time, the social sphere is largely outside of EU's competence. In addition, the lack of communication and cooperation between the ministers further exacerbates their divide.

7.1.5 Impacts

Impacts on the EP are shown in Table 5, which is based on Figure 21. The forest bio-energy policy mix impact on EP alleviation in Sofia is both positive and negative. The policy mix conflicts reduce the appliance change programs' negative impacts on "Energy affordability" while the "Use of modern and safe energy" are primarily negative. On the other hand, the synergies have a positive influence on all indicators. Nevertheless, the "Ability to keep home adequately warm" depends more on the living conditions and the income of the household than the performance of the policy mix. Finally, it is determined that no policy instrument impacting forest bio-energy use has an effect on factors connected to the fourth indicator. Thus, "Dwelling with a leaking roof, damp walls, floors or foundation, or rot in window frames or floors" is excluded from the analysis.

The forest bio-energy policy mix is associated with a lack of consistency and coherence between the different levels of government and the different policy areas, as well as a lack of comprehensiveness. Nevertheless, the EU's EE policies enhance the impacts of the appliance-changing programs. The impact of forest bio-energy policy mix characteristics on EP in Sofia is mixed as shown in Table 5. First, "Energy affordability" is positively influenced by the policy mix conflicts. On the other hand, the lack of consistency, coherence, comprehensiveness and credibility has a negative effect on the "Use of modern and safe energy" due to their effect on participation in the appliance change programs. In the end, the impact of the characteristic of the policy mix on the "Ability to keep adequately warm" is mainly neutral; the indicator is influenced by factors outside the influence of the policy mix. Thus for each household, the impact will be different, tempting the EE of their homes, their Ability to pay higher bills without reducing consumption.

Overall the forest bio-energy policy mix does not help in alleviating the EP in Sofia. The Ability to keep a home is most positively influenced but only for households which are able to pay the higher energy costs for adequate consummation or are able to buy high-quality fuels and appliances. The lack of consistency, coherence, comprehensiveness and credibility undermines the susses of the appliance change program and thus reduces the use of modern and safe energy in the observed period. Nevertheless, participation in the municipal program is exposing the households to higher energy costs due to the lack of comprehensiveness. Therefore, the same conflicts that

are negatively influencing the use of modern and safe energy are positively influencing energy affordability.

Table 5: Impact of Forest Bio-energy Policy mix on Energy Poverty in Sofia

	Characteristic	Energy affordability	Use of modern and safe energy	Ability to keep home adequately warm
Conflict over "Air Quality"	Consistency	+	-	+
Conflict over "Traditional fuels consumption"	Consistency	+ / -	-	+
Synergy between EE instruments and appliance change program	Consistency	+ / -	+	+
Lack of capability of national institutions	Coherence	-	- / +	- / +
Lack of capability of the local administration staff	Coherence	+ / -	- / +	+
Conflict of perception between the MA, MLSA, and the rest of the stakeholders	Coherence	+	-	+
Lack of instrument addressing market failures	Comprehensiveness	-	- / +	+
Instruments not part of the strategic framework	Comprehensiveness	+	-	+
Institutional trust	Credibility	+ / -	-	+

7.2 Discussion

This study strives to make theoretical as well as empirical contributions. The main theoretical contribution is in the realm of the policy mix literature; more specifically the policy mix instruments, characteristics, vertical and horizontal dimensions and the operationalisation of the policy mix. The research confirms the importance of exploring the policy mixes in the vertical and horizontal dimensions by underlying the existing interactions between the EU, national and local levels and between the institutions and policy on a single level. Furthermore, the adoption of broader instrument classification allows the use of the Rogge and Reichardt (2016) framework in a larger domain of issues outside the innovation studies. Finally, the study shows the capabilities of the policy to be used in evaluating the policy mix's impact on an outcome of interest.

The empirical contribution relates to the insight into the forest biomass energy policy. However, the finding can be applied to other energy transition problems in Sofia, such as energy efficiency or solar energy and their impact on energy poverty. Moreover, the insight could be extended to other cities and regions in Bulgaria and Central and East Europe. While there is a difference in the contextual factors, the use of traditional fuels has the same social structure in the CEE.

Ultimately, this research does not argue to contribute to the energy poverty theory. Nevertheless, it supports the notion that EP definition should be suited to a contextual environment. Further, it emphasises the need for energy access and quality indicators, which are common in developing countries but are ignored by the EU studies and the methodology provided by EPOV (Thema & Vondung, 2020).

7.2.1 Theoretical contribution

This research builds on the theoretical framework of Rogge and Reichardt (2016), which recognises the three building blocks of the policy mixes. The main focus of this analysis was the policy mix elements, more specifically, the policy instruments and the policy mix characteristics. Regarding

the policy instruments, the research adopts the Howlett and Rayner (2007) classification; which distinguish between substantive and procedural policy instruments by purpose and Authority, Treasury, Nodality and Organisation types. Thus, it is more suitable for policy areas outside the innovation policy or energy transition, representing a continuation of combining policy and innovation studies conceptualisation depicted by Kern et al. (2019). In line with the (Howlett & Rayner, 2007) and the later research Howlett et al. (2017), the findings of this research show the importance of the procedural instrument alongside the substantive one. In the case of the appliance change program, despite the high target, the actual households applied for the program are significantly fewer. At the same time, the lack of horizontal coherence on national can be addressed by using substantive policy instruments. Furthermore, except for the "energy benefits" and "direct wood sell", there are no other major goal conflicts existing in the policy mix due to the "procedural" tools established on the EU level.

Alongside the types and purposes of the instrument, the design features play an essential role, as argued by Rogge and Reichardt (2016). In the case of Sofia, the type of alternatives selected by the policymakers and the requirements embedded in the programs determine who can participate in the program as well as its effectiveness and the impact on energy poverty as well.

Several studies have argued the importance of the policy mix's vertical and horizontal dimensions of the policy mix (Howlett & Rayner, 2013; del Río, 2014; Howlett et al., 2015; Rogge & Reichardt, 2016; Rogge et al., 2017). The results of this research support this argument as well. Whine the national and local governments rely on EU funds and are subject to EU regulation, they still can develop contradicting policies, which is the case of the "energy benefits" and the "direct wood sell". Moreover, the implementation of the upper-level policies is done by lower-level institutions. Therefore, the sustainability requirements designed on the EU level are not practical on their own without the control that should be enacted on the national level.

The policy mix concept is used to determine which part of the policy mix impacts energy poverty, in what way and why, representing a significant difference between this study and previous research. Prior policy mix studies mainly examine the policy mix's effectiveness or success. As shown, the forest bio-energy policy mix is associated with a lack of coherence, comprehensiveness and, to some extent, consistency; however, not all conflicts result in negative impacts on energy poverty. On the contrary, the inconsistency and incoherence that limited the participation in the appliance change program reduce the number of people who would have higher energy costs. Nonetheless, the lack of comprehensiveness has negative results as well. For example, the national policy aiming to reduce the cost of firewood is limiting the number of participants in the municipal programs, especially those with lower incomes who are receiving benefits.

Several conclusions regarding the policy mix theoretical framework could be made based on the above findings. First, the nature of the policy mix impacts on outcomes outside the policy mix, depends on the outcome itself as well as the policy mix interactions. Second, the way policy mix elements are identified determines the impact on the outcomes of interest. Therefore, when the impacts of the policy mix are explored the policy mixed that is explored should be identified based on strategic intent (top-down approach).

7.2.2 Empirical contribution

Several studies have established the relation between energy transition and EP (Nguyen et al., 2019; Green & Gambhir, 2020), arguing that while there is an existing trade-off between the two concepts, there should not be the case. This study finds that designing a comprehensive, coherent, consistent and credible policy mix can overcome this trade-off. However, the policy instrument should be well-targeted, as argued by Streimikiene et al. (2020). In addition, the research finding underlines the need for considering energy poverty in the policy-making process, as recommended by Kyprianou et al. (2019) and Bajomi et al. (2021). Sofia's current forest-biomass policy mix provides a choice to the households: heating with polluting and affordable round-wood and coal or switching to a safer but more expensive alternative. With well design policy mix, that choice can be eliminated. For example, by ending the energy benefits for round-wood, providing support for participation in the appliance change program and increasing the energy benefits for other income

groups, major conflicts in the policy mix will be eliminated, which will lead to more people being able to afford to switch to sustainable alternatives without the risk of increasing energy costs.

Increasing housing energy efficiency and the energy-saving practice will decrease energy consumption and mitigate all the balancing loops that originate from the appliance change, enhancing the synergies in the policy mix. There would not be a high increase in costs; at the same time, the households will receive all the health benefits from not using wood or coal for heating. In the case of Lithuania, Žičkienė et al. (2022) shows the approach of reducing energy consumption by increasing the recitations buildings' energy efficiency before moving to sustainable energy sources.

7.3 Recommendation

Based on the findings of the analysis, significant progress is required in the policy design and implementation. The design of the policy instruments is the first issue that needs to be addressed. The use of proper substantive and procedural policy instruments that are not in conflict. The cost of energy fuels and their overall cost plays a significant role in the choice of a household to participate in appliance-changing programs. Hence, a change in the design feature of the energy benefits is needed from supporting all energy types to just those that are sustainable. So the sustainable alternative becomes more economically effective. Stopping the direct wood sale is necessary as well. Both instruments conflict with the other objectives of the policy mix by increasing the use of unsustainably harvested wood and air pollution. At the same time, abolishing this policy exposes the most vulnerable users of traditional fuels to increasing energy poverty. Hence, they should be directly targeted with appliance-changing programs.

Nevertheless, this requires reforming the design features of the substantive component of the program because they are not accessible to the poorest at the moment. Eliminating the energy benefit for round-wood will enhance the willingness to participate in the program, making them a substantive economic instrument. Thus the balancing effects of all negative loops can be mitigated. More participation in the program will positively influence the use of modern energy sources and the ability to keep warm.

While the appliance change is the right step in achieving adequate warmth, it is not enough. Figure 17 shows that this indicator is dependable on the level of housing EE, energy-saving practices and general EE of the heating appliances. Increasing the level of EE will increase the household's ability to warm. However, it will enhance the participation in the stove changing program by increasing the positive effect that the households that have to change their appliances by reducing energy consumption. Nonetheless, high sustainability and appliance requirements can reduce the desirability of appliance change, in combination with a higher price of round-wood and lack of energy benefits. Thus, resulting in a more comprehensive and consistent policy mix.

The coherence and credibility problems that the policy mix faces are more difficult to address. The political instability and low institutional trust in Bulgaria make tackling these two issues more difficult. The capability problem comes from the lack of financial resources; hence, increasing the financial support for the municipality or allowing it other sources of income should significantly improve the capability and motivation of the municipal staff. When it comes to the different perceptions of the institution, mainly on the national level, which results in a conflicting instrument, that should be mitigated by introducing a mechanism that evaluates the policy instrument and aligns them with the existing policy strategies regardless of the policy field or source of financing. Finally, when all energy transition policies are developed, energy poverty alleviation should be considered.

7.4 Limitations and Further Research

There are several limitations of this study that should be taken into account when the findings are discussed. The limitations originated from the choice of energy poverty indicators, methods, data sources and the analysis itself. First, the energy poverty indicators selected for this study predetermine the possible conclusion. For example, access to modern energy sources can be directly associated with stove-changing programs. Nevertheless, this indicator, as well as the other two, are

affected by multiple factors. Finally, it should be noted that changes in the indicators or inclusion or exclusion of indicators can influence the analysis results, constituting a critical limitation to the overall approach.

Second, the choice of a single case study limits the scope of the research to a single city with its specific contextual factors. While, as argued in Section 4, this does not make the finding less applicable to other cases; it is a limit to the analysis. In addition to the geographical limitation, the policy focus and the time scope are also narrow; however, this does not change the outcome of the analysis because there is no great variety of policies introduced by the municipality or the national government. Moreover, the focus of policies impacted the forest biomass energy range from energy efficiency and renewable energy to air quality and social assistance.

The choice of qualitative methods could be seen as a substantive limitation of the research; however, several factors should be considered. First, there is a lack of quantitative data on a local level in Bulgaria. Moreover, the national and local authorities rarely monitor the policy outcomes. Thus, relying only on qualitative methods would not be suitable. There are a variety of mixed methods that quantify qualitative data. For example, a subjective appraisal is used to measure the weight of the causal relations. Nevertheless, the mixed methods require the participation of a more significant number of interviews to achieve consensus on weight or to be representative of all possible views on the subject, so the average of their appraisal is accepted as an objective representation of reality. Otherwise, quantifying the subjective observations does not provide more truth to the research but increases the complexity of the research process.

This research represents the first step in understanding the impact of the forest bio-energy policy mix on the EP in Sofia, Bulgaria. While it provides insight into the interaction between the existing policy instruments, the focus of further research should be the policy process and the dynamic of the policy mix. Furthermore, the CLD developed in the research process can be used as a reference for what type of data should be collected regarding Bulgaria's policy outcomes and socio-economic structure. Regarding EP, the following studies concerning cases in CEE should give more attention to access to modern and safe energy sources aspect.

References

Aguilar, F., Antti, A., Glasenapp, S., McCusker, A., Glavonjic, B., Mabee, W., ... Weimar, H. (2018). *Wood energy in the ece region; data, trends and outlook in europe, the commonwealth of independent states and north america (ece/tim/sp/42).* 12

Andersen, S., Allen, B. & Domingo, G. (2021). *Biomass in the eu green deal: Towards consensus on the use of biomass for eu bioenergy.* Institute for European Environmental Policy (IEEP). Retrieved from https://ieep.eu/publications/biomass-in-the-eu-green-deal-towards-consensus-on-sustainable-use-of-biomass-for-eu-bioenergy 12, 13, 86

Auping, W., Pruyt, E. & Kwakkel, J. (2014, 12). Dealing with multiple models in system dynamics: Perspectives on the future of copper. *International Journal of System Dynamics Applications*, *3*, 17-35. doi: 10.4018/ijsda.2014100102 31

Bahn-Walkowiak, B. & Wilts, H. (2017). The institutional dimension of resource efficiency in a multi-level governance system—implications for policy mix design. *Energy Research & Social Science*, *33*, 163-172. doi: https://doi.org/10.1016/j.erss.2017.09.021 12, 79, 83

Bajomi, A. Z., Feldmár, N. & Tirado-Herrero, S. (2021). Will plans to ease energy poverty go up in smoke? assessing the hungarian necp through the lens of solid fuel users' vulnerabilities. *Sustainability*, *13*(23). doi: 10.3390/su132313047 13, 16, 17, 61, 73, 74, 75, 76

Barroco Fontes Cunha, F., Carani, C., Nucci, C. A., Castro, C., Santana Silva, M. & Andrade Torres, E. (2021). Transitioning to a low carbon society through energy communities: Lessons learned from brazil and italy. *Energy Research & Social Science*, *75*. doi: https://doi.org/10.1016/j.erss.2021.101994 13

Bartiaux, F., Maretti, M., Cartone, A., Biermann, P. & Krasteva, V. (2019). Sustainable energy transitions and social inequalities in energy access: A relational comparison of capabilities in three european countries. *Global Transitions*, *1*, 226-240. doi: https://doi.org/10.1016/j.glt.2019.11.002 13, 14, 24, 70, 71, 73

Bassi, A., Costantini, V. & Paglialunga, E. (2021). Modelling the european union sustainability transition: A soft-linking approach. *Sustainability (Switzerland)*, *13*(11). doi: 10.3390/su13116303 12

Bouzarovski, S. & Tirado Herrero, S. (2015). The energy divide: Integrating energy transitions, regional inequalities and poverty trends in the european union. *European Urban and Regional Studies*, *24*(1), 69–86. doi: 10.1177/0969776415596449 12, 13, 17, 24

Bouzarovski, S. & Tirado Herrero, S. (2017, JAN). The energy divide: Integrating energy transitions, regional inequalities and poverty trends in the european union. *European urban and regional studies*, *24*(1), 69-86. doi: 10.1177/0969776415596449 14, 16, 24, 73, 74, 75, 76

Braungardt, S., Bürger, V. & Köhler, B. (2021). Carbon pricing and complementary policies—consistency of the policy mix for decarbonizing buildings in germany. *Energies*, *14*(21). doi: 10.3390/en14217143 21, 79, 83

Calvo, R., Álamos, N., Huneeus, N. & O'Ryan, R. (2022). Energy poverty effects on policy-based pm2.5 emissions mitigation in southern and central chile. *Energy Policy*, *161*. doi: 10.1016/j.enpol.2021.112762 17, 73, 74, 75, 76

Castaño-Rosa, R. & Okushima, S. (2021). Prevalence of energy poverty in japan: A comprehensive analysis of energy poverty vulnerabilities. *Renewable and Sustainable Energy Reviews*, *145*, 111006. doi: https://doi.org/10.1016/j.rser.2021.111006 13

Castrejon-Campos, O., Aye, L. & Hui, F. (2020). Making policy mixes more robust: An integrative and interdisciplinary approach for clean energy transitions. *Energy Research and Social Science*, *64*. doi: 10.1016/j.erss.2020.101425 70, 71

Chapman, A. & Okushima, S. (2019). Engendering an inclusive low-carbon energy transition in japan: Considering the perspectives and awareness of the energy poor. *Energy Policy*, *135*, 111017. doi: https://doi.org/10.1016/j.enpol.2019.111017 73, 74, 75, 76

Commission, E., Centre, J. R., Camia, A., Giuntoli, J., Jonsson, R., Robert, N., ... Mubareka, S. (2021). *The use of woody biomass for energy production in the eu.* Publications Office. doi: doi/10.2760/831621 13

Crowe, S., Cresswell, K., Robertson, A., Huby, G., Avery, A. & Sheikh, A. (2011). The case study approach. *BMC Medical Research Methodology*, *11*, 100. doi: 10.1186/1471-2288-11-100 23, 24

de Boon, A., Sandström, C., Arbieu, U., Hansen, I., Lehnen, L., Marino, A., ... Rønningen, K. (2021). Governing dual objectives within single policy mixes: an empirical analysis of large carnivore policies in six european countries. *Journal of Environmental Policy & Planning*, *23*(4), 399-413. doi: 10.1080/1523908X.2020.1841614 79, 83

del Río, P. (2014). On evaluating success in complex policy mixes: The case of renewable energy support schemes. *Policy Sciences*, *47*(3), 267-287. doi: 10.1007/s11077-013-9189-7 13, 18, 19, 61, 79, 82, 83

del Río, P. (2017). Why does the combination of the european union emissions trading scheme and a renewable energy target makes economic sense? *Renewable and Sustainable Energy Reviews*, *74*, 824-834. doi: 10.1016/j.rser.2017.01.122 22, 79, 83

Dong, K., Ren, X. & Zhao, J. (2021). How does low-carbon energy transition alleviate energy poverty in china? a nonparametric panel causality analysis. *Energy Economics*, *103*, 105620. doi: https://doi.org/10.1016/j.eneco.2021.105620 13, 73, 74, 75, 76

Douglas, D. & Radicic, D. (2020). Network additionality and policy mix of regional and national public support for innovation. *Economics of Innovation and New Technology*, *31*(3), 148-172. doi: 10.1080/10438599.2020.1789277 79, 83

EC. (2012). *Innovating for sustainable growth: A bioeconomy for europe.* Retrieved from https://ec.europa.eu/research/bioeconomy/pdf/201202_innovating_sustainable_growth_en.pdf 85

EC. (2017). *Sustainable and optimal use of biomass for energy in the eu beyond 2020.* Retrieved from https://energy.ec.europa.eu/sustainable-and-optimal-use-biomass-energy-eu-beyond-2020_en 86

EC. (2019a). *Clean energy for all europeans.* Retrieved from https://op.europa.eu/en/publication-detail/-/publication/b4e46873-7528-11e9-9f05-01aa75ed71a1/language-en?WT.mc_id=Searchresult&WT.ria_c=null&WT.ria_f=3608&WT.ria_ev=search 85

EC. (2019b). *European green deal.* Retrieved from https://eur-lex.europa.eu/resource.html?uri=cellar:b828d165-1c22-11ea-8c1f-01aa75ed71a1.0002.02/DOC_1&format=PDF 12, 85

EC. (2019c). *Types of eu law.* Retrieved from https://ec.europa.eu/info/law/law-making-process/types-eu-law_en 34

Edmondson, D., Kern, F. & Rogge, K. (2019). The co-evolution of policy mixes and socio-technical systems: Towards a conceptual framework of policy mix feedback in sustainability transitions. *Research Policy*, *48*(10). doi: 10.1016/j.respol.2018.03.010 12, 18, 19, 21, 71, 79, 82

Ehnert, F., Kern, F., Borgström, S., Gorissen, L., Maschmeyer, S. & Egermann, M. (2018). Urban sustainability transitions in a context of multi-level governance: A comparison of four european states. *Environmental Innovation and Societal Transitions*, *26*, 101-116. doi: https://doi.org/10.1016/j.eist.2017.05.002 12, 24, 35

Enserink, B., Hermans, L., Kwakkel, J., Thissen, W., Koppenjan, J. & Bots, P. (2010). *Policy analysis of multi-actor systems.* Lemma. 28, 29, 32, 58

European Union. (2002). *Treaty on european union (consolidated version), treaty of maastricht, 7 february 1992.* Official Journal of the European Communities C 325/5. Retrieved from https://www.refworld.org/docid/3ae6b39218.html (Accessed on July 20th 2022) 34

Falcone, P., Lopolito, A. & Sica, E. (2017). Policy mixes towards sustainability transition in the italian biofuel sector: Dealing with alternative crisis scenarios. *Energy Research and Social Science*, *33*, 105-114. doi: 10.1016/j.erss.2017.09.007 79, 83

Feenstra, M., Middlemiss, L., Hesselman, M., Straver, K. & Tirado Herrero, S. (2021). Humanising the energy transition: Towards a national policy on energy poverty in the netherlands. *Frontiers in Sustainable Cities*, *3*. doi: 10.3389/frsc.2021.645624 13, 16, 73, 74, 75, 76

Flanagan, K., Uyarra, E. & Laranja, M. (2011). Reconceptualising the 'policy mix' for innovation. *Research Policy*, *40*(5), 702-713. doi: 10.1016/j.respol.2011.02.005 13, 18, 19, 21, 22, 79, 82, 83, 84

Flyvbjerg, B. (2006). Five misunderstandings about case-study research. *Qualitative Inquiry*, *12*, 219-245. doi: 10.1177/1077800405284363 14, 24

Ganev, G. & Primatarova, A. (2007, 04). Regional policy: Actors, institutions and policy making structures in bulgaria in relation to eu membership. 35

Gomel, D. & Rogge, K. (2020). Mere deployment of renewables or industry formation, too? exploring the role of advocacy communities for the argentinean energy policy mix. *Environmental Innovation and Societal Transitions*, *36*, 345-371. doi: 10.1016/j.eist.2020.02.003 18, 19, 21, 79, 82

Green, F. & Gambhir, A. (2020). Transitional assistance policies for just, equitable and smooth low-carbon transitions: who, what and how? *Climate Policy*, *20*(8), 902-921. doi: 10.1080/14693062.2019.1657379 61

Guzowski, C., Ibañez Martín, M. M. & Zabaloy, M. (2021). Energy poverty: conceptualization and its link to exclusion. brief review for latin america. *Ambiente & Sociedade*, *24*. doi: 10.1590/1809-4422asoc20200027r2vu2021l2de 13, 17, 73, 74, 75, 76

Harrison, H., Birks, M., Franklin, R. & Mills, J. (2017, 01). Case study research: Foundations and methodological orientations. *Forum: Qualitative Social Research*, *18*. 14, 23, 24

Herington, M. & Malakar, Y. (2016). Who is energy poor? revisiting energy (in)security in the case of nepal. *Energy Research & Social Science*, *21*, 49-53. doi: https://doi.org/10.1016/j.erss.2016.06.025 17, 73, 74, 75, 76

Howlett, M. (2000, 01). Managing the "hollow state": Procedural policy instruments and modern governance. *Canadian Public Administration*, *43*, 412-431. 19

Howlett, M. (2005). *What is a policy instrument? tools, mixes, and implementation styles.* 18, 19, 79, 82

Howlett, M., How, Y. & del Rio, P. (2015). The parameters of policy portfolios: verticality and horizontality in design spaces and their consequences for policy mix formulation. *Environment and Planning C: Government and Policy*, *33*(5), 1233-1245. doi: 10.1177/0263774X15610059 12, 18, 20, 21, 61, 80, 82, 83

Howlett, M. & Rayner, J. (2007). Design principles for policy mixes: Cohesion and coherence in 'new governance arrangements'. *Policy and Society*, *26*(4), 1-18. doi: https://doi.org/10.1016/S1449-4035(07)70118-2 2, 18, 19, 20, 21, 22, 26, 27, 31, 61, 79, 82, 84

Howlett, M. & Rayner, J. (2013, 06). Patching vs packaging in policy formulation: Assessing policy portfolio design. *Politics and Governance*, *1*, 170. doi: 10.17645/pag.v1i2.95 61

Howlett, M., Vince, J. & Del Río, P. (2017). Policy integration and multi-level governance: Dealing with the vertical dimension of policy mix designs. *Politics and Governance*, *5*(2), 69-78. (cited By 55) doi: 10.17645/pag.v5i2.928 18, 20, 22, 61, 80, 83

Huang, P. (2019). The verticality of policy mixes for sustainability transitions: A case study of solar water heating in china. *Research Policy*, *48*(10). doi: 10.1016/j.respol.2019.02.009 18, 21, 80, 83

Jiang, L., Yu, L., Xue, B., Chen, X. & Mi, Z. (2020). Who is energy poor? evidence from the least developed regions in china. *Energy Policy*, *137*, 111122. doi: https://doi.org/10.1016/j.enpol.2019.111122 13, 73, 74, 75, 76

Kahouli, S. & Okushima, S. (2021). Regional energy poverty reevaluated: A direct measurement approach applied to france and japan. *Energy Economics*, *102*, 105491. doi: https://doi.org/10.1016/j.eneco.2021.105491 13, 70, 71, 73

Karpinska, L. & Śmiech, S. (2021). Will energy transition in poland increase the extent and depth of energy poverty? *Journal of Cleaner Production*, *328*, 129480. doi: https://doi.org/10.1016/j.jclepro.2021.129480 13

Kern, F., Kivimaa, P. & Martiskainen, M. (2017). Policy packaging or policy patching? the development of complex energy efficiency policy mixes. *Energy Research & Social Science*, *23*, 11-25. doi: https://doi.org/10.1016/j.erss.2016.11.002 80, 84

Kern, F. & Rogge, K. (2018). Harnessing theories of the policy process for analysing the politics of sustainability transitions: A critical survey. *Environmental Innovation and Societal Transitions*, *27*, 102-117. doi: https://doi.org/10.1016/j.eist.2017.11.001 12

Kern, F., Rogge, K. & Howlett, M. (2019). Policy mixes for sustainability transitions: New approaches and insights through bridging innovation and policy studies. *Research Policy*, *48*(10). doi: https://doi.org/10.1016/j.respol.2019.103832 12, 14, 18, 61, 80

Kerr, N., Gillard, R. & Middlemiss, L. (2019). Politics, problematisation, and policy: A comparative analysis of energy poverty in england, ireland and france. *Energy and Buildings*, *194*, 191-200. doi: 10.1016/j.enbuild.2019.04.002 16, 73, 74, 75, 76

Kim, H. & Andersen, D. F. (2012). Building confidence in causal maps generated from purposive text data: mapping transcripts of the federal reserve. *System Dynamics Review*, *28*(4), 311-328. doi: https://doi.org/10.1002/sdr.1480 29, 31, 46

Kivimaa, P. & Virkamäki, V. (2014). Policy mixes, policy interplay and low carbon transitions: The case of passenger transport in finland. *Environmental Policy and Governance*, *24*(1), 28-41. doi: 10.1002/eet.1629 83

Kona, A., Bertoldi, P. & Kılkış, (2019). Covenant of mayors: Local energy generation, methodology, policies and good practice examples. *Energies*, *12*(6). doi: 10.3390/en12060985 24

Korteland, M., de Vries, J. & van Berkel, S., P. end de Bruyn. (2022). *Health-related social costs of air pollution due to residential heating and cooking version 1.2.* CE Delft. Retrieved from `https://cedelft.eu/publications/health-related-social-costs-of-air-pollution-due-to-residential-heating-and-cooking/` 17, 86

Kovacic, Z., Musango, J. K., Buyana, K., Ambole, A., Smit, S., Mwau, B., ... Brent, A. (2021). Building capacity towards what? proposing a framework for the analysis of energy transition governance in the context of urban informality in sub-saharan africa. *LOCAL ENVIRONMENT*, *26*, 364-378. doi: 10.1080/13549839.2020.1849075 70, 71

Kyprianou, I., Serghides, D., Varo, A., Gouveia, J., Kopeva, D. & Murauskaite, L. (2019). Energy poverty policies and measures in 5 eu countries: A comparative study. *Energy and Buildings*, *196*, 46-60. doi: https://doi.org/10.1016/j.enbuild.2019.05.003 61

Lanahan, L. & Feldman, M. (2015). Multilevel innovation policy mix: A closer look at state policies that augment the federal sbir program. *Research Policy*, *44*(7), 1387-1402. doi: 10.1016/j.respol.2015.04.002 80, 84

Li, L., Wang, Z. & Wang, Q. (2020). Do policy mix characteristics matter for electric vehicle adoption? a survey-based exploration. *Transportation Research Part D: Transport and Environment*, *87*, 102488. doi: https://doi.org/10.1016/j.trd.2020.102488 80, 84

Lindberg, M. (2019). The eu emissions trading system and renewable energy policies: Friends or foes in the european policy mix? *Politics and Governance*, *7*(1), 105-123. doi: 10.17645/pag.v7i1.1800 70, 71, 80, 84

Lowans, C., Furszyfer Del Rio, D., Sovacool, B., Rooney, D. & Foley, A. (2021). What is the state of the art in energy and transport poverty metrics? a critical and comprehensive review. *Energy Economics*, *101*. doi: 10.1016/j.eneco.2021.105360 16, 73, 74, 75, 76

Madlener, R. (2019). *Sustainable energy transition and increasing complexity: Trade-offs, the economics perspective and policy implications.* doi: 10.1016/B978-0-12-817674-0.00011-4 73

Magro, E. & Wilson, J. (2019). Policy-mix evaluation: Governance challenges from new place-based innovation policies. *Research Policy*, *48*(10). doi: 10.1016/j.respol.2018.06.010 21, 22, 80, 84

Martiskainen, M., Sovacool, B. K., Lacey-Barnacle, M., Hopkins, D., Jenkins, K. E. H., Simcock, N., ... Bouzarovski, S. (2021). New dimensions of vulnerability to energy and transport poverty. *Joule*, *5*, 3-7. doi: 10.1016/j.joule.2020.11.016 70, 71, 73

Mashhoodi, B. (2021). Who is more dependent on gas consumption? income, gender, age, and urbanity impacts. *APPLIED GEOGRAPHY*, *137*. doi: 10.1016/j.apgeog.2021.102602 70, 71, 73

Mastropietro, P. (2019). Who should pay to support renewable electricity? exploring regressive

impacts, energy poverty and tariff equity. *Energy Research & Social Science*, *56*. doi: https://doi.org/10.1016/j.erss.2019.101222 13

Matti, C., Consoli, D. & Uyarra, E. (2017). Multi level policy mixes and industry emergence: The case of wind energy in spain. *Environment and Planning C: Politics and Space*, *35*(4), 661-683. doi: 10.1177/0263774X16663933 80, 84

Mattioli, G., Lucas, K. & Marsden, G. (2018). Reprint of transport poverty and fuel poverty in the uk: From analogy to comparison. *Transport Policy*, *65*, 114-125. doi: 10.1016/j.tranpol.2018.02.019 73

Mavrot, C., Hadorn, S. & Sager, F. (2019). Mapping the mix: Linking instruments, settings and target groups in the study of policy mixes. *Research Policy*, *48*(10), 103614. doi: https://doi.org/10.1016/j.respol.2018.06.012 22

Musango, J. K. & Bassi, A. M. (2021). Towards a systemic assessment of gendered energy transition in urban households. *ENERGIES*, *14*. doi: 10.3390/en14217251 71, 73

Nguyen, T. T., Nguyen, T.-T., Hoang, V.-N., Wilson, C. & Managi, S. (2019). Energy transition, poverty and inequality in vietnam. *Energy Policy*, *132*, 536-548. doi: 10.1016/j.enpol.2019.06.001 14, 61, 71, 73, 74, 75, 76

Nsi. (2021). Retrieved from `https://www.nsi.bg/bg` 24, 36, 37

Odyssee-mure. (2021). Retrieved from `https://www.odyssee-mure.eu/publications/efficiency-by-sector/households/influence-income-consumption-dwelling.html` 12

Okushima, S. (2019). Understanding regional energy poverty in japan: A direct measurement approach. *Energy and Buildings*, *193*, 174-184. doi: 10.1016/j.enbuild.2019.03.043 73, 75, 76

Ossenbrink, J., Finnsson, S., Bening, C. R. & Hoffmann, V. H. (2019). Delineating policy mixes: Contrasting top-down and bottom-up approaches to the case of energy-storage policy in california. *Research Policy*, *48*(10), 103582. doi: https://doi.org/10.1016/j.respol.2018.04.014 21, 25, 26, 27, 58

Peneva, T. (2019, 01). Sustainable development and energy poverty: Challenges for the governing institutions. *Ikonomicheski Izsledvania*, *28*, 174-182. 42

Primc, K., Dominko, M. & Slabe-Erker, R. (2021). 30 years of energy and fuel poverty research: A retrospective analysis and future trends. *Journal of Cleaner Production*, *301*. doi: https://doi.org/10.1016/j.jclepro.2021.127003 16, 73, 75, 76

Rogge, K. & Dütschke, E. (2018, 09). What makes them believe in the low-carbon energy transition? exploring corporate perceptions of the credibility of climate policy mixes. *Environmental Science & Policy*, *87*, 74-84. doi: 10.1016/j.envsci.2018.05.009 21, 80, 84

Rogge, K., Kern, F. & Howlett, M. (2017). Conceptual and empirical advances in analysing policy mixes for energy transitions. *Energy Research and Social Science*, *33*, 1-10. doi: 10.1016/j.erss.2017.09.025 12, 14, 18, 19, 61, 71, 80

Rogge, K., Pfluger, B. & Geels, F. (2020). Transformative policy mixes in socio-technical scenarios: The case of the low-carbon transition of the german electricity system (2010–2050). *Technological Forecasting and Social Change*, *151*. doi: 10.1016/j.techfore.2018.04.002 81, 84

Rogge, K. & Reichardt, K. (2016, 10). Policy mixes for sustainability transitions: An extended concept and framework for analysis. *Research Policy*, *45*, 1620-1635. doi: 10.1016/J.RESPOL.2016.04.004 2, 13, 14, 18, 20, 21, 22, 25, 26, 27, 28, 31, 32, 55, 60, 61, 71, 80, 82, 83, 84

Rogge, K. & Schleich, J. (2018). Do policy mix characteristics matter for low-carbon innovation? a survey-based exploration of renewable power generation technologies in germany. *Research Policy*, *47*(9), 1639-1654. doi: https://doi.org/10.1016/j.respol.2018.05.011 81, 84

Rosenow, J., Kern, F. & Rogge, K. (2017). The need for comprehensive and well targeted instrument mixes to stimulate energy transitions: The case of energy efficiency policy. *Energy Research and Social Science*, *33*, 95-104. doi: 10.1016/j.erss.2017.09.013 21, 22, 71, 81, 84

Sadik-Zada, E., Gatto, A. & Blick, N. (2022). Rural electrification and transition to clean cooking: The case study of kanyegaramire and kyamugarura solar mini-grid energy cooperatives in

the kyenjojo district of uganda. *World Sustainability Series*, 547-562. doi: 10.1007/978-3-030-86304-3_32 73

Saeri, M., Lotfi, M. M. & Mazidi, M. R. (2019). A causal loop diagram to analyze various long-term effects of pv integration into power systems. In *2019 27th iranian conference on electrical engineering (icee)* (p. 852-855). doi: 10.1109/IranianCEE.2019.8786514 29

Scarlat, N., Dallemand, J., Taylor, N., Banja, M., Sanchez Lopez, J. & Avraamides, M. (2019). *Brief on biomass for energy in the european union* (Nos. KJ-07-17-187-EN-N (online),KJ-07-17-187-EN-C (print)). Luxembourg (Luxembourg). doi: 10.2760/546943(online),10.2760/49052(print) 12

Schmidt, T. S. & Sewerin, S. (2019). Measuring the temporal dynamics of policy mixes – an empirical analysis of renewable energy policy mixes' balance and design features in nine countries. *Research Policy*, *48*(10), 103557. doi: https://doi.org/10.1016/j.respol.2018.03.012 18, 71, 72

Siksnelyte-Butkiene, I., Streimikiene, D. & Balezentis, T. (2022). Addressing sustainability issues in transition to carbon-neutral sustainable society with multi-criteria analysis. *Energy*, *254*. doi: 10.1016/j.energy.2022.124218 16, 17, 73, 75, 76

Sofiaplan. (2021, Oct). Retrieved from `https://sofiaplan.bg/api/` 14, 24, 36

Sovacool, B. K., Turnheim, B., Hook, A., Brock, A. & Martiskainen, M. (2021). Dispossessed by decarbonisation: Reducing vulnerability, injustice, and inequality in the lived experience of low-carbon pathways. *World Development*, *137*. doi: 10.1016/j.worlddev.2020.105116 71, 73

Streimikiene, D., Kyriakopoulos, G., Lekavicius, V. & Siksnelyte-Butkiene, I. (2021). Energy poverty and low carbon just energy transition: Comparative study in lithuania and greece. *Social Indicators Research*, *158*(1), 319-371. doi: 10.1007/s11205-021-02685-9 74

Streimikiene, D., Lekavičius, V., Baležentis, T., Kyriakopoulos, G. & Abrhám, J. (2020). Climate change mitigation policies targeting households and addressing energy poverty in european union. *Energies*, *13*(13). doi: 10.3390/en13133389 16, 17, 61, 74, 75, 77

Thema, J. & Vondung, F. (2020). *Epov indicator dashboard: Methodology guidebook.* Wuppertal Institut fur Klima, Umwelt, Energie GmbH. Retrieved from `https://energy-poverty.ec.europa.eu/energy-poverty-observatory_en` 60

Vlahinic Lenz, N. & Grgurev, I. (2017, Apr.). Assessment of energy poverty in new european union member states: The case of bulgaria, croatia and romania. *International Journal of Energy Economics and Policy*, *7*(2), 1–8. 13

Vondung, F. & Thema, J. (2019). Energy poverty in the eu - indicators as a base for policy action. In (Vol. 2019-June, p. 569-578). 14, 16, 17, 24, 74, 75, 77

Wee, B. V. & Banister, D. (2016). How to write a literature review paper? *Transport Reviews*, *36*(2), 278-288. doi: 10.1080/01441647.2015.1065456 16, 32, 70, 73

Willand, N., Middha, B. & Walker, G. (2021). Using the capability approach to evaluate energy vulnerability policies and initiatives in victoria, australia. *Local Environment*, *26*, 1109-1127. doi: 10.1080/13549839.2021.1962830 71, 74

Yadav, P., Malakar, Y. & Davies, P. J. (2019). Multi-scalar energy transitions in rural households: Distributed photovoltaics as a circuit breaker to the energy poverty cycle in india. *Energy Research & Social Science*, *48*, 1-12. doi: https://doi.org/10.1016/j.erss.2018.09.013 13, 74

Yin, R. (2011). *Applications of case study research.* SAGE Publications, Inc. 14, 23

Žičkienė, A., Morkunas, M., Volkov, A., Balezentis, T., Streimikiene, D. & Siksnelyte-Butkiene, I. (2022). Sustainable energy development and climate change mitigation at the local level through the lens of renewable energy: Evidence from lithuanian case study. *Energies*, *15*(3). doi: 10.3390/en15030980 62

A Appendix. Knowledge Gap Literature Review

The literature review is based on the framework established by Wee and Banister (2016) and executed by the following steps:

1. Description of the search process
2. Grouping the articles by common themes
   - focus
   - approach
   - scope
3. Discussion of the articles

A.1 Literature Search

Figure 22 shows the three queries that have been formulated in the Scopus database. The article selected for this literature review was drawn from the results of the second query with additional literature recommend by the thesis supervisor. Table 6 indicates the source of each article.

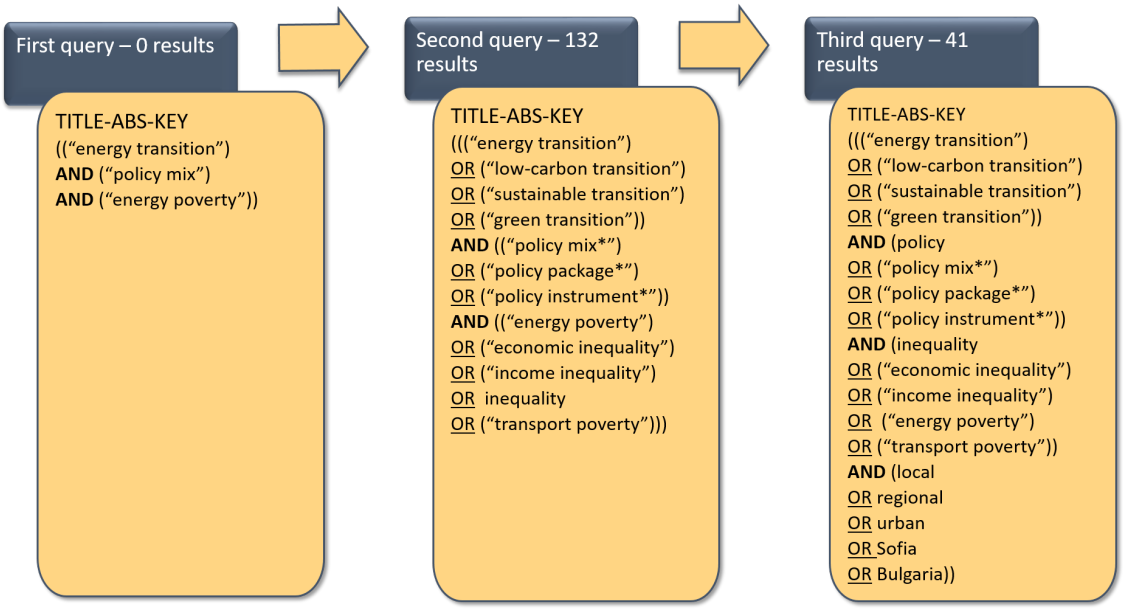

Figure 22: Search queries for identifying knowledge gap

Table 6: Literature Sources for the Knowledge Gap Literature Review

#	Article	Source
1	Bartiaux et al. (2019)	Second query Fig.22
2	Castrejon-Campos et al. (2020)	Second query Fig.22
3	Kahouli and Okushima (2021)	Second query Fig.22
4	Kovacic et al. (2021)	Second query Fig.22
5	Lindberg (2019)	Second query Fig.22
6	Martiskainen et al. (2021)	Second query Fig.22
7	Mashhoodi (2021)	Second query Fig.22

8	Musango and Bassi (2021)	Second query Fig.22
9	Nguyen et al. (2019)	Second query Fig.22
10	Rogge et al. (2017)	Second query Fig.22
11	Rosenow et al. (2017)	Second query Fig.22
12	Sovacool et al. (2021)	Second query Fig.22
13	Willand et al. (2021)	Second query Fig.22
14	Rogge and Reichardt (2016)	Supervisor Reference
15	Edmondson et al. (2019)	Supervisor Reference
16	Schmidt and Sewerin (2019)	Supervisor Reference

A.2 Content Analysis

Table 7: Knowledge Gap Literature Review - Focus, Approach, Scope

#	Article	Focus	Approach	Scope
1	Bartiaux et al. (2019)	Policy impact / Energy poverty	Comparative Case study / Capabilities Framework	National
2	Castrejon-Campos et al. (2020)	Policy effectiveness / Policy mix	Analytical Framework	Conceptual
3	Kahouli and Okushima (2021)	Policy impact / Energy poverty	Comparative Case study / Direct measurement approach	National
4	Kovacic et al. (2021)	Policy effectiveness	Case study / Analytical Framework	Sub-National
5	Lindberg (2019)	Policy effectiveness	Comparative Case study	National
6	Martiskainen et al. (2021)	Policy impact / Energy poverty	Literature Analysis	Conceptual
7	Mashhoodi (2021)	Policy impact / Energy poverty	Quantitative Case study	National
8	Musango and Bassi (2021)	Policy impact / Energy poverty	System Dynamics	sub-National
9	Nguyen et al. (2019)	Policy impact / Energy poverty	Quantitative Case study	National
10	Rogge et al. (2017)	Policy effectiveness / Policy mix	Literature Analysis	Conceptual
11	Rosenow et al. (2017)	Policy effectiveness / Policy mix	Comparative Case study	National
12	Sovacool et al. (2021)	Justice, Inequality / Policy mix	Comparative Case study	National
13	Willand et al. (2021)	Policy impact / Energy poverty	Case study / Capabilities Framework	Sub-National
14	Rogge and Reichardt (2016)	Policy mix	Analytical Framework	Conceptual
15	Edmondson et al. (2019)	Policy effectiveness / Policy mix	Analytical Framework	Conceptual

16	Schmidt and Sewerin (2019)	Policy effectiveness / Policy mix	Comparative Case study	National

B Appendix. Energy poverty Literature Review

The literature review is based on the framework established by Wee and Banister (2016) and executed by the following steps:

1. Description of the search process
2. Grouping the articles by common themes
    - Concept, Research Objective
    - Approach, Methods, Scope
    - Measurement type, Measurement unit
3. Discussion of the articles

B.1 Literature Search

The following search query was formulated in Scopus database:

(TITLE-ABS-KEY ("energy poverty"OR"fuel poverty") AND TITLE-ABS-KEY ("energy transition"OR"sustainable transition" OR "green transition"))

The query resulted in 155 articles from which 17 were selected for analysis based on their focus on Energy Poverty measurement and the to represent various research approaches and represent different contexts. Table 8 shows the source of each study.

Table 8: Energy Poverty Literature Review - Articles Sources

#	Article	Source
1	Bajomi et al. (2021)	Query
2	Bartiaux et al. (2019)	Appendix A Tab. 6
3	Bouzarovski and Tirado Herrero (2017)	Query
4	Calvo et al. (2022)	Query
5	Chapman and Okushima (2019)	Query
6	Dong et al. (2021)	Query
7	Feenstra et al. (2021)	Query
8	Guzowski et al. (2021)	Query
9	Herington and Malakar (2016)	Query
10	Jiang et al. (2020)	Query
11	Kahouli and Okushima (2021)	Query, Appendix A Tab. 6
12	Kerr et al. (2019)	Query
13	Lowans et al. (2021)	Query
14	Madlener (2019)	Query
15	Martiskainen et al. (2021)	Appendix A Tab. 6
16	Mashhoodi (2021)	SAppendix A Tab. 6
17	Mattioli et al. (2018)	Query
18	Musango and Bassi (2021)	Appendix A Tab. 6
19	Nguyen et al. (2019)	Appendix A Tab. 6
20	Okushima (2019)	Query
21	Primc et al. (2021)	Query
22	Sadik-Zada et al. (2022)	Query
23	Siksnelyte-Butkiene et al. (2022)	Query
24	Sovacool et al. (2021)	Appendix A Tab. 6

25	Streimikiene et al. (2020)	Query
26	Streimikiene et al. (2021)	Query
27	Vondung and Thema (2019)	Query
28	Willand et al. (2021)	Appendix A Tab. 6
29	Yadav et al. (2019)	Appendix A Tab. 6

B.2 Content Analysis

Table 9: Energy Poverty Literature Review - Articles Focus and Objective

#	Article	Focus	Research Objective
1	Bajomi et al. (2021)	Energy poverty vulnerability	Two map EP vulnerability in Hungary and to access the Hungarian NECP according to these vulnerabilities.
2	Bouzarovski and Tirado Herrero (2017)	Energy transition, Regional inequalities, energy poverty	Relationship between European energy transitions and existing socio-economic and regional inequalities
3	Calvo et al. (2022)	Energy poverty, Emissions mitigation	Impact of energy poverty conditions on expected emission trajectories for PM2.5 emissions.
4	Chapman and Okushima (2019)	Energy poverty, just transition	To identify the prevalence of self-reported or subjective energy poverty in Japan.
5	Dong et al. (2021)	Energy poverty, energy transition	Exploring the impact of energy transition on energy poverty
6	Feenstra et al. (2021)	Energy poverty, multi-level government	What does the national government of the Netherlands need to do to address energy poverty in its energy transition policy
7	Guzowski et al. (2021)	Just transition	Revision of the definition of energy poverty and the diverse indicators used to measure it
8	Herington and Malakar (2016)	Energy poverty	Conceptualizing, identifying and defining energy poverty
9	Jiang et al. (2020)	Energy poverty	Identification of an energy poverty line
10	Kerr et al. (2019)	Energy poverty	Exploring the problematisation of energy poverty as a political issue.
11	Lowans et al. (2021)	Energy poverty, transport poverty	Energy and transport poverty measurement
12	Nguyen et al. (2019)	Energy poverty, energy transition, inequality	The change of energy poverty and inequlity over ime and factors affecting them

13	Okushima (2019)	Regional energy poverty	Developing an energy povery measurment and evaluaitng regional poverty in Japan
14	Primc et al. (2021)	Energy poverty and Fuel poverty	Analysis of energy and fuel poverty definitions
15	Siksnelyte-Butkiene et al. (2022)	Energy poverty, eneryg transition	Provide a methodological framework for country level EP assessment and measure EP as a complex issue.
16	Streimikiene et al. (2020)	Energy poverty, climate mitigation policy	e integrated framework for development of an innovative climate change mitigation policies in households aiming at removing the behavioral barriers of climate change mitigation actions in energy poor households in EU
17	Vondung and Thema (2019)	Energy poverty, policy making	investigates the role of energy poverty indicators for policy making

Table 10: Energy Poverty Literature Review - Articles Focus and Objective

#	Article	Approach	Methods	Scope
1	Bajomi et al. (2021)	Case study	Qualitative	Hungary
2	Bouzarovski and Tirado Herrero (2017)	Comprehensive data review	Statistical analysis	EU
3	Calvo et al. (2022)	Case study	Regression analysis	Chile
4	Chapman and Okushima (2019)	Case study	Quantitative	Japan
5	Dong et al. (2021)	Case study	Quantitative	China
6	Feenstra et al. (2021)	Case study	Qualitative	Netherlands
7	Guzowski et al. (2021)	Concept conceptualisation	Descriptive analysis	Latin America
8	Herington and Malakar (2016)	Concept conceptualisation	Qualitative	Nepal
9	Jiang et al. (2020)	Case study	Qualitative	Qinghai, China
10	Kerr et al. (2019)	Comparative case study	Qualitative	England, Ireland, France
11	Lowans et al. (2021)	Literature review	Content analysis	Conceptual
12	Nguyen et al. (2019)	Case study	Quantitative	Vietnam
13	Okushima (2019)	Case study	direct measurement approach	Japan
14	Primc et al. (2021)	Literature review	Content analysis	Conceptual
15	Siksnelyte-Butkiene et al. (2022)	Framework development	Bellagio STAMP	EU
16	Streimikiene et al. (2020)	Literature review	Content analysis	EU
17	Vondung and Thema (2019)	Comparative case study	Mix methods	EU

Table 11: Energy Poverty Literature Review - Measurement

#	Article	Measurement Type	Measurement Unit
1	Bajomi et al. (2021)	Multidimensional	Energy source mix, energy expenditure, areas of utility bills, access to gas of district heating, energy consumption, Cannot heat their home adequately, Heating method
2	Bouzarovski and Tirado Herrero (2017)	Multidimensional	Ability to keep home adequately warm, having arrears in utility bills, living in a home with a leaking roof, or the presence of damp and rot
3	Calvo et al. (2022)	Energy services	Use of traditional fuels
4	Chapman and Okushima (2019)	Multidimensional	Household income, Affordability of energy sources
5	Dong et al. (2021)	Energy expenditure	share of income spent for energy
6	Feenstra et al. (2021)	Multidimensional	
7	Guzowski et al. (2021)	Energy services	Access and quality of energy services
8	Herington and Malakar (2016)	Energy services	Access and quality of energy services
9	Jiang et al. (2020)	Energy expenditure	share of income spent for energy
10	Kerr et al. (2019)	Multidimensional	
11	Lowans et al. (2021)		Expenditure measures, self-reported measures, Direct measurement, which compares measured home energy use against standards.
12	Nguyen et al. (2019)	Energy expenditure	share of income spent for energy
13	Okushima (2019)	Multidimensional	Direct measurement - Fulfilment of energy services and affordability (price of electricity)
14	Primc et al. (2021)		
15	Siksnelyte-Butkiene et al. (2022)	Multidimensional	Economic, Social, Environmental

16	Streimikiene et al. (2020)	Multidimensional	Limited availability of energy supply, High energy prices and low income of households, Restrictions of choice of energy supply options, High energy losses, Discrepancies between energy needs and available energy services, Lack of knowledge and awareness
17	Vondung and Thema (2019)	Multidimensional	Expenditure-based metrics, Self-reported assessments of indoor housing conditions, Direct measurement of the level of energy services, Outcome-based metrics focus on outcomes associated with energy poverty e.g. disconnections, arrears, cold-related mortality

C Appendix. Policy mix Literature Review

C.1 Literature Search

The Policy mix literature reviewed in this study is acquired by query search in Scopus database, cross-referencing and finally through reference by the thesis supervisors. Two separated queries were executed. First, was narrow and intended weather the there is policy mix researched exploring the multi-governance dimension (Table 12). However it produce 12 results, hence a second query was formulated. As depicted on Table 12 it represented much broader search resulting in 58 results. At the end 34 article were selected for literature review (Table 13).

C.2 Content Analysis

The content of the selected articles was analysis using NVivo software. First, each article was coded automatically. First the theses in a article were identified and each paragraph was codded by paragraph according to these themes. This method is systematic and it does not rely on the focus and capability of the researcher as well as its bias. Nevertheless, it has several shortcomings. First, it is a black-box, researcher does not know how the themes are unidentified. Moreover, it can result in many themes that are formulated in a different way but refer to the same issue. For example, energy transition could be substituted with other terms such as sustainable or green transition which has the same meaning. Despite these shortfalls this method represent a fast way of identifying commonalities between the multiple articles.

After additional review based the automatic coding a manual codding was performed based on the following themes:

Table 12: Search Queries in Scopus

Query	Number of Results	Search within	Search Documents
First	12	Article Title, Abstract, Keywords	”multilevel policy mix” OR ”multilevel policy package”
			OR (”multi-level policy mix” OR ”multi-level policy package”)
			OR (”urban policy mix*” OR ”urban policy package*”)
			OR (”regional policy mix*” OR ”regional policy package*”)
			OR (”vertical policy mix*” OR ”vertical policy package*”)
Second	58	Article Title, Abstract, Keywords	”energy transition” OR ”green transition” OR ”sustainable transition” OR ”low-carbon transition”
			AND (”policy mix*” OR ”policy package*”)

C.3 Results

The results of the literature review are summarised in section

Table 13: Policy mix literature: Research Approach, Research Focus

#	Title	Reference	Research Approach	Research Focus
1	The institutional dimension of resource efficiency in a multi-level governance system	Bahn-Walkowiak and Wilts (2017)	Comparative case study	Policy mix design in a multi-level context
2	Carbon Pricing and Complementary Policies—Consistency of the Policy Mix for Decarbonizing Buildings in Germany	Braungardt et al. (2021)	Case study	Interactions of policy instruments
3	Governing dual objectives within single policy mixes: an empirical analysis of large carnivore policies in six European countries	de Boon et al. (2021)	Comparative case study	Policy mix characteristics
4	On evaluating success in complex policy mixes: the case of renewable energy support schemes	del Río (2014)	Framework conceptualization	Policy mix interactions
5	Why does the combination of the European Union Emissions Trading Scheme and a renewable energy target makes economic sense?	del Río (2017)	Case study	Policy mix evaluation
6	Network additionality and policy mix of regional and national public support for innovation	Douglas and Radicic (2020)	Case study	Multi-level policy mix
7	The co-evolution of policy mixes and socio-technical systems: Towards a conceptual framework of policy mix feedback in sustainability transitions	Edmondson et al. (2019)	Framework conceptualization	Policy mix dynamics
8	Policy mixes towards sustainability transition in the Italian biofuel sector: Dealing with alternative crisis scenarios	Falcone et al. (2017)	Case study	Policy mix evaluation
9	Reconceptualising the 'policy mix' for innovation	Flanagan et al. (2011)	Framework conceptualization	Policy mix framework
10	Mere deployment of renewables or industry formation, too? Exploring the role of advocacy communities for the Argentinean energy policy mix	Gomel and Rogge (2020)	Framework conceptualization	Policy process, policy learning
11	What is a policy instrument? Tools, mixes, and implementation styles	Howlett (2005)	Framework conceptualization	Instrument mix
12	Design Principles for Policy Mixes: Cohesion and Coherence in 'New Governance Arrangements'	Howlett and Rayner (2007)	Framework conceptualization	Coherence and consistency of the policy mix

13	The parameters of policy portfolios: verticality and horizontality in design spaces and their consequences for policy mix formulation	Howlett et al. (2015)	Framework conceptualization	Verticality and horizontality of the policy mix
14	Policy Integration and Multi-Level Governance: Dealing with the Vertical Dimension of Policy Mix Designs	Howlett et al. (2017)	Comparative case study	Verticality and horizontality of the policy mix
15	The verticality of policy mixes for sustainability transitions: A case study of solar water heating in China	Huang (2019)	Case study	Policy mix elements
16	Policy packaging or policy patching? The development of complex energy efficiency policy mixes	Kern et al. (2017)	Case study	Policy mix design
17	Policy mixes for sustainability transitions: New approaches and insights through bridging innovation and policy studies	Kern et al. (2019)	Literature review	Policy mix concept
18	Multilevel innovation policy mix: A closer look at state policies that augment the federal SBIR program	Lanahan and Feldman (2015)	Event history analyzes	Multilevel innovation policies
19	Do policy mix characteristics matter for electric vehicle adoption? A survey-based exploration	Li et al. (2020)	Case study	Relations between psychological factors, policy mix characteristics, and EV purchase intention
20	The EU Emissions Trading System and Renewable Energy Policies: Friends or Foes in the European Policy Mix?	Lindberg (2019)	Case study	Actors' policy preferences
21	Policy-mix evaluation: Governance challenges from new place-based innovation policies	Magro and Wilson (2019)	Framework conceptualization	Interaction between governance processes and policy mix evaluation
22	Energy and innovation policies fostering the emergence of regional wind energy industry. Multiple dimensions of the Spanish policy mix	Matti et al. (2017)	Case study	Policy learning, interaction, decision-making, design and implementation
23	Policy mixes for sustainability transitions: An extended concept andframework for analysis	Rogge and Reichardt (2016)	Framework conceptualization	Policy mix framework
24	Conceptual and empirical advances in analysing policy mixes for energy transitions	Rogge et al. (2017)	Literature review	Policy mix framework
25	What makes them believe in the low-carbon energy transition? Exploring corporate perceptions of the credibility of climate policy mixes	Rogge and Dütschke (2018)	Case study	Policy mix credibility

26	Do policy mix characteristics matter for low-carbon innovation? A survey-based exploration of renewable power generation technologies in Germany	Rogge and Schleich (2018)	Case study	Policy mix characteristics
27	Exploring the role of phase-out policies for low-carbon energy transitions: The case of the German Energiewende	Rogge et al. (2020)	Case study	Destabilization policies
28	The need for comprehensive and well targeted instrument mixes to stimulate energy transitions: The case of energy efficiency policy	Rosenow et al. (2017)	Comparative case study	Comprehensive of instrument mix

Table 14: Policy Mix Theoretical Framework Conceptualisation

#	Reference	Research Domain	Concept description	Advantages	Disadvantages
1	del Río (2014)	Sustainable tranisition	Evaluation of the success of complex policy mixes. Underlines role of the conflicts and synergies within the policy mix by defining what success is.	Useful for policy recommendation. Emphasis the vertical and horizontal dimension of the policy mix	The definition of success depends on the context. Does not take into account the policy processes.
2	Edmondson et al. (2019)	Innovation studies	Assessment of the dynamic between policy mix and socio-technical system, focusing on the processes	Provides insight on the policy processes within the dynamic context	Less attention to the policy instrument, characteristics and the vertical dimension.
3	Flanagan et al. (2011)	Innovation studies	Interactions, tensions and conflicts occurring across multiple dimension spaces	Integrates the multi-dimensional nature of the policy mix.	No much focus on the policy processes
4	Gomel and Rogge (2020)	Innovation studies	Impact of policy-making process on socio-technical change	Integrates the policy change in the policy mix concept.	Limited to policy processes
5	Howlett (2005)	Policy studies	Conceptualises Instruments mix and their design	Easy to apply	Narrow definition
6	Howlett and Rayner (2007)	Policy studies	Assessing the implementation of instrument mixes	Focuses on the design and implementation of the policy mix	Does not take into account the multiple dimensions.
7	Howlett et al. (2015)	Policy studies	Policy mix design	Underlines the complexity of the policy mix	Not useful to evaluation impact of the policy mix
8	Rogge and Reichardt (2016)	Innovation studies	Three building blocks: elements, processes and characteristics. Takes into account the multiple dimensions.	Broad definition	Difficult to apply

Table 15: Policy Mix Case Studies

#	Reference	Theoretical Framework	Case	Policy mix scope	Findings
1	Bahn-Walkowiak and Wilts (2017)	Rogge and Reichardt (2016)	Resource efficiency polices in 32 European countries	Characteristics, vertically, horizontally	Capability of the actors should be addressed
2	Braungardt et al. (2021)	Rogge and Reichardt (2016)	Carbonation of the building sector in Germany	Consistency of the policy mix	Underlines the importance of complementary policies
3	de Boon et al. (2021)	Rogge and Reichardt (2016)	Large carnivores policies in six European countries	Vertically, Horizontally, Characteristics and Processes	To achieve coherent, consistent and comprehensive policy mix needs systemic approach in stakeholder involvement, collaboration and addressing multiple objectives.
4	del Río (2017)	del Río (2014)	ETS and RE targets in the EU.	Policy instruments	Success of the policy instruments can be enhance by coordination and proper instrument choice and design.
5	Douglas and Radicic (2020)	(Flanagan et al., 2011)	Impact of regional and national funding on corporate relationships in Spain	Multi-level governance	Policy coordination could not lead to more synergies in policy mix due to the changing goals and rationals.
6	Falcone et al. (2017)	(Kivimaa & Virkamäki, 2014)	Bio-fuels sector in Italy	Instruments, processes	The effectiveness of the policy mix changes based on the context
7	Howlett et al. (2017)	Howlett et al. (2015)	Marine zones in Australia and coastal management in Europe	Multi-level governance	Broader and more consistent definition of policy mix concept is needed
8	Huang (2019)	Rogge and Reichardt (2016)	Solar water heating in China	Verticality, Strategies, instrument, characteristics.	More attention to the dynamic nature of the policy mix is needed and to the design of the policy mix.

9	Kern et al. (2017)	Howlett and Rayner (2007)	Energy efficiency in the EU	Policy instruments	Policy patching is more effective than creating new policy packages.
10	Lanahan and Feldman (2015)	Flanagan et al. (2011)	Federal SBIR program in the US	Multi-level governance	Research should focus on policy mixes across different political systems and policy areas.
11	Li et al. (2020)	Rogge and Reichardt (2016)	Electric vehicle sector in China	Policy mix characteristics	More objective indicators are needed to understand the policy mix characteristics
12	Lindberg (2019)	Rogge and Reichardt (2016)	ETS and RE Policies in the EU	Policy processes	Importance of understanding the policy preferences of the actors
13	Magro and Wilson (2019)	Rogge and Reichardt (2016)	Smart specialization, Basque Country in Spain	Policy mix evaluation, Policy dynamics, credibility and verticality	
14	Matti et al. (2017)	(Flanagan et al., 2011)	Wind energy in Spain	Multi-dimensional	Coordination mechanisms are needed to reduce the difference in preference between the levels of government.
15	Rogge and Dütschke (2018)	Rogge and Reichardt (2016)	Low-carbon transition, Germany	Credibility	Policy credibility is influenced by the coherence, constancy and comprehensiveness of the policy mix
16	Rogge and Schleich (2018)	Rogge and Reichardt (2016)	Low-carbon transition, Germany	Characteristics	More focus on the characteristics is needed
17	Rogge et al. (2020)	Rogge and Reichardt (2016)	Low-carbon transition, Germany	Credibility	Importance of destabilisation policy on credibility
18	Rosenow et al. (2017)	Rogge and Reichardt (2016)	EE policy in 14 EU countries	Instrument mix, comprehensiveness	Underlines the importance of a comprehensive instrument mix

D Appendix. Reviewed Documents

Table 16: Desk Research - Analysed Documents

#	Document	Name	Type	Found through
1	EC (2012)	Innovating for Sustainable Growth	Strategy	Cross-reference
2		A new EU Forest Strategy: for forests and the forest-based sector	Strategy	Cross-reference
3		Bioeconomy: the European way to use our natural resources	Action plan	Cross-reference
4	EC (2019a)	Clean energy for all Europeans	Strategy	Google Search / ec.europa.eu
5	EC (2019b)	The European Green Deal	Roadmap	Google Search / ec.europa.eu
6		Strategic Plan 2020-2024	Action Plan	Google Search / ec.europa.eu
7		New EU Forest Strategy for 2030	Strategy	Google Search / ec.europa.eu
8		Energy strategy of the Republic of Bulgaria till 2020 for Reliable, Efficient and Cleaner Energy	Action Plan	
9		National Renewable Energy Action Plan	Action Plan	
10		Third National Action Plan on Climate Change for the Period 2013-2020	Action Plan	
11		National Energy Efficiency Action Plan 2014-2020	Action Plan	
12		National Nearly Zero-Energy Building Plan 2015–2020	Action Plan	
13		Long-term National Strategy to Support the Renovation of the National Building Stock of Residential and Non-residential Buildings by 2050	long-term Strategy	
14		Integrated Energy and Climate Plan of the Republic of Bulgaria 2021–2030	Strategy	
15		National Climate Change Adaptation Strategy and Action Plan	Action Plan	
16		National Action Plan for Energy Development from Forest Wood Biomass 2018-2027	Action plan	
17		Action Plan for Sustainable Energy Development of Sofia Municipality 2012-2020		
18		Sustainable Energy and Climate Action Plan of Sofia Municipality 2021-2030		

19		Program for Atmospheric Air Quality Managementof of Sofia Municipality 2015-2020		
20		Program for promoting the use of energy from renewable sources and biofuels 2017-2019 of Sofia Municipality		
21		Short-term program to promote the use of energy from renewable energy sources and biofuels of Sofia Municipality 2020 - 2022		
22		Assessment of the final national energy and climate plan of Bulgaria		
23		Review of the National Air Pollution Control Programme – Bulgaria		
24	Andersen et al. (2021)	Biomass in the EU Green Deal: Towards consensus on sustainable use of biomass for EU bioenergy?	Policy report	Google Search
25	EC (2017)	Sustainable and optimal use of biomass for energy in the EU beyond 2020	Policy report	Google Search / ec.europa.eu
26	(Korteland et al., 2022)	Health-related social costs of air pollution due to residential heating and cooking	Report	Google Search

E Appendix. Interviews Summery

E.1 Interview protocol

This section presents two interview protocols, one for semi-structured exploratory interviews and one for validation interviews. The protocols are structured in a way to allow the interview to share as much information without the researcher specifically asking for it. And to help the researcher follow the flow of the conversation without missing to ask pre-defined questions.

E.1.1 Exploratory Interview

Q1: Hello, Thank you for agreeing to this interview. First, can you confirm that you have read the consent form and you agree with it?

A: I have not read it

R: *Reading the consent form*

A: I Agree

Q2: Thank you! What is your role in the organization you work for and what are the problems and projects you are working on?

* Issues raised by the interviewee (If the issues are connected to predefined questions start with these questions, if they are not, raise them at the end)

-
-
-

Q3: let's go to biomass energy. What policy there are addressing the energy from forest biomass?

* List of policies

-
-
-

Q4: What implications have these policies?

Q5: Which stakeholders have developed then and which are responsible for the implementation?

Q6: Is there coordination and cooperation between the various stakeholders, more specifically between the different levels of government?

Q7: Are the policies targeting a specific group?

Q8: What is the mechanism of monitoring the outcomes?

Q9: I want to look a bit more specifically at the forest biomass. Who is responsible for the biomass quality?

Q10: What factors influence the price of biomass?

Q11: How do the EU-level policies influence biomass production and biomass energy?

Q12: Now can we look a bit more specific on Sofia Municipality, How the Sofia Municipality is participating in the development of the energy transition policies to the extent you are familiar with?

Q13: How the Sofia Municipality is managing the implementation of the policies, more specifically the stove changing program?

Q14: How the Sofia Municipality is managing the implementation of the policies, more specifically the stove changing program?

Q15: What factors make people participate in this program?

* Additional questions about the stove changing program.
Q16: A few questions about the strategic document that exists on the topic. Who is producing the many action plans and strategies that exist?

Q17: How these strategies are coordinated between the different stakeholders?

Q18: What is the role of the Sustainable Energy Development Agency?

Q19: What is the involvement of the NGOs and academic organisations with policy development and implementation?

Q20: How does the National government participate in the decision-making on the EU and local level?

* Hereafter the question concerning energy poverty may not be used in all interviews

Q21: I would like to move to a few questions regarding energy poverty. What is your understanding of energy poverty?

Q22: Based on your understanding of energy poverty what are the factors that impact alleviating the energy poverty?

E.2 Interview Summary

E.2.1 Exploratory Interview 1 (EI1)

The first interview was conducted with a representative of an NGO that is assisting Sofia Municipality in Energy Transition issues but is operating separately from the Municipality. The Interview (I1) has underlined that the stove changing program is the only major policy of the municipality. Due to lack of capacity, many of the initiatives of the municipality are delayed in time or completely abandoned. Policy instruments such as the one-stop-shop and pellets manufacturing from waste wood are not even started despite being part of the policy plans for the last decade. I1 underline that the household does not participate in the stove changing program that does not have the resources to pay for the additional costs or is not aware of the benefits of the

program. An enhancing factor for the willingness to participate in the program is the existence of strong communities and knowledge of people that have to change their appliances and now are experiencing benefits.

Nevertheless, I1 raise the issue that the information campaign and community meeting are not fully utilized due to the lack of political will, administration capacity and motivation. The willingness to change heating appliances is also lessened by the riding price of the alternatives and the lower price of traditional fuels such as coal and wood. The price of the alternatives with exception of electricity has risen in the last year, whether due to increased demand, speculation or other factors. The ability to transfer to other heating sources is further deteriorated by the lack of district heating and natural gas networks. I1 elaborated that some of the households who change their appliances do not experience the full potential of the change to the low energy effeminacy of their homes. Another factor of not experiencing the full benefits is the risen costs which make families lower their heating consumption.

Finally, I3 make a key point of explaining that there is are low level of communication between the different stakeholder. Moreover, each ministry makes its only policy based on its objectives. Furthermore, the Municipally relays heavily on EU funds and generally cam administrative capacity to develop and implement policy mostly to staff shortage and finances.

E.2.2 Exploratory Interview 2 (EI2)

The second interviewee (I2) has worked on energy efficiency training projects and is involved in the monitoring of the municipality stove changing program as part of organisation working on energy poverty and energy efficiency issues. The energy efficiency training programs include social services and municipal staff as well as energy mentors and energy-poor households. The training of the public administration staff is intended to ride both awareness about the issues as well to increase the capability of the administration. While the objective of energy mentors is to train supporters who would visit energy-poor households and make them aware of the ways to improve their energy efficiency. I2 said that the municipal administration staff that participate in training and different initiatives seems to understand the problem but are overworked due to staff shortage.

I2 also describes the meeting with the households that have to change their stoves under the program. The many people participating in the program are not energy poor or socially poor. Moreover, likely many poor do not know who is in bigger need do not know about the program or do not know about the benefits of the program.

E.2.3 Exploratory Interview 3 (EI3)

The third interviewee (I3) is a government expert familiar with the biomass energy policy and has been participating in the development of The National Action plan for energy development from forest wood biomass. I3 provided insight on the objectives, stakeholders relations, biomass production and land use management.

First, according to I3, the objective of the EU, national and local policy is to encourage the use of sustainable biomass. Moreover, the use wood biomass should be used for heating energy due to its low efficiency in producing electricity. Furthermore, the wood biomass has to shift from round wood, used predominately by low-income households, to the use of low-quality waste wood products such as pellets. The pellets are the more effective and low moisture alternative to the round wood. I3 said that the old stove used for burning wood in the residential sector is very inefficient and represents a health risk for the dwellers. On the other hand, the pellets produced from low-quality waste wood are a much more safe alternative. However, I3 express concern that a lot of the pellets on the market are of low quality due to the increased demand, rising production cost and the inability of the state institutions to control the quality.

Second, the National Action plan for energy development from forest wood biomass is developed in cooperation with municipalities and other ministries as well NGO sector. However, as I3 pointed out the other ministries are involved but as much to wear their interest is considered. The Ministry of Environment and Water is interested in air quality while the Ministry of Energy in

the RE potential of the wood biomass. I3 stated that at the moment the government has no idea how much of the harvested wood is used for heating, while Bulgaria is reporting that 60% of all logging goes for heating there is no mechanism for monitoring that. Furthermore, the potential of sustainable logging is underutilized, although the majority of the forest in Bulgaria are state owed. I3 also pointed out that Bulgaria stands better than other EU countries regarding forest land use and logging because the Bulgarian forest is owned by the state with a low percentage being privately owned. Hence, the coming changes in the RES directive and other regulations would not have a significant effect on the land use and logging practices.

Finally, when asked about the price of biomass, I3 stated that the price is determined based on the market mechanism (demand-supply). And the demand outside Bulgaria could increase the price of biomass in the country. Nevertheless, I3 said that the forest is managed by National Enterprises that count intervene in providing affordable wood to the residential consumers. But that is not done for the other sectors.

E.2.4 Exploratory Interview 4 (EI4)

The fourth interview was with a person familiar with energy poverty and energy efficiency issues. The interviewee (I4) made several points that there is a lack of communication and coordination between the national and local policies and on the policies. This lack of communication and coordination exists between the ministries as well. I4 gave the example of the national EE program for a multistory building which includes only energy efficiency measures for the building, not anything else. On the stove changing programs are entirely in the domain of the Ministry of Environment and Waters and are concerning just the air quality. On the other hand, I4 explained that there is good communication between the NGOs regardless of their policy focus. And they are relying on EU financing, mostly the Horizon 2020 for developing training programs for the administration and energy-poor households.

I4 made the point the Sofia Municipality is unique with its sizes and that makes it difficult in managing it. Furthermore, I4 argued that the information campaigns are too limited due to the lack of political will and the administration capability but also the fact that they are done by firms which are offering the lowest financial offer in a public procurement. Further, I4 explained the lack of knowledge about the benefits of EE and RES programs in general. I4 explained that the pellets cost rise is due to demand-supply factors and it is not aware of low-quality pellets use for heating due to the rising heating costs of using them.

E.2.5 Exploratory Interview 5 (EI5)

The fifth interviewee (I5) is part of environmental NGOs working in the field of the energy transition on the National and local levels. I5 described the lack of communication on the part of the ministries with the municipalities, NGOs and academic sector. I5 gave an example of a short time for a reaction when opinions are sought for policy development. I5 also said that there is not enough knowledge about the benefit of the benefits of the energy transition. I5 underlined the lack of political will on the national and local levels.

F Appendix. Stakeholder Analysis

Table 17: Actors' Criticality

Actor	**Important resource**	**Replaceable?**	**Dependency: limited, average, high**	**Critical actor? Yes/no**
EC	Approves funding and adopt regulations and directives. Can impose financial sanctions if EU policy is not implemented.	No	High	Yes
EP	Approves funding and adopts regulations and directives.	No	High	Yes
Council of EU	Approve funding and adopt regulations and directives.	No	High	Yes
European Environmental Agency (EEA)	Knowledge about the development and implementation of environmental policy	Yes	Limited	No
EPOV	Knowledge about energy poverty measures and impacts	Yes	Limited	No
National Assembly	Adopts laws and implements EU directives. Approves financing	No	High	Yes
MRDI	Sets energy efficiency and construction standards and operates regional development funds	No	High	Yes
ME	Sets National Energy policy, National Energy Efficiency policy, and National Renewable Energy policy.	No	High	Yes
Sustainable Energy Development Agency (SEDA)	Controls Municipal sustainable climate and energy plans	Yes	Limited	No
MA	Operate the forests in Bulgaria thought regional companies	No	Average	Yes
EFA	Sets National Forest Biomass policy and controls forest exploitation.	No	Average	Yes
MEW	Sets national air quality policy and controls its implementation. Operates the Environment Operational Program. Develops and implements quality standouts for solid fuels	No	High	Yes
Executive Environment Agency (ExEA)y	Controls air quality and emissions	No	Average	Yes
MLSA	Provides energy assistance	No	Limited	No
Sofia Municipality (SM)	Sets Municipal policy and implements national and EU policy.	No	High	Yes
Biomass producers	Provides sustainable biomass for heating	Yes	Limited	No
Academic institutions	Knowledge about the biomass energy use and energy poverty	Yes	Yes	No

NGOs	Knowledge about the biomass energy use and energy poverty	Yes	Limited	No
Biomass energy users	Buy biomass and vote	Yes	Limited	No
Non-biomass energy users	Vote	Yes	Limited	No

Table 18: Actors' Problem Formulation

Actor	Interest	Objectives	Existing or expected situation and gap	Causes	Possible solutions
EC	Sustainable development for all EU citizens	• Reduce GHG emissions • Increase the share of RE • Increase EE • Protection of biodiversity • Improvement of Air Quality • Alleviate energy poverty	Unsustainable use of forest biomass. Only use of sustainably forest biomass for energy production.	Slow policy implementations. Desire of other stakeholders to utilise the full capacity of the forests. Lack of ability of households to pay for change of heating appliances	Implement more strict quality standards and Land use restrictions. Finance change of heating appliances

EP	Sustainable economic development for all EU citizens.	• Reduce GHG emissions • Increase the share of RE • Increase EE • Protection of biodiversity • Improvement of Air Quality • Alleviate energy poverty	Unsustainable use of forest biomass. Only use of sustainably forest biomass for energy production.	Slow policy implementations. Lack of ambition on the lower levels. Lack of ability of households to pay for change of heating appliances	Implement more strict quality standards. Finance change of heating appliances
Council of EU	Economic Development	Keep the competitiveness of the European economy	Manageable regulation on forest exploitation. Future increase in the land use regulation and forest exploitation	Need of reduction of emissions and protection of biodiversity	Slow the implementation of stricter regulations
EEA	Environmental protection	Reduce GHG emissions. Increase the share of renewable energy. Increase Energy efficiency. Protection of biodiversity. Improvement of Air Quality	Unsustainable use of forest biomass. Only use of sustainably forest biomass for energy production.	Slow policy implementations. Desire of other stakeholders to utilise the full capacity of the forests. Lack of ability of households to pay for change of heating appliances	Implement more strict quality standards and Land use restrictions. Finance change of heating appliances

EPOV	Energy poverty alleviation	Decrease people unable to adequately heat and cool themselves	A lot of people are unable to pay their energy bills and the same time heat or cool themselves properly. No people should experience energy poverty	lack if interest in energy poverty on national and municipal level	more active cooperation with NGOs and academic organisation on local and national level
National Assembly	Economic Development	Keep the competitiveness of the economy and increase economic growth	Existence of EE and RE laws but not fully align with European policy	Unstable political situation and lack of interest in energy transition.	Re-framing the narrative of energy transition
MRDI	Regional Development	Increase energy efficiency of the public and residential building	Low quality housing. Need of substantial public and private investment to improve EE	Lack of resources and administrative capacity	Implement more training and reforms. EE program
ME	Reduce energy dependency and providing sustainable energy supply	Increase the share of RE and EE of the economy	slow paste of RE increase and EE. Need more production of RE in combination with EE	Cheap energy sources	Incentives for switching to sustainable energy sources. Regulation to increase the price of fossil fuels. Financial assistance.
SEDA	Sustainable energy	Increase of energy Efficiency and renewable energy	Slow development of municipal energy plans and with low quality	lack of administrative capacity on local level	Training programs for municipal administration
MA	Protection and development of forests biodiversity and sustainable use of the forests. Providing wood for the citizens	Increase sustainable use of the forests. Provide affordable wood supply	Cheap wood but need to reduce the use of firewood. How to reduce the use of wood without loosing popularity	Lack of economic ability of population to switch appliance	program to switch appliances

EFA	Protection and development of forests biodiversity and sustainable use of the forests	Increase sustainable use of the forests.	Large use of fire wood. Need for sustainable use of wood for heating	Lack of economic ability of population to switch appliance	program to switch appliances
MEW	Clean and sustainable environment	Improve air quality and reduce emissions	Law air quality due to wood burning	Lack of economic ability of population to switch appliance	program to switch appliances
ExEA	Clean and sustainable environment	Improve air quality and reduce emissions	Use of low efficient burners	difficult to control	more resources for control on heating appliances
MLSA	Quality life of Bulgarian citizens	Decrease in number of households which cannot heat themselves	Not all in need reserve heat assistance. All people who need assistance should have it	lack of resources	Reform in energy assistance program
SM	Good living condition for the Sofia citizens	Improve air quality, increase RE and EE in the municipality	Low air quality, lack of increase in RE and EE	No incentives	Program to switch appliances
Biomass producers	Company growth	Increase of profits	Relatively low standards. Expected increase in standards. How to keep competitive with high standards	Need to improve air pollution	Promote the qualities of the sustainable biomass
Academic institutions	Sustainable development	Develop technology and acquire knowledge about energy transition			
NGOs	Sustainable development	Promote the use of sustainable energy and energy transition without social cost	Mot much public awareness and involvement	No communication	More campaigns

Biomass energy users	Good life	Decrease in energy expenditure	Cheap but inefficient biomass, expensive to change heating appliance. Expensive alternative	Low income	vote for people promising cheap energy
Non-biomass energy users	Good life	Decrease in energy expenditure	Cheap electricity, unpredictable price of natural gas. Expected rise in electricity price. Difficult to switch to other appliance	Low income	vote for people promising cheap energy

G Appendix. CLD

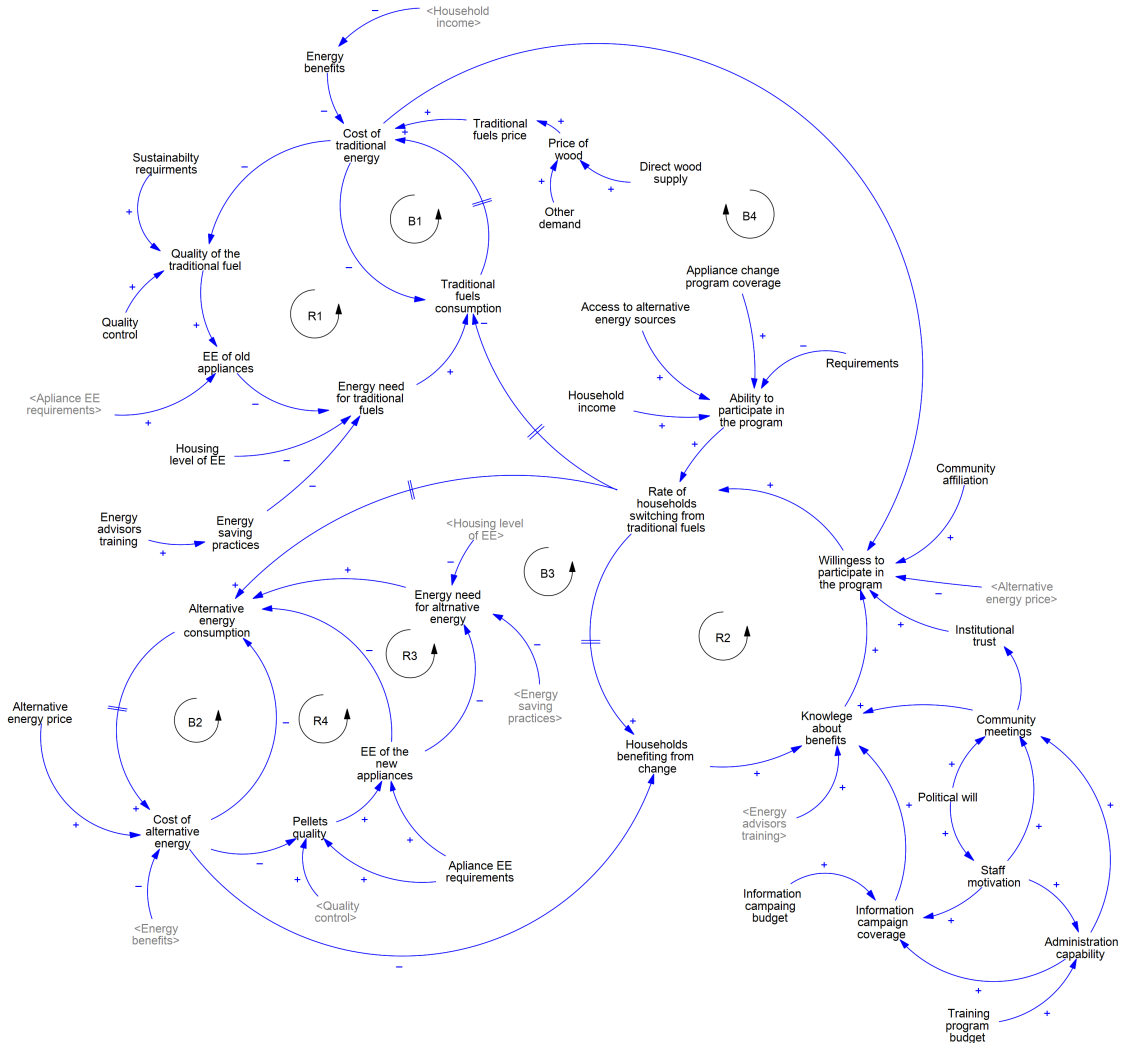

Figure 23: CLD used for the validation interviews

Table 19: Factor relations

#	Cause	Effect	Relation	Interview citation	Document source
1	Sustainability requirements enforcement	Quality of the traditional fuel	positive	"also have certain problems with the reporting of this wood for burning, ... , all this wood in the Firewood category is given as burned, but de facto it is not all burned wood" - I3; "European regulations difinne how much the moisture in the wood should be. But we have dificulty to control this." - I3; "... in Bulgaria they still consider firewood to be biomass and when they report to Europe they say that you see a lot of biomass. We use but these are firewood that burns with 45 percent efficiency..."- I4	
2	Sustainability requirements	Quality of the traditional fuel	positive	"European regulations difinne how much the moisture in the wood should be. But we have dificulty to control this." - I3;	
3	Cost of traditional energy	Quality of the traditional fuel	negative	"The wet wood costs less than the dry. You do not need to keep it storage to dry. " - I1 ; "Socially weak or energy-poor families. .... in fact they give them some help, they give them 300 400 levs which are actually used to buy wet coal and wet wood and only make them sick and sick everyone around." - I5	
4	Quality of the traditional fuel	Air quality	positive	"The problem there (rural areas) is that they are heated on very low efficiency stoves, which means they get little energy from burning wood. Then they emit a lot of moisture a lot of smoke a lot of carbon dioxide" - I3; "Socially weak or energy-poor families. .... in fact they give them some help, they give them 300 400 levs which are actually used to buy wet coal and wet wood and only make them sick and sick everyone around." - I5	
5	Quality of the traditional fuel	EE of old appliances	positive	"Socially weak or energy-poor families. .... in fact they give them some help, they give them 300 400 levs which are actually used to buy wet coal and wet wood and only make them sick and sick everyone around." - I5	

6	Appliance EE requirements	EE of old appliances	positive	”. . . there are already European criteria for the quality of these stoves to burn wood and in fact manufacturers must meet certain criteria for theirs” - I3
7	EE of old appliances	Energy need for traditional fuels	negative	”The problem there (rural areas) is that they are heated on very low efficiency stoves, which means they get little energy from burning wood. Then they emit a lot of moisture a lot of smoke a lot of carbon dioxide” - I3;
8	Energy saving practices	Energy need for traditional fuels	negative	”... these are people who are committed to their energy efficiency. . . families for which it is clear that the family household does not have much money. But they are investing extremely smartly to control their consumption” - I2; ”We give advice on how to take some measures to reduce bills and increase comfort. These measures range from soft measures or the simplest things to very complex expensive measures such as replacing an installation, then replacing windows, replacing insulation, replacing installations, and so on” - I2;
9	Housing level of EE	Energy need for traditional fuels	negative	”It is undoubtedly home renovation because it leads to a reduction in consumption” - I1; ”We made a very small base of 24 apartments, we put the devices for measuring the hourly energy consumption of room temperature, etc. And so on. And we showed a real but still very small sample what is the effect of one a well-insulated dwelling or a poorly insulated dwelling” - I4
10	Energy need for traditional fuels	Traditional fuels consumption	positive	”It currently provides about BGN 450 in cash for the season for vulnerable households, as they are called,... including firewood, they provide extra for the elderly or other households at a minimum wage...” - I1; ”The wet wood costs less than the dry. You do not need to keep it storage to dry. ” - I1 ; ”Socially weak or energy-poor families. . . . . in fact they give them some help, they give them 300 400 levs which are actually used to buy wet coal and wet wood and only make them sick and sick everyone around.” - I5

11	Households using traditional fuels	Traditional fuels consumption	positive	”The problem there (rural areas) is that they are heated on very low efficiency stoves, which means they get little energy from burning wood. Then they emit a lot of moisture a lot of smoke a lot of carbon dioxide” - I3;
12	Traditional fuels consumption	Air quality	negative	”The problem there (rural areas) is that they are heated on very low efficiency stoves, which means they get little energy from burning wood. Then they emit a lot of moisture a lot of smoke a lot of carbon dioxide” - I3; ”The problem there (rural areas) is that they are heated on very low efficiency stoves, which means they get little energy from burning wood. Then they emit a lot of moisture a lot of smoke a lot of carbon dioxide” - I3; ”Socially weak or energy-poor families. .... in fact they give them some help, they give them 300 400 levs which are actually used to buy wet coal and wet wood and only make them sick and sick everyone around.” - I5
13	Traditional fuels consumption	Cost of traditional energy	balancing effect with deley (B1)	”It currently provides about BGN 450 in cash for the season for vulnerable households, as they are called,... including firewood, they provide extra for the elderly or other households at a minimum wage...” - I1; ”The wet wood costs less than the dry. You do not need to keep it storage to dry. ” - I1 ; ”Socially weak or energy-poor families. .... in fact they give them some help, they give them 300 400 levs which are actually used to buy wet coal and wet wood and only make them sick and sick everyone around.” - I5
14	Energy benefits	Cost of traditional energy	negative	”It currently provides about BGN 450 in cash for the season for vulnerable households, as they are called,... including firewood, they provide extra for the elderly or other households at a minimum wage...” - I1; ”The wet wood costs less than the dry. You do not need to keep it storage to dry. ” - I1 ; ”Socially weak or energy-poor families. .... in fact they give them some help, they give them 300 400 levs which are actually used to buy wet coal and wet wood and only make them sick and sick everyone around.” - I5

15	Traditional fuels price	Cost of traditional energy	positive	"The problem there (rural areas) is that they are heated on very low efficiency stoves, which means they get little energy from burning wood. Then they emit a lot of moisture a lot of smoke a lot of carbon dioxide" - I3; "The problem there (rural areas) is that they are heated on very low efficiency stoves, which means they get little energy from burning wood. Then they emit a lot of moisture a lot of smoke a lot of carbon dioxide" - I3; "Socially weak or energy-poor families. .... in fact they give them some help, they give them 300 400 levs which are actually used to buy wet coal and wet wood and only make them sick and sick everyone around." - I5
16	External demand	Traditional fuels price	positive	"... state-owned enterprises that operate on a purely market basis. ... This is somewhat protected by a state veto ... there were periods when this wood is exported, for example, to Romania or Greece because they gave a higher price and at some point preferences need to be made for the local population" - I3
17	Direct wood supply	Traditional fuels price	negative	"... state-owned enterprises that operate on a purely market basis. ... This is somewhat protected by a state veto ... there were periods when this wood is exported, for example, to Romania or Greece because they gave a higher price and at some point preferences need to be made for the local population" - I3
18	Household income	Energy benefits	negative	"It currently provides about BGN 450 in cash for the season for vulnerable households, as they are called,... including firewood, they provide extra for the elderly or other households at a minimum wage..." - I1

19	Access to alternative energy sources	Willingness to participate in the program	positive	”You want natural gas. But we don’t have gas everywhere, for example, there is natural gas in the so-called southern regions, the South Arc. In other part in the north almost none... while biomass is everywhere even and in the center of Sofia.... But you have to keep in mind that 70% of Sofia is district heating. - I1; ”Some who do not want to heat with pellets. They say you are forcing us to insert pellets again. We want natural gas. But we don’t have Gas everywhere So on we make one such card which.” - I1;
20	Community affiliation	Willingness to participate in the program	positive	”Roma community for example in Botev has a lot of participation. Once the rumor started about the program they organized and there is a community center which help them to apply” - I1; ”district’s Facebook groups helped the district administrations a lot. In the villages also remained so and mayors who are more active in
21	Alternative energy price	Willingness to participate in the program	negative	”due to the rise in price of natural gas there is no big interest at the moment, although there are contracts with households to replace.” - I1
22	Cost of traditional energy	Willingness to participate in the program	positive	”Coal have become more expensive because are imported from Ukraine. This, in the end, turned out to be still wood it ’s the cheapest, as well air conditioners. Because the price of electricity is maintained low.” - I1; ”At a time when pellets have become more expensive, I guess many people would go back to the woods after being energy-poor after doubling their costs. So it is debatable to me how useful this is as a long-term solution to the problem.” - I4;
23	Institutional trust	Willingness to participate in the program	positive	”They actually reduce electricity bills by 40%. That’s it. That’s actually the huge advantage. The point is that here we have to overcome for years, as I explained to you in the media, a mistrust deliberately created that this is expensive and that is, in fact” - I5;
24	Awareness about benefits	Willingness to participate in the program	positive	”It turned out that not all of these people who have applied for this project have any idea what the benefits of the new device will be” - I2

25	Willingness to participate in the program	Rate of households switching from traditional fuels	positive	I2
26	Rate of households switching from traditional fuels	Households benefiting from new appliance	positive	I1
27	Households benefiting from new appliance	Awareness about benefits	positive	I2,I1,I5
28	Energy advisors training	Awareness about benefits	positive	I2
29	Information campaign coverage	Awareness about benefits	positive	I1, I2
30	Information campaign budget	Information campaign coverage	positive	I1, I2, I4
31	Administration capability	Information campaign coverage	positive	”district’s Facebook groups helped the district administrations a lot. In the villages also remained so and mayors who are more active in smaller villages.” - I1; ”Of course, the municipal administration is well aware that these are extremely important issues. My impression is that they just don’t have enough hours but they don’t have enough people to be able to work more focused.” - I2

32	Administration capability	Community meetings	positive	"district's Facebook groups helped the district administrations a lot. In the villages also remained so and mayors who are more active in smaller villages." - I1 "Of course, the municipal administration is well aware that these are extremely important issues. My impression is that they just don't have enough hours but they don't have enough people to be able to work more focused." - I2
33	Staff training budget	Administration capability	positive	Direction of capacity building in employees if you will. There are no employees in the small municipalities and the people in charge of European projects say so. He is responsible for energy efficiency, he is responsible for the environment, he is responsible for changing stoves and so on. One person or two or three team up. Speaker1: They torment when they can. Speaker2: And very often there are others I have seen who have a stake in the training of the administration. Precisely in relation to the Energy Efficiency or Renewable Energy Pact. This training m3 represents what it consists of or is just a proforma. Speaker3: We have also done such trainings. It was also funded by the so-called Norwegian European Economic Area program. The idea was to increase the capacity of the employees, but from then on they still need resources from people. You need teams to absorb millions. These teams need to be trained to pass the time if you are going to be confused to gain experience in order to become good in the end. That is why a lot of unspent funds remain. There is also construction in Sofia, they can't help but organize it. Come on, the procedures are complicated, everything is complicated, but in the end huge funds remain unspent due to lack.
34	Staff motivation	Administration capability	positive	I1, I2, I4

35	Political will	Staff motivation	positive	I1, I2, I4
36	Political will	Community meetings	positive	"district's Facebook groups helped the district administrations a lot. In the villages also remained so and mayors who are more active in smaller villages." - I1;
37	Community meetings	Institutional trust	positive	"district's Facebook groups helped the district administrations a lot. In the villages also remained so and mayors who are more active in smaller villages." - I1; "Of course, the municipal administration is well aware that these are extremely important
38	Ability to participate in the program	Rate of households switching from traditional fuels	positive	I1, I2
39	Co-financing amount	Ability to participate in the program	negative	I1, I2
40	Administrative requirements for receiving subsidy	Ability to participate in the program	negative	I1, I2
41	Types of subsidised appliances	Ability to participate in the program	positive	I1
42	Appliance EE requirements	Types of subsidised appliances	negative	"Natural gas for replacement of appliances will not be allowed for a year and in practice the use of pellet heating remains. And district heating remains somewhat as an option central heating and heat pumps in the form of air conditioners and systems as there again we go to more large sums of funding" - I1

43	Sustainability requirements	Types of subsidised appliances	negative	"Natural gas for replacement of appliances will not be allowed for a year and in practice the use of pellet heating remains. And district heating remains somewhat as an option central heating and heat pumps in the form of air conditioners and systems as there again we go to more large sums of funding" - I1
44	Rate of households switching from traditional fuels	Households using traditional fuels	negative	I3
45	Rate of households switching from traditional fuels	Alternative energy consumption	positive	I1
46	Alternative energy consumption	Cost of alternative energy	balancing effect with delay (B2)	I1
47	Energy benefits	Cost of alternative energy	negative	I1
48	Alternative energy price	Cost of alternative energy	positive	"... the main thing is increased demand, including the export of pellets, with everything just like natural gas ... supply Is limited and speculation. It is alleged that large quantities were bought, hidden and then released at a higher price. And of course. There is also a known factor with reduced logging" - I1
49	Cost of alternative energy	Households benefiting from new appliance	negative	I1, I2, I3,I5
50	Energy need for alternative energy	Alternative energy consumption	positive	I2

51	Housing level of EE	Energy need for alternative energy	negative	”It is undoubtedly home renovation because it leads to a reduction in consumption” - I1; ”We made a very small base of 24 apartments, we put the devices for measuring the hourly energy consumption of room temperature, etc. And so on. And we showed a real but still very small sample what is the effect of one a well-insulated dwelling or a poorly insulated dwelling” - I4
52	Energy saving practices	Energy need for alternative energy	negative	I2
53	EE of the new appliances	Energy need for alternative energy ’	negative	
54	Appliance EE requirements	EE of the new appliances	positive	”... there are already European criteria for the quality of these stoves to burn wood and in fact manufacturers must meet certain criteria for theirs” - I3

G.1 Validation Interviews

G.1.1 Validation Interview Protocol

Q1: Hello, Thank you for agreeing to this interview. First, can you confirm that you have read the consent form and you agree with it?

A: I have not read it

R: *Reading the consent form*

A: I Agree

Q2: Thank you! The goal of this interview is to validate the causal relations that I have found. So I will ask you specific question that you can agree or disagree. But first let me give some context of the problem. I am interest of a causality exist between two factors and what is the nature of the causality, positive or negative and not if that is the most influential factor. Do you understands?

- More explanation about CLD, System Dynamic and assumptions made in the model

Q3: Let me show me the causal loop diagram that I have developed (Show Figure 23). - Continue wit question regrading each causal relation

Q4: Is there anything you see that does not make sense to you? If Yes, what is it?

Thank you vary much for the interview!

G.1.2 Validation Interview 1 (VI1)

The first validation interview was conducted with a person who monitors an appliance change program in Sofia and other municipalities. VI1 confirmed the causal relation between the Ability to participate in the program and the willingness to change appliances. However, VI1 underlies that does not have knowledge about how the price of the firewood and the other energy sources is formed. The issue the VI1 had with the CLD was in connection to the quality of the pellets. According to VI1 in short term, a household can switch to low-quality pellets but the technology of the pellets burners does not allow the use of low-quality pellets and that lead to high maintenance cost for the households. So the use of low-quality pellets is limited by the technology of the appliances. VI1 also explained that the goal of the program is to improve air quality and hence, for the most part, the households are experiencing an increase in costs.

G.1.3 Validation Interview 2 (VI2)

The second validation interview was with an NGO expert familiar with wood and pellets markets and quality standards. VI2 comments were in connection to that how the piece of energy source was formulated in the model. VI2 noted that the wood price is formed based on demand and supply and that domestic consumption should play role in it. Nonetheless, domestic consumption according to VI2 plays a little role due to speculations in the market and demand from the neighbouring countries. The same can be said for the pellets market as well.

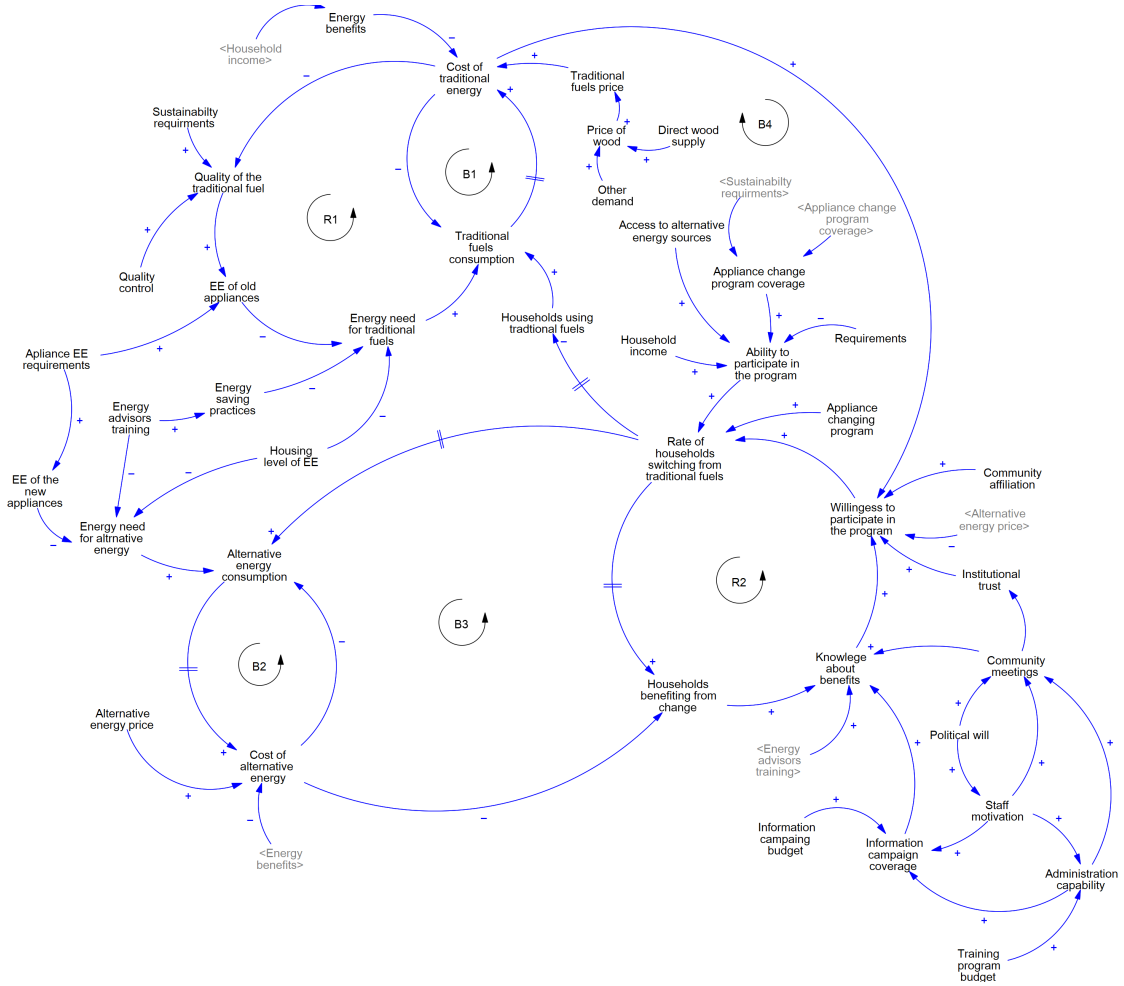

Figure 24: Validated CLD