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SPES Focus - Work Package #5
Mapping the policy mix in Europe: the case of energy efficiency in the residential sector

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Disclaimer

This SPES Focus for the project SPES has been prepared by Université de Bordeaux, as an additional working paper for Work Package #5. This task has allowed SPES research partners to map the policy mix in Europe focusing on the case of energy efficiency in the residential sector. This work provides useful evidence on policy related task among the Consortium members. This deliverable contains original unpublished work except where clearly indicated otherwise. Acknowledgement of previously published material and of the work of others has been made through appropriate citation, quotation or both. The information and views set out in this report are those of the authors and do not necessarily reflect the official opinion of the Commission. Neither the Commission nor any person acting on the Commission's behalf may be held responsible for the use which may be made of the information contained therein. The project SPES is funded by European Union's Horizon Europe Programme under Grant Agreement No. 101094551.

Contents

Abstract

In light of the growing urgency of climate change and the subsequent socio-economic implications, the development and adoption of eco-innovation represents a potential solution. Nevertheless, the success of this endeavor may be contingent upon the implementation of well-designed policies. The design of national policy mixes can provide insights to understand the extent and significance of the efforts devoted to eco-innovation. This report presents two main descriptive observations. First, the European environmental policy landscape is examined, revealing the dispersion of heterogeneous information across four major environmental policy databases. Second, the report employs a fuzzy matching approach to consolidate data on national policy mixes in the residential energy efficiency sector. The results of the principal component analysis demonstrate a notable degree of heterogeneity in policy mix design across European countries. Comprehensive policy mixes often seek to achieve a balance between strong technology-push and demand-pull measures, while soft and systemic instruments are less prominent. An analysis of the sequencing of policy instruments reveals that a number of leading countries tend to favour either technology-push measures or demand-pull measures, predominantly. Nevertheless, the anticipated shift from a technology-push to a demand-pull orientation is not corroborated by the evidence. The report highlights the necessity for consolidated policy data related to sustainability transitions as a prerequisite for evaluating the impacts of policy mix on eco-innovation.

1. Introduction

The SPES project provides a Sustainable Human Development vision within the context of sustainability transitions. Specifically, the project seeks to promote policy interventions that reconcile productivity enhancement and value-generation with inclusiveness and environmental protection, aiming to achieve shared prosperity and human flourishing (Biggeri et al., 2023).[1] The SPES-specific pillars are:

1. **Productivity**, defined as the efficient use of economic, human, and natural resources for the provision of goods and services, expanding human capabilities and increasing the standards of living for all.

2. **Equity**, defined as ensuring equitable access to economic, political, social, and cultural opportunities for all.

3. **Environmental sustainability**, defined as the practice of responsibly managing and preserving natural resources and ecosystems, ensuring a balance between current and future well-being.

4. **Participation & empowerment**, defined as enabling individuals and communities to be active agents of their own future by ensuring a level playing field for the societal engagement of citizens and stakeholders.

5. **Human security**, defined as the sum of capabilities "freedom from want, freedom from fear, and freedom to live with dignity."

Productivity and environmental sustainability pillars are both important dimensions of eco-innovation and a potential outcome of policy.[2] On one hand, eco-innovations should lead to environmental benefits (OECD, 2009); on the other hand, they are expected to enhance long-term productivity gains (Lanoie et al., 2011; Porter and Linde, 1995). However, without well-designed policies, eco-innovations are unlikely to develop or be adopted (Kemp and Pontoglio, 2011). An exten-

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[1] The SPES framework bridges the 2030 Agenda's 5 Ps for Sustainable Development with the five pillars of Sustainable Human Development.The 2030 Agenda's 5 Ps include People, Prosperity, Planet, Partnership, and Peace. The five pillars of Sustainable Human Development encompass productivity, equity, sustainability, empowerment, and human security (the last one newly included through the SPES framework).

[2] The most generalized definition of eco-innovation (or environmental innovation) is the "production, assimilation or exploitation of a product, production process, service or management or business methods that is novel to the firm [or organization] and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives" (Kemp and Pearson, 2007).

sive body of literature highlights the role of policy mix for eco-innovations.[3] Such a policy mix is expected to influence the rate of R&D activities and adoption of eco-innovations (e.g Nemet, 2009), the type of eco-innovation (e.g., product or process), and the direction (which technologies are targeted) (e.g. Schmidt et al., 2012). A comprehensive policy mix addresses the dynamic, multi-level nature of innovation processes (Geels, 2002; Rogge and Reichardt, 2016), by providing diverse instruments at various stages of maturity (e.g. Costantini et al., 2015).

A coherent policy mix sequence seems to be crucial for stimulating eco-innovations, as different instruments target various mechanisms and stages of the innovation process. Typically, the expected sequence starts with an initial push on the technology side to stimulate early-stage innovation, followed by a demand-pull orientation to support the demand side and market creation at a certain stage of maturity (e.g. Costantini et al., 2015; Hoppmann et al., 2013; Nemet, 2009). If necessary, new or enhanced complementary institutions will accompany these distinct phases. However, not all countries follow this sequence. Given the variation in national policy mixes, it is essential to analyze and characterize policy mixes across Europe before evaluating their impact on eco-innovation. This requires databases to identify the number and type of instruments as well as other design features of policy mixes. Building on these premises, the present report has two main objectives:

- To map the policy mix in various European countries using four major public databases: IEA Policy, EEA Policies and Measures, MURE, and STI Policies. The databases offer information on environmental policy instruments, but there are some differences between them. In order to operationalize policy mixes, a data consolidation stage is a requisite step in the process. The report presents a descriptive analysis of the extent to which the databases in question exhibit common elements, including structure, scope, content, and instrument taxonomy.

- To characterize the policy mix using indicators, with the residential energy efficiency sector in Europe as a case study. Following the consolidation of data using a fuzzy matching method, a series of indicators are calculated to identify the orientation of a country's policy mix with regard to stimulating demand or supply of eco-innovations, the balance and completeness of the mix, and the sequence adopted over time.

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[3] Various definitions of policy mix exist, with the simplest emphasizing the number and combination of policy instruments (Rogge et al., 2017).

The energy efficiency sector provides an appropriate case study for the application of the policy mix indicators.[4] Indeed, the pursuit of energy efficiency serves to orient eco-innovation and represents a core component of the three pillars of the EU 2030 Climate and Energy Strategy (IEA, 2014). The residential energy efficiency sector is of particular importance in the context of sustainability transition challenges for two main reasons. First, it is a priority area for the EU, as evidenced by the European Commission directives, including the Energy Performance of Buildings Directive (EPBD) (2002)[5] and the Energy Efficiency Directive (EED) (2012)[6] . Both of these directives have undergone revisions over time. The EPBD (2002) establishes requirements for calculating energy performance, setting minimum building standards, and promoting renewable energy and smart buildings (Royal Institution of Chartered Surveyors, 2024). The EED (2012) has the objective of reducing energy consumption by 20% by 2020 through the implementation of energy-saving schemes and the setting of national targets (IEA, 2023). The transposition of these directives into national legislation allows for the identification of specific policy mixes tailored to the needs of each country.

Second, the enhancement of residential energy efficiency is aligned with the SPES framework, particularly in regard to the productivity and environmental sustainability pillars. Other pillars may be concerned, such as the equity pillar. Energy efficiency policies have the potential to stimulate job creation in the construction sector, which could benefit small and medium-sized enterprises (SMEs) that contribute approximately 9% to Europe's GDP and employ nearly 25 million people (European Commission, 2024). Furthermore, energy efficiency has been shown to stimulate innovation, with a 10% increase in global patent activity for clean energy technologies over the past 20 years (IEA, 2022). Such examples include the utilisation of advanced technologies, such as smart thermostats and a new generation of heat pumps. In terms of the sustainability transitions pillar, residential energy efficiency is crucial for reducing GHG emissions and mitigating climate change. As stated in the IPCC Special Report (2019), end-use energy efficiency technology represents one of the most cost-effective strategies for reducing GHG emissions and stabilizing the temperature increase at 1.5°C by the end of the century. Since 1990, the European residential sector has undergone a substantial reduction in its carbon footprint, largely due to increased R&D investments and the adoption of energy-efficient technologies (ODYSSEE-MURE, 2015). In 2020, the residential sector accounted for 35% of total energy-related GHG emissions, underscoring its significant potential for cost-effective mitigation (EEA, 2024). Additionally, energy efficiency in the residential sector promotes social inclusion and equity by mitigating energy poverty. Energy efficiency in older homes improves living conditions by addressing poor insula-

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[4] Energy efficiency can be simply defined as the use of less energy to perform the same task or produce the same result (U.S. Department of Energy, 2024).

[5] https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en

[6] https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficiency-targets-directive-and-rules/energy-efficiency-directive_en

tion and inadequate heating and cooling systems (Bank, 2019; EC, 2024), reducing energy bills and benefiting low-income families. Since 2000, such technologies have increased household savings by 1.8% annually across the EU (ODYSSEE-MURE, 2015).

These factors render the examination of energy efficiency in the residential sector an intriguing case study, particularly concerning the relationships between eco-innovation, the policy mix, productivity and environmental sustainability.

Our analysis confirms the necessity for the consolidation of data pertaining to policies that offer support for sustainability transitions. This would facilitate the development of new measures for the analysis and evaluation of national policy mixes. Furthermore, the characterisation of policy mixes for residential energy efficiency measures provides interesting results. While the European Commission mandates member states to transpose directives into national plans and instruments, each country designs and implements a customised policy mix. This heterogeneity is also evident in the sequencing of policy instruments. The leading countries tend to favour either technology-push measures or demand-pull measures, predominantly. However, the expected shift from technology-push to demand-pull orientation is not evident. Furthermore, soft and systemic measures appear underrepresented in current policy mixes. The comprehensiveness and balance of instrument types in a given policy mix provide insights for developing policy strategies to address potential deficiencies in existing mixes.

The report is structured into four distinct sections. The first section presents a literature review on the policy mix framework and its empirical developments. The second section addresses the methodological challenges associated with evaluating the policy mix, with a particular focus on the comparison of data sources. This results in the presentation of a descriptive analysis of the four policy databases and the proposal of a fuzzy matching approach to consolidate the data. This methodology is then applied to the case of energy efficiency in the residential sector, with the objective of characterising the policy mix orientation for each European country. The third section presents the case study results and examines policy mix orientations, the balance between these orientations, and the different country profiles regarding comprehensiveness, using principal component analysis. By examining data from two points in time (2007 and 2017), it is possible to observe how the orientation of policy mixes among EU nations has evolved with their comprehensiveness. The fourth section concludes the report.

2. Literature review

The Porter Hypothesis (Porter and Linde, 1995) lies at the heart of our understanding of how to consider economic and environmental performance simultaneously. Porter's main argument is that well-designed regulation can enhance competitiveness by stimulating the search for new, profitable opportunities through eco-innovation (Kemp and Pontoglio, 2011). Regulatory stringency is known to play a crucial role in promoting eco-innovation (e.g. Barbieri et al., 2016; Porter and Linde, 1995). However, the urgent need to accelerate the diffusion of eco-innovations raises considerations on the assessment of other policy characteristics, such as the timing, flexibility, and predictability of the instrument (Kemp and Pontoglio, 2011). In this context, quantitative metrics are being developed to assess not only individual instruments, but the 'mix of policies' (e.g. Mavrot et al., 2019; Rogge and Schleich, 2018).

The policy mix concept has emerged as a promising framework for implementing, understanding, and evaluating policies that promote eco-innovations. The policy mix has been developed through interdisciplinary scientific contributions, including those from innovation studies and political science (Rogge et al., 2017), driven by the imperative to address transformative system change. One of the main challenges in assessing the policy mix stems from its multi-element and multi-dimensional nature, which has been studied in different fields, resulting in diverse terminologies.

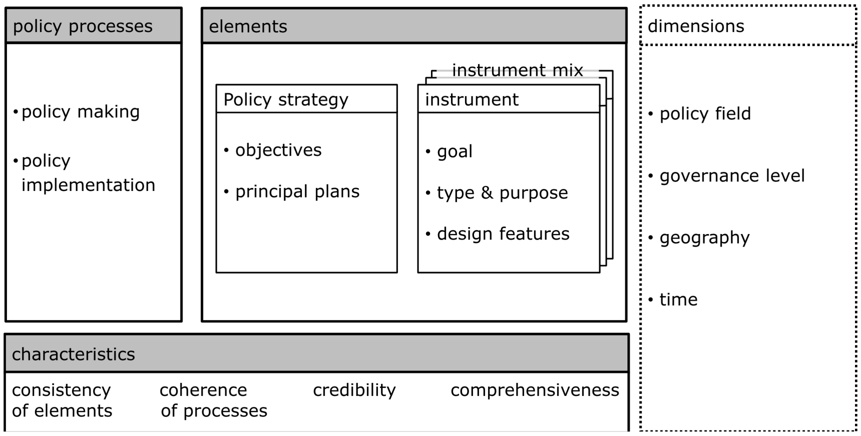

Figure 2.1: *Policy mix for sustainability transitions framework*
(Rogge and Reichardt, 2016, p. 1629)

Rogge and Reichardt (2016) proposed a first comprehensive conceptual framework of the policy mix for sustainability transitions (see Figure 1), comprising three main blocks: (1) the mix of policy instruments and the policy strategy; (2) the policy processes related to the stages of policy making and policy implementation; and (3) the characteristics used to evaluate the overall policy mix.

However, previous studies have mainly focused on developing indicators at the instrument level.[7] Specifically, several attempts have been made to assess individual instruments focusing on two key components: design features (stringency, compliance deadlines, long-term commitment) and type (command and control vs economic vs voluntary agreements) (e.g. Kemp and Pontoglio, 2011).

Studies on design features for sustainability transitions emphasize that stringent environmental policies enhance innovation and productivity (e.g. Albrizio et al., 2017; Ambec et al., 2013; Dechezleprêtre and Sato, 2017). Various indicators of environmental policy stringency have been proposed in the literature, including measures of pollution abatement efforts, composite indicators, and emission-based indicators (Galeotti et al., 2020). The level of ambition of environmental instruments at the country level, such as the OECD's Environmental Policy Stringency (EPS) index, is the most commonly used measure of environmental policy stringency (Kruse et al., 2022).[8] Only a few other design features have been empirically developed. For example, "policy intensity" captures the sum of efforts, resources and political activities allocated (Schaffrin et al., 2015), and "technological specificity" measures the degree of speciality to target certain technologies (Schmidt and Sewerin, 2019).

Existing research also highlights the critical role of instrument types in stimulating eco-innovation. Environmental and innovation policies are often categorized using the demand-pull and technology-push taxonomy, sometimes including soft and systemic types (e.g. Horbach et al., 2012; Kemp and Pontoglio, 2011; Rennings, 2000).From a conceptual standpoint, Rogge and Reichardt (2016) have added these categories to help distinguish instrument purposes. At an empirical level, Costantini et al. (2017), Costantini et al. (2020), and Consoli et al. (2023), have carried out quantitative studies using these same categories.

Technology-push instruments, such as the traditional R&D subsidies and feed-in tariffs, directly address underinvestment in R&D (Johnstone et al., 2010). Conversely, demand-pull instruments aim to stimulate socio-technical change by increasing demand for new technologies (Edler and Georghiou, 2007). Demand-pull instruments include the development of standards, trad-

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[7] An instrument refers to a policy or a measure, we use the terms 'policy' and 'instrument' interchangeably.

[8] The OECD's EPS indicator is defined "as a higher, explicit or implicit, cost of polluting or environmentally harmful behavior" (Botta and Koźluk, 2014).

ing schemes, pollution taxes, deposit refund schemes, and public procurement (Ghisetti and Quatraro, 2017). Scholars agree that demand-pull policies create markets for eco-innovation and reduce the risks and uncertainties associated with green R&D, while addressing the double externality problem (Rennings, 2000).[9]

The literature on the policy mix has pointed to the need to develop appropriate characteristics and to assess the mix as a whole. However, there are measurement problems associated with the policy dimensions. So far, three quantitative measures have been proposed, such as (1) the number of instruments (i.e., comprehensiveness of the mix; e.g., Costantini et al., 2017), (2) the quadratic term of this quantification, which reflects the degree to which the integration of an additional instrument does not lead to detrimental interactions with the current mix (i.e., consistency of the mix; e.g., Consoli et al., 2023), and (3) the balance between instrument types (i.e., balance of the mix, e.g., Consoli et al., 2023).

3. Methodology

3.1. The general European environmental policy landscape

This section presents a descriptive analysis of the European environmental policy landscape using four major public databases. These databases provide information on environmental policy instruments. The section analyzes to what extent the databases share common elements, such as structure, scope, content, and instrument taxonomy. It also shows how different databases can lead to different interpretations of leading and lagging countries in Europe in terms of implementation of environmental instruments.

Consolidating policy data from different sources is essential to operationalize the policy mix for environmental transitions, the second objective of this report. Given the challenge of analyzing policy mixes from heterogeneous databases, the report proposes a fuzzy matching approach. With some adjustments, this method can be applied across different sectors to consolidate and cross-reference policy data from the identified databases.

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[9] The double externality phenomenon suggests that firms have a limited ability to capture environmental benefits resulting from the diffusion of eco-innovations, which benefits society and might produce positive knowledge externalities, while bearing costs associated with developing eco-innovations, such as R&D expenses.

3.1.1. Data sources & descriptive analysis

Four public environmental policy databases serve as the primary data source in this analysis: (1) the IEA Policies and Measures database from the International Energy Agency,[10] (2) the Climate and Energy Policies and Measures from the European Environmental Agency,[11] (3) the Science, Technology and Innovation (STI) Policies that explicitly support the transition to net zero emissions from the European Commission, the International Energy Agency and the OECD,[12] and (4) the MURE Energy Efficiency Policies and Measures from the Odysee Project.[13]

Table 3.1: *Description of the databases*

Database	Obs.	Includes UE Policies	Interval of Years	Includes Policy Status	Policy Types
IEA Policy	3511	Yes	1951-2025 (planned)	Yes	158
EEA PaM	2247	No	1997-2022	Yes	18
STI	1027	Yes	1954-2023	No	28
MURE	1102	Yes	1934-2030 (planned)	No	3

As shown in Table 1, the various data sources share content but are not exactly the same.[14] For example, only half of them incorporate the policy status, providing annual information on the policy's state, such as planned, announced, implemented, suspended, or ended. Moreover, there is significant heterogeneity in policy types between the databases, with a few containing a wide range of types (e.g., the IEA contains 158 distinct types). Each instrument may be associated with multiple types. This poses a particular challenge in combining instruments into a comprehensive dataset.

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[10] IEA Policies and Measures - https://www.iea.org/policies.
[11] Climate and Energy Policies and Measures - https://pam.apps.eea.europa.eu.
[12] STI Policies - https://stip.oecd.org/stip.
[13] MURE Energy Efficiency Policies and Measures - https://www.measures.odyssee-mure.eu.
[14] For an overview of the distinct features of the databases, refer to Appendix 1.

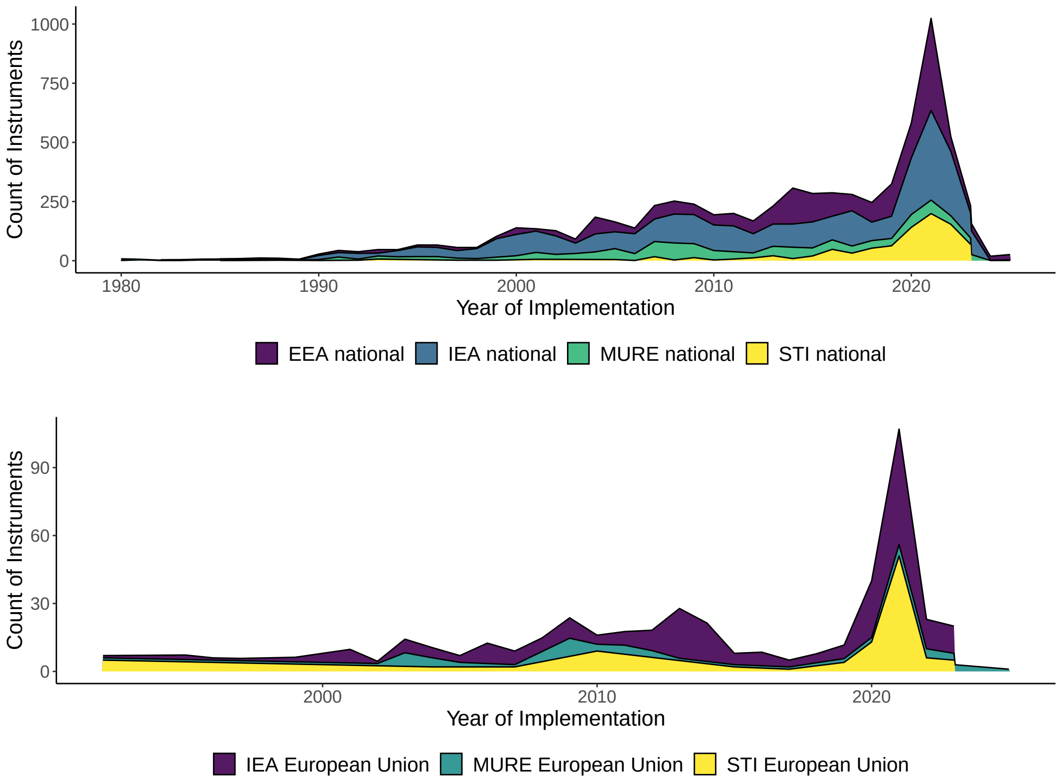
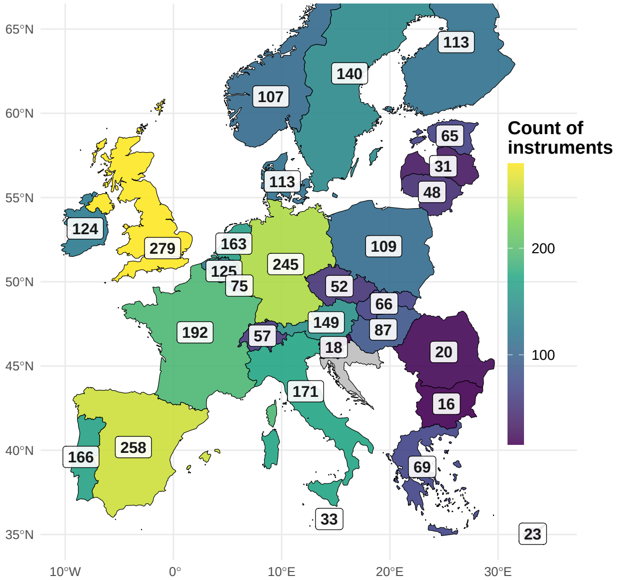


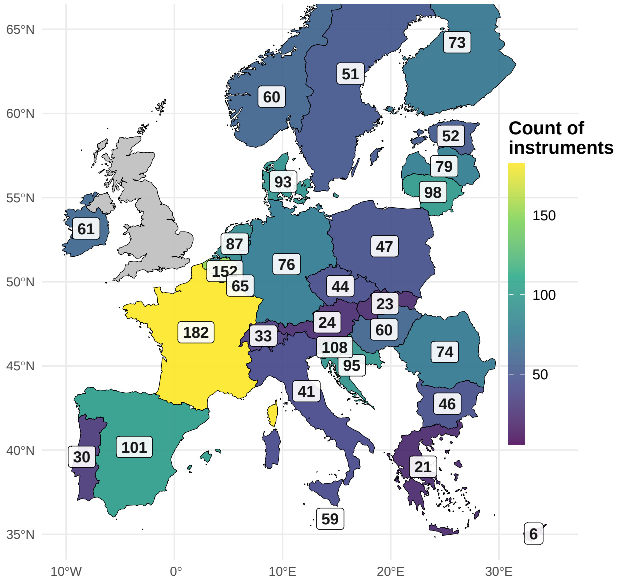
Figure 3.2: *Count of instruments over time per green policy database (1980-2025)*

From Figure 2, we observe that most instruments were introduced in Europe starting from the 1990s. There is also a clear trend of increased implementation between 2018 and 2020 and a notable decrease between 2020 and 2021 at the national and EU levels. The decrease between 2020 and 2021 suggests a need for updated data in the most recent periods, affecting all datasets. Additionally, planned instruments have also become available from this period. To provide an overview of the European environmental policy landscape, we use maps to display the number of policy instruments implemented in each country, separately from each dataset, within a common time frame (1990-2022).



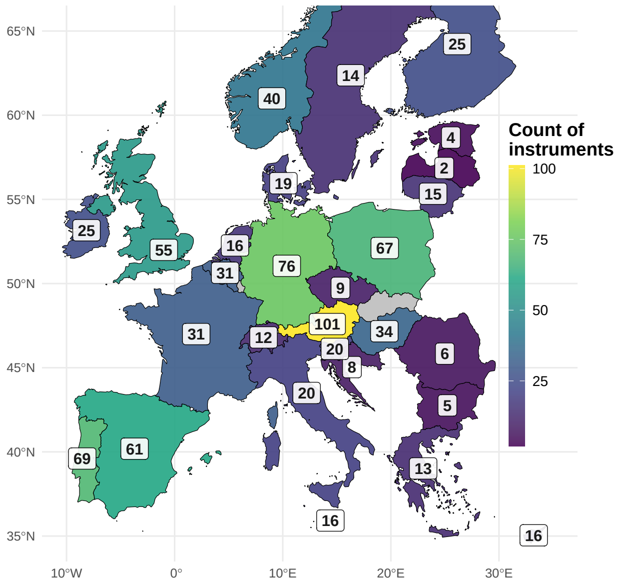
Grey countries correspond to those with no value

Figure 3.3: ***IEA Policies and Measures (1990-2022)***
(labels represent the total counting of instruments)



Grey countries correspond to those with no value

Figure 3.4: ***EEA Policies and Measures (1990-2022)***
(labels represent the total counting of instruments)



Grey countries correspond to those with no value

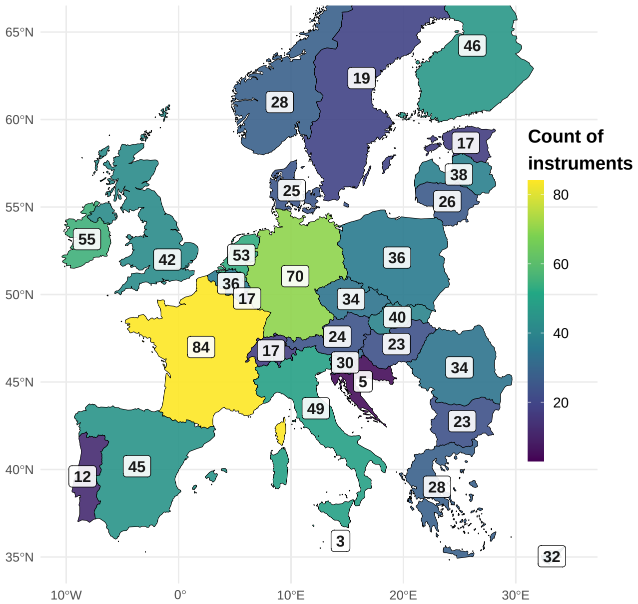


Figure 3.5: ***STI Policies and Measures (1990-2022)***
(labels represent the total counting of instruments)

Figure 3.6: ***MURE Policies (1990-2022)***
(labels represent the total counting of instruments)

The first two maps illustrate the differences in instrument counts between the Figure 3 (IEA) and Figure 4 (EEA) databases, which both cover several environmental objectives. IEA refers to policies and measures that reduce greenhouse gas emissions, improve energy efficiency, and support the development and deployment of renewable and other clean energy technologies. EEA contains Europe's climate and energy policies and measures.[15]

The following two figures are derived from more targeted databases. Figure 5 (STI) refers particularly to Science, Technology and Innovation Policies that explicitly support the transition to net zero emissions, while Figure 6 (MURE) refers to energy efficiency policies and measures implemented in Europe.

The analysis shows that Spain, the United Kingdom, Germany, Belgium, and France emerged as the front-runners in policy implementation up to 2022 in Europe (IEA and EEA). In addition, as regards the explicit coverage of energy efficiency instruments by MURE, Germany and France appear to have implemented most of the instruments. Finally, as regards the promotion of science, technology, and innovation policies aimed at achieving net zero emissions (STI), Germany, Austria, Poland, Spain, and Portugal are the primary pioneers of such policies.

Overall, eastern countries, such as Estonia, Romania, and Bulgaria, tend to provide fewer environmental instruments than western ones. However, what stands out from these maps is that the leading countries differ depending on the dataset, even among those similar in their diversity of instruments (IEA and EEA).

The descriptive analysis suggests that attempts to evaluate environmental policy mixes may be compromised by difficulties in consolidating and cross-referencing heterogeneous databases, which may lead to different results and interpretations depending on the database chosen. Therefore, the policy analysis highlights the heterogeneity of data sources and emphasises the need for caution when interpreting quantitative results of European environmental policies.

3.1.2. Methodological issues in analyzing the policy mix

As mentioned in the literature, one of the main challenges in assessing policy mixes arises from their multi-element and multi-dimensional nature (Rogge and Reichardt, 2016). The ongoing debate includes how to operationalize several policy mix components, such as design features (Kemp and Pontoglio, 2011), characteristics (Rogge and Reichardt, 2016), framework's blocks (i.e., the policy processes and policy strategy; Rogge and Reichardt, 2016), as well as instrument interactions (e.g. Boonekamp, 2006; Wiese et al., 2018). This report focuses solely on developing

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[15] This includes reducing GHG emissions, producing additional renewable energy, or reducing overall energy consumption.

quantitative characteristics of the policy mix applied to the residential energy efficiency sector (Consoli et al., 2023; Costantini et al., 2020,1).

Additionally, as mentioned in Section 3.1, the dispersion of heterogeneous information (in content, structure, scope, and instrument taxonomy) across different databases complicates the operationalization of the policy mix concept. There is also no straightforward classification procedure to assign an instrument as reported in an official database to a common conceptual taxonomy, such as the one of demand-pull and technology-push. This report uses the IEA's taxonomy, which classifies green instruments into six distinct policy types for categorizing environmental instruments related to the residential energy efficiency sector. This taxonomy has been applied in previous studies to the residential energy efficiency sector in Europe, using only instruments from the IEA Policy database (Consoli et al., 2023).

3.1.3. Connecting databases using a fuzzy matching method

Dealing with heterogeneous databases poses a challenge in analyzing the policy mix for sustainability transitions. To address this issue, a fuzzy matching approach is proposed in the report. A major advantage of fuzzy matching is its ability to compare two strings, identifying similarities instead of relying solely on strict exact matches. Seven common variables were identified across the datasets. The policy status and sector are absent from the STI and MURE.

Table 3.2: *Common variables between the databases*

Variable /Database	Policy Title (English format)	Country	Policy Type	Policy description	Policy Status	Sector	Year of implementation
IEA Policy	Yes	Yes	Yes	Yes	Yes	Yes	Yes
EEA PaM	Yes	Yes	Yes	Yes	Yes	Yes	Yes
STI	Yes	Yes	Yes	Yes	No	No	Yes
MURE	Yes	Yes	Yes	Yes	No	No	Yes

Matching proceeds through three main steps. The first step involves normalizing the common variables in each dataset, followed by an exact matching. This normalization involves lowercase conversion, removal of punctuation characters and blank spaces, as well as stop words.[16] Subsequently, modalities are homogenized, and words are reduced to their root form. The stemming

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[16] A set of commonly used words, examples in English are 'the', 'is', or 'are'.

is applied using the Snowball stemming algorithm, which provides particular efficiency and fast computation. Exact matching is performed on the country, policy status, and year of implementation, with a three-year window (t-1 to t+1).

After normalization and exact matching, the second step involves applying fuzzy matching to pairwise strings between databases: (1) Fuzzy matching to policy titles (English format) using the Full Damerau-Levenshtein distance, particularly useful for short strings. This distance considers the minimal number of insertions, deletions, substitutions, and transpositions of characters required to transform one policy title into another. We include the transposition penalty (swapping adjacent characters) to account for variations of word position, given that most of the policy titles are translated into English. Each operation counts as one unit of distance, with higher distances indicating a lower probability of overlap between pairwise policy titles.

(2) Fuzzy matching to policy descriptions using the Q-gram distance, suitable for longer strings. This method involves dividing each string into a vector of sub-strings of length q and counting the number of common sub-strings between the two strings divided by the total. In the same way, each operation counts as one unit of distance, with higher distances indicating a lower probability of overlap between policy descriptions.

In the third and final step, a case-specific cut-off threshold must be determined to account for overlap. A suggested method for selecting the cut-off involves starting with the closest instruments (i.e., policy title and description) and incrementally increasing distances until potential matches become unclear. A manual review of the grey area of matching may then be necessary.

3.2. Energy efficiency in the residential sector: an illustrative case of the policy mix

This section outlines the methodology used to characterise the policy mix for energy efficiency in the residential sector in Europe. The sector was chosen for three main reasons. First, it is a priority sector for the European Union, as reflected in the European Commission directives, such as the Energy Performance of Buildings Directive (EPBD) and the Energy Efficiency Directive (EED). Second, energy efficiency in the residential sector is in line with the SPES framework, in particular the productivity and environmental sustainability pillars. More specifically, it supports job creation in the construction sector, stimulates innovation and provides a cost-effective way to reduce GHG emissions. Third, while there is no agreed quantitative measure of the policy mix for sustainability transitions, residential energy efficiency has been a key focus, prompting scholars to explore and develop relevant policy mix orientations and characteristics (Consoli et al., 2023; Costantini et al., 2020,1; Rosenow et al., 2017).

3.2.1. Identifying instruments & consolidating databases

The IEA Policies and Measures and MURE Policies database have been consolidated using fuzzy matching to measure a comprehensive policy mix for residential energy efficiency. The two databases contain instruments at the national level for the EU-27 nations. To identify relevant sectors according to the IEA, we filtered instruments containing at least one of the following sectors: *« Residential|Existing buildings and retrofits|Heating and Cooling|Combined heat and power|New buildings|Apartment in high-rise building|Apartment in low-rise building| Attached house|Detached house »*. We directly extracted energy efficiency policies related to the 'household' sector from the MURE database. Following the application of fuzzy matching, the aggregated database comprises 1,965 instruments.

We manually matched the two distinct typologies to sort instruments within common types using the IEA's framework as a reference.[17] Subsequently, we conducted a net cumulative instrument counting in three steps that considered the weight of each instrument within the IEA's categories for each country over time. First, each instrument is fractionally allocated according to the IEA categories during its year of implementation. More precisely, if an instrument spans multiple policy types within the same IEA category, it is counted once; however, if it falls under two IEA categories, it is equally divided. For example, an instrument implemented in Austria in 2000, classified under both 'Economic' and 'Regulatory' types, would be allocated a share of 0.5 each. Second, as some instruments ended over time, fractional shares within each IEA category were removed when instruments expired. For instance, if an instrument implemented in Austria in 2000 under both 'Economic' and 'Regulatory' types ends in 2007, each type loses a share of 0.5 in 2007. Third, the cumulative count of instrument types is calculated per country from 1996 to 2017.

3.2.2. Policy mix orientations

As mentioned in the literature review, environmental and innovation policies aimed at stimulating eco-innovation are typically categorized as demand-pull, technology-push, soft, or systemic (e.g. Costantini et al., 2017). These categories represent the instrument purposes in Rogge and Reichardt (2016)'s policy mix framework for sustainability transitions. Quantitative studies on policy mix, such as those by Costantini et al. (2020,1) or Consoli et al. (2023), have used this taxonomy to empirically characterize different policy mix design orientations. The policy mix orientations are used in the present report to analyze policy mix design in the residential energy efficiency sector. In general, demand-pull instruments aim to expand markets and increase innovation profitability by changing market size and demand (Costantini et al., 2020). The demand-pull measure can involve a price-based mechanism, such as implicit taxation of household en-

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[17] See Appendix 2 for the detailed matching example.

ergy consumption (Consoli et al., 2023; Costantini et al., 2020,1). In our case study, the demand-pull measure represents the average tax rate imposed annually on energy consumption in the residential sector for each country. Tax rates are weighted by energy consumption from two sources (natural gas and electricity), obtained from IEA Energy Prices and Taxes Statistics, and IEA Energy Balance Statistics.

The pre-processing steps from 1996 to 2017 for all European countries include: (1) Extraction in national currencies and conversion of all units to kWh. (2) Multiplication of prices by consumption quantities (energy tax calculated as the difference between prices with and without taxes and levies). (3) Conversion of national currencies to constant USD prices using the HICP (Harmonized Indices of Consumption Prices) specific to the energy sector with the year 2015 as a base. The demand-pull unit is a million USD constant price in 2015 for each kWh consumed. The demand-pull formula applied in this report is taken from Consoli et al. (2023).

$$Demand\ pull_{i,t} = \frac{\sum_{n=1}^{2}(\text{Energy tax}_{i,t}^{n} \cdot \text{Energy consumption}_{i,t}^{n})}{\sum_{n=1}^{2}(\text{Energy price}_{i,t}^{n} \cdot \text{Energy consumption}_{i,t}^{n})}$$

Where i,t, and n, represent the country, year, and energy source respectively. The demand-pull measure is normalized between 0 and 1 using a min-max scaling procedure: $(\text{Demand pull}_{i,t} - \text{min}(\text{Demand pull}_{i,t}))/(\text{max}(\text{Demand pull}_{i,t}) - \text{min}(\text{Demand pull}_{i,t}))$.

Technology-push measures include public and private R&D funding and adoption incentives to promote new technologies (Costantini et al., 2020). In our case study, the technology-push indicator measures a national system's capacity to convert investment efforts in energy-efficient technology into innovation in the residential sector (Consoli et al., 2023; Costantini et al., 2020,1). The technology-push formula applied in this report is taken from Consoli et al. (2023).

$$Technology\ push_{i,t} = \frac{Patent\ stock_{i,t}(1)}{\dfrac{KRD_{i,t}(2)}{GERD_{i,t}(3)}}$$

The indicator is constructed using three measures. (1) The domestic cumulative patent stock in energy-efficient technologies in the building sector, accounting for the obsolescence rate of knowledge δ.[18] We consider an average discount rate (δ) of 15% as suggested by OECD (2009), to adjust the value of knowledge over time, considering that older knowledge might become less relevant or obsolete as new knowledge emerges.[19]

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[18] Patent applications (PATSTAT) from 1996 to 2017 based on priority date (EPO), with at least one CPC code starting with 'Y02B' (for more information on green CPC codes, refer to Veefkind et al., 2012), and at least one inventor address from a nation within the EU-27 (full counting).

[19] As a robustness check, different thresholds have been tested (from 0.1 to 0.2, by 0.01), results were partic-

$$Patent\ Stock_{i,t} = \sum_{s=0}^{t} (Patent_{i,s} \cdot e^{[-\delta(t-s)]})$$

Where i represents a country and t a year, s represents an index of years up to and including year t.

(2) The domestic cumulative R&D public stock is computed using the Perpetual Inventory Method. This method estimates the knowledge stock by accumulating past R&D flows while considering the obsolescence rate. The R&D public stock is based on public budget expenditures on R&D in energy efficiency in the building sector (IEA R&D Energy statistics), converted to USD 2015 constant prices (Harmonized Index of Consumer Prices specific to the energy sector). Due to data missing within certain intervals, we employed linear interpolation for imputation. This method assumes linearity, estimating values via weighted averages of known points.[20] The domestic cumulative R&D public stock is computed in two parts, one solely for the first year and the other for subsequent periods.

$$KRD_{i,t0} = \frac{RD_{i,t0}}{g_i + \delta}$$

KRD_{it0} represents the estimated domestic cumulative stock of R&D investment in energy efficiency in the building sector up to the first year available (t_0=1996), where i denotes a country. Concerning g_i, it represents the country-specific average annual growth rate of R&D expenditures at constant prices over the entire period. Hence, g_i indicates the rate at which knowledge tends to accumulate over time in that country (a higher rate indicates faster knowledge accumulation).

$$KRD_{i,t} = KRD_{i,t-1}(1 - \delta) + RD_{i,t}$$

Within the second part, KRD_{it} corresponds to the cumulative domestic stock of R&D investment in energy efficiency in the building sector annually after t_0.

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ularly stable around 15%. For a vizualisation, refer to Appendix 3.

[20] We validated linearity using Shapiro-Wilk and Anderson-Darling tests on the distributions of potential imputations for each country (ten countries in total), with four countries receiving imputations.

(3) $GERD_{i,t}$ (Gross domestic and public expenditure on R&D - OECD Statistics) represents the total domestic expenditure on R&D activities (private or public), converted to millions USD 2015 constant prices (HIPC general). After computing the technology-push measure, we address upper outlier values by capping those exceeding 4000. Subsequently, employing a min-max scaling procedure, we normalize the technology-push measure to range between 0 and 1: $(\text{Technopush}_{i,t} - \min(\text{Technopush}_{i,t}))/(\max(\text{Technopush}_{i,t}) - \min(\text{Technopush}_{i,t}))$.

Soft instruments can be defined as non-coercive policy tools aimed at involving civil society. Soft instruments include the use of information and voluntary approaches to raise consumer awareness of the benefits of adopting environmentally friendly behaviour (e.g. Carraro and Lévêque, 2013; Costantini et al., 2017). Systemic instruments, on the other hand, target structural and procedural systemic problems and aim to influence the overall functioning of the system (e.g. Costantini et al., 2017; Wieczorek and Hekkert, 2012).

In addressing an empirical indicator for soft and systemic measures, Costantini et al. (2020) counted instruments from the IEA's types where their nature is prevalent. Specifically, three types were chosen: 'Information and Education', 'Policy support', and 'Voluntary approaches'.[21] While empirical studies tend to aggregate soft and systemic measures - partly because they are poorly documented in public databases - we decided to conduct a separate analysis as the stakeholder targets and mechanisms may be different.

To derive individual measures, we disaggregated the metrics associated with 'Voluntary approaches' and 'Information and Education' as soft instruments and 'Policy support' as systemic instruments. A value of 1 is assigned if an instrument is in one of the types for each country annually. The type is determined by the cumulative domestic count of instruments in force over time. As addressed in Section 3.4.1, the instrument cumulative counting is net within the IEA's categories for each country over time, considering both the implementation and conclusion of the instrument. The formula applied in this report to soft and systemic instruments is taken from Costantini et al. (2020).

$$\text{Soft}_{i,t} = \sum_{q\in\{2,6\}} \left(\sum_{S=0}^{t} \text{POL}_{i,s}^{q} \right)$$

$$\text{Systemic}_{i,t} = \sum_{q\in\{3\}} \left(\sum_{S=0}^{t} \text{POL}_{i,s}^{q} \right)$$

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[21] Refer to Appendix 4 for the content of the policy types provided by the International Energy Agency.

Where $q \in [2, 3, 6]$ represents the three policy types selected. The soft & systemic measures are normalized between 0 and 1 using a min-max scaling procedure:
$(\text{Soft\&Systemic}_{i,t} - \min(\text{Soft\&Systemic}_{i,t}))/(\max(\text{Soft\&Systemic}_{i,t}) - \min(\text{Soft\&Systemic}_{i,t}))$.

3.2.3. Policy mix characteristics

To analyze national policy mix design, we rely on characteristics identified in prior studies, such as comprehensiveness and balance of instrument types(Consoli et al., 2023; Costantini et al., 2020,1). Comprehensiveness is defined as the extent to which the instrument mix addresses all policy goals, encompassing the capacity to address relevant failures and barriers using diverse instrument types (Consoli et al., 2023).

$$\text{Comprehensiveness}_{it} = \text{KPOL}_{it}^{\text{res}} = \sum_{k=1}^{6} \text{kpol}_{it}^{k}$$

$$\text{With kpol}_{it}^{k} = \{kpol_{it}^{eco}, kpol_{it}^{inf\&edu}, kpol_{it}^{supp}, kpol_{it}^{reg}, kpol_{it}^{R\&D}, kpol_{it}^{vol}\}$$

Considering the country i, the year y, k the instrument category (IEA's taxonomy), and kpol the policy stock.

Similarly to the soft and systemic measures, we use the weighted counting method described in Section 3.4.1.[22]

Finally, the balance of instrument types, especially between demand-pull and technology-push policies, is known to be important in promoting eco-innovation. An imbalance in favor of either type could lead to reduced technological variety and potential lock-in effects (Costantini et al., 2017). For instance, the disproportionate use of technology-push instruments could reduce private investments in new technologies (Antonelli et al., 2022). The balance between demand-pull and technology-push is recognized to have a significant positive impact on fostering eco-innovations (Costantini et al., 2017). Two quantitative measures have been proposed (Costantini et al., 2017; Schmidt and Sewerin, 2019). We refer to the extension of Consoli et al. (2023) via the cognitive proximity matrix.

$$\text{PolicymixBalance}_{it} = \ln\left(\frac{|\text{Demand pull}_{it} - \text{Technology push}_{it}|}{\sqrt{\text{Demand pull}_{it} + \text{Technology push}_{it}}}\right)^{-1}$$

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[22] Specifically, this method counts the cumulative number of instruments, taking into account the new ones and the ones that have ended.

3.2.4. Principal Component Analysis

A Principal Component Analysis (PCA) is used to explore descriptively the positioning and temporal sequencing of EU countries policy mix through some design features (whether the policy mix is mainly oriented towards demand-pull, technology-push, soft or systemic approaches) and comprehensiveness. The PCA approach offers the advantage of reducing the dimensionality of the data while preserving its key variability, thus enabling a statistical interpretation of the relationships between European countries and policy mixes. The analysis is conducted for the most recent observation period (2017; in cases where there were no observations, values from the last three years, 2015 to 2017 were averaged). Countries are clustered based on comprehensiveness quantiles in 2017. We also include the EU nations in 2007 (in cases where there were no observations, average values from 2005 to 2007) as supplementary data points. Therefore, the data points in 2007 are not included in the analysis but are projected onto the principal component space to observe their directions relative to the main analysis. This approach allows for tracking changes in national policy mix sequences over time.

4. Results

4.1. Analyzing the policy mix in the case of energy efficiency of the residential sector

In this section, we map the design and comprehensiveness of EU countries' policy mixes over two decades (1996-2006 and 2007-2017), focusing on the number of instruments, their orientations, and their alignment with different policy objectives. This analysis aims at descriptively examining the overall distribution and heterogeneity of policy mixes among EU countries and how these mixes have evolved over time.

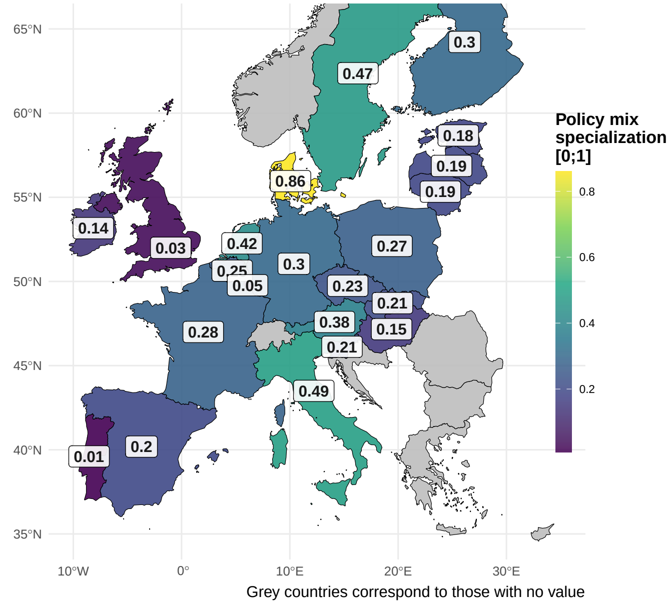


Figure 4.7: ***Average Demand-pull measure of the Policy mix*** *for Energy Efficiency in the Residential sector (1996-2006)*

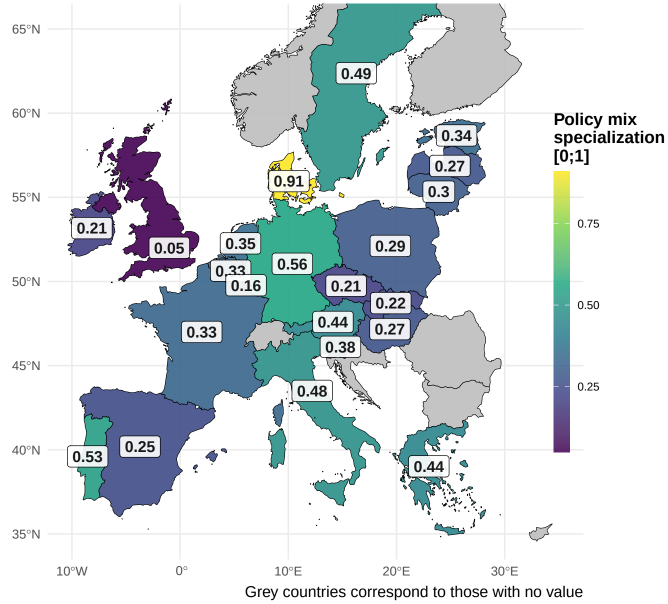
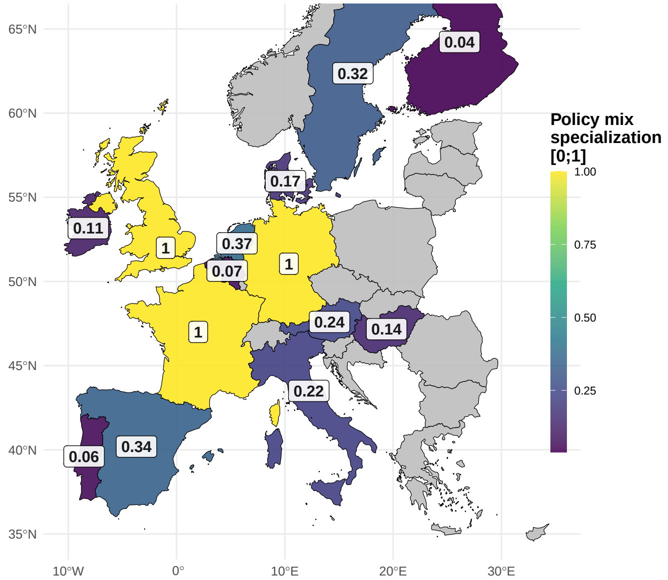
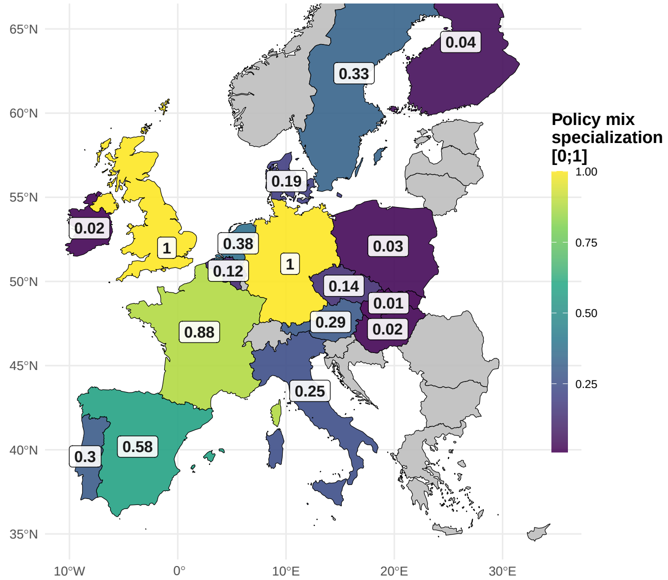


Figure 4.8: ***Average Demand-pull measure of the Policy mix*** *for Energy Efficiency in the Residential sector (2007-2017)*



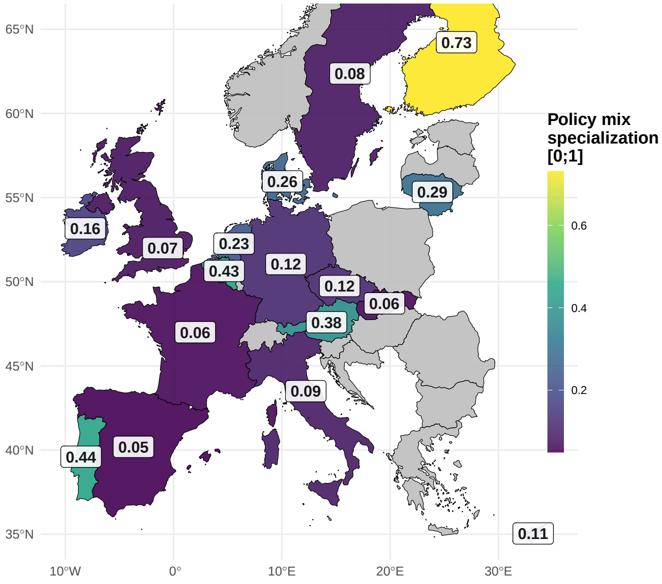
Grey countries correspond to those with no value

Figure 4.9: ***Average Technology-push measure of the Policy mix*** *for Energy Efficiency in the Residential sector (1996-2006)*



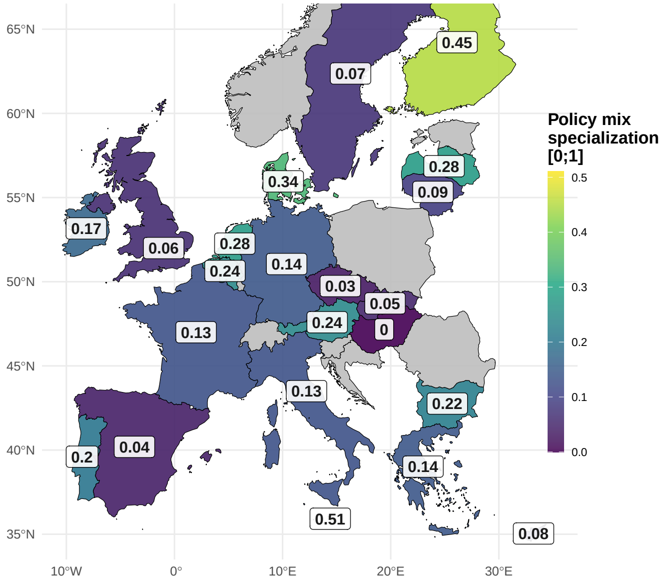
Grey countries correspond to those with no value

Figure 4.10: ***Average Technology-push measure of the Policy mix*** *for Energy Efficiency in the Residential sector (2007-2017)*



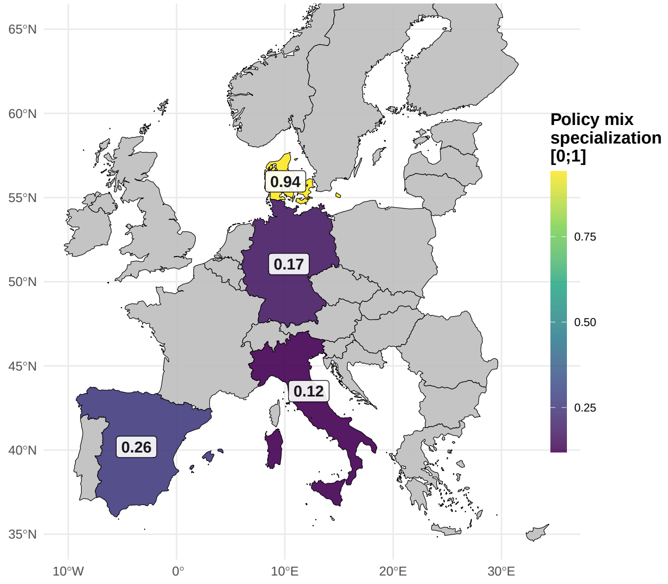
Grey countries correspond to those with no value

Figure 4.11: ***Average Soft measure of the Policy mix*** *for Energy Efficiency in the Residential sector (1996-2006)*



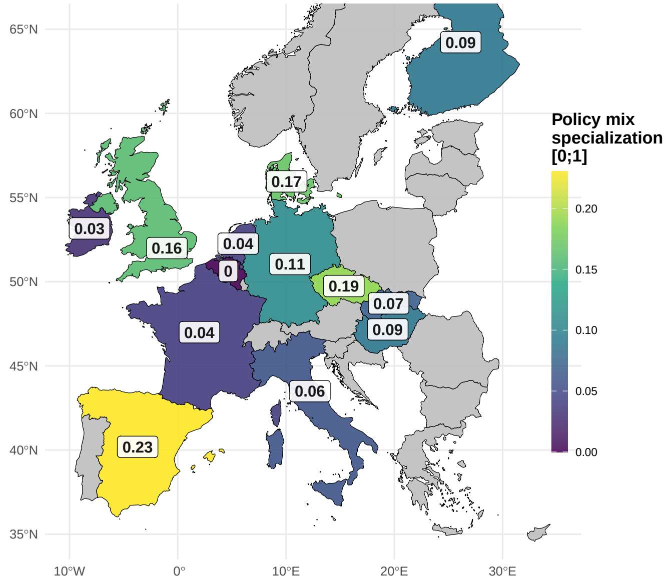
Grey countries correspond to those with no value

Figure 4.12: ***Average Soft measure of the Policy mix*** *for Energy Efficiency in the Residential sector (2007-2017)*



Grey countries correspond to those with no value

Figure 4.13: ***Average Systemic measure of the Policy mix*** *for Energy Efficiency in the Residential sector (1996-2006)*



Grey countries correspond to those with no value

Figure 4.14: ***Average Systemic measure of the Policy mix*** *for Energy Efficiency in the Residential sector (1996-2006)*

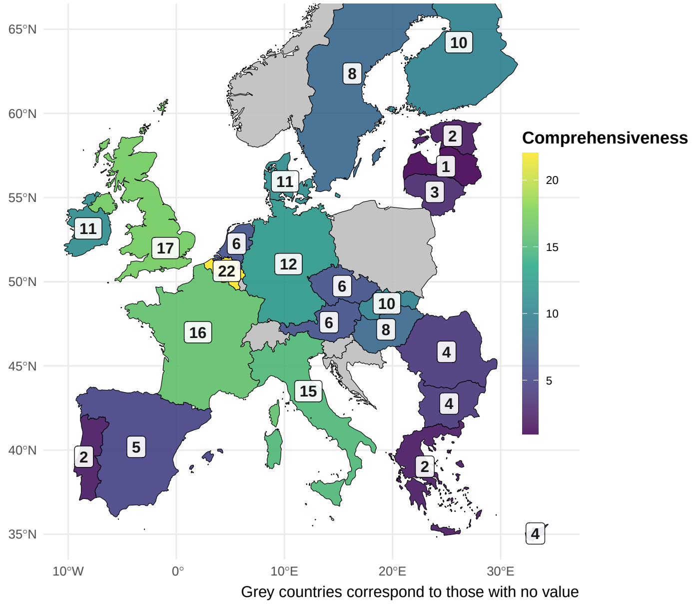


Figure 4.15: ***Comprehensiveness of the Policy Mix*** *for Energy Efficiency in the Residential Sector (1996-2006)*

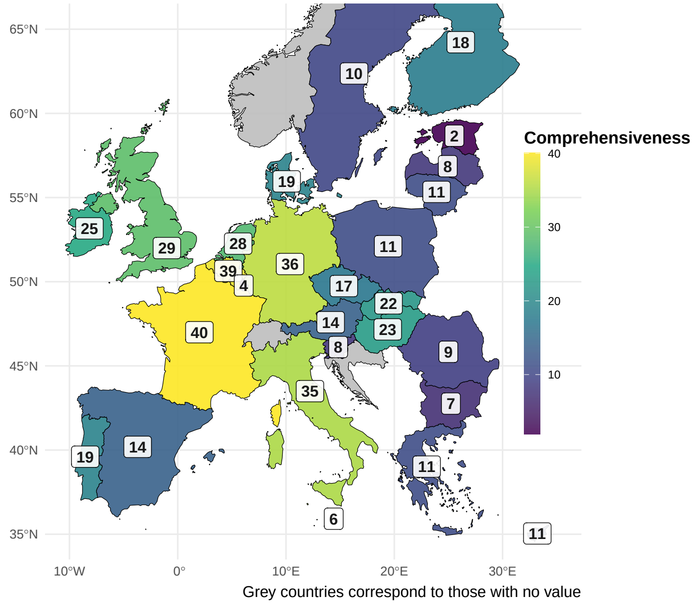


Figure 4.16: ***Comprehensiveness of the Policy Mix*** *for Energy Efficiency in the Residential Sector (2007-2017)*

National policy mixes in Europe vary in terms of their demand-pull, technology-push, soft, and systemic orientation. Demand-pull measures highlight countries that focus their efforts on stimulating demand for new technologies by introducing implicit taxes on household energy consumption. Denmark is strongly oriented towards demand-pull measures in both periods. More recently, countries such as Spain, Slovakia, and Greece have also started to prioritize these measures. In general, countries such as Denmark, Sweden, Italy, the Netherlands, and Austria are oriented towards demand-pull measures.

In terms of technology-push measures, the UK, Germany, and France are a highly oriented triplet for improving energy efficiency in the residential sector. The Netherlands and Sweden also show some orientation, but to a lesser extent. Over the last decade, Spain has shown a marked shift towards technology-push measures. These countries excel in translating investment efforts in energy-efficient technologies into innovation, in particular by addressing underinvestment in public R&D for buildings. Germany shows a high dual orientation in both demand-pull and technology-push measures, with Sweden and the Netherlands showing a similar, albeit lower, degree of orientation.

In the area of soft measures, which includes non-coercive policy instruments using information, education, and voluntary approaches, Finland emerges as the most oriented European country. Portugal and Austria also show a lower degree of orientation. Most of Finland's soft instruments were implemented in the first decade (1996-2006). More recently, countries such as Denmark, Latvia, and the Netherlands have started to show an increased orientation towards soft measures. Overall, however, the use of soft instruments remains one of the least common approaches to improving energy efficiency in the residential sector in Europe.

With regard to systemic measures, which include policy instruments aimed at systemic changes in structures and processes, we can see that Denmark has a high degree of co-orientation between demand-pull and systemic measures, having implemented most of its systemic instruments by 2006.

Finally, regarding comprehensiveness measures, during the first decade (1996-2006), Belgium primarily focused on the comprehensiveness of its policy mix, i.e., in implementing a diverse range of policy instruments, as classified by the IEA's taxonomy, to achieve multiple objectives in enhancing energy efficiency in the residential sector.[23] From 2007 to 2017, Italy, Germany, and France emerged as leaders in the comprehensiveness of policy mix in the residential energy efficiency sector.

Overall, the mapping of the policy mix in Europe suggests that technology-push and/or demand-pull instruments make up the bulk of the existing mix, while soft and systemic instruments are under-represented. However, a more diverse mix could be beneficial, in particular by including more soft and systemic instruments that can address a wider range of stakeholder interests other than firms and technology users. Soft instruments aimed at engaging civil society are crucial for promoting consumer uptake of technologies such as heat pumps and energy efficient appliances. These instruments can take various forms, including public awareness campaigns, energy efficiency rebate schemes that reduce upfront costs for

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[23] See Appendix 2 for the alignment between initial instrument types and the IEA's taxonomy.

consumers, and mandatory product labelling to inform consumers about energy efficiency. Systemic measures, which target the energy system as a whole, also complement existing policies by removing systemic barriers and establishing quality services and institutions.

4.2. The balance of policy mix design in the case of residential energy efficiency

To what concerns the examination of policy mix balance in their design, the report identifies the top five European nations with the most and least balanced policy mix orientations.

Table 3, 4, 5, 6, 7 & 8: Top five European countries with the most/least balanced orientations related to residential energy efficiency (averaged from 2015 to 2017)

Country	Avg. Balance
Germany	-0.81
France	-0.75
Spain	-0.56
Czechia	-0.52
Netherlands	-0.35
Hungary	-1.57
Slovakia	-1.61
Portugal	-1.64
UK	-3.89
Denmark	-4.93

Demand-pull vs. Technology-push

Country	Avg. Balance
Austria	-0.23
Hungary	-0.28
Portugal	-0.33
Slovakia	-0.56
Netherlands	-0.66
Spain	-1.73
Finland	-1.99
France	-1.99
Germany	-5.12
UK	-10.98

Soft vs. Technology-push

Country	Avg. Balance
Ireland	-0.60
Netherlands	-0.65
Latvia	-0.67
Belgium	-0.69
UK	-0.69
Denmark	-1.56
Italy	-1.60
Sweden	-1.80
Germany	-1.82
Portugal	-2.06

Soft vs. Demand-pull

Country	Avg. Balance
Ireland	-0.42
Czechia	-0.52
Slovakia	-0.56
Denmark	-0.57
Finland	-0.62
Italy	-1.05
Netherlands	-1.70
France	-3.05
UK	-3.44
Germany	-8.49

Systemic vs. Technology-push

Country	Avg. Balance
Czechia	-0.15
UK	-0.37
Spain	-0.39
Hungary	-0.74
Slovakia	-1.11
Netherlands	-1.68
Italy	-2.30
Belgium	-2.32
Germany	-2.36
Denmark	-11.65

Systemic vs. Demand-pull

Country	Avg. Balance
Slovakia	-0.13
Germany	-0.45
France	-0.56
Italy	-0.57
UK	-0.73
Netherlands	-1.03
Czechia	-1.23
Belgium	-1.31
Finland	-1.36
Denmark	-1.41

Soft vs. Systemic

The tables (3, 4, 5, 6, 7 & 8) highlight potential imbalances in the design of policy mix. Aiming for balance may not always be ideal, depending on the national context. Balance may be a diversification option reserved for countries that can already address underinvestment in R&D (technology-push orientation). Recent research suggests that a balanced policy mix between demand-pull and technology-push can positively induce eco-innovation(Costantini et al., 2017). Based on the tables and policy mix analysis, we derive potential results for a few countries.

For example, in the most recent period (2015-2017), the UK, with a strong focus on technology-push, showed significant imbalances across the demand-pull, soft, and systemic orientations. Conversely, Denmark has a strong focus on the demand-pull side, resulting in an imbalance towards other orientations. Germany also shows notable imbalances, but with a strong focus on both technology-push and demand-pull.

In terms of the balance between dominant orientations (e.g., demand-pull vs. technology-push) and comprehensiveness, Germany, France, Spain, the Czech Republic and the Netherlands are identified as the most balanced.

4.3. Country clusters by policy mix: results from a PCA

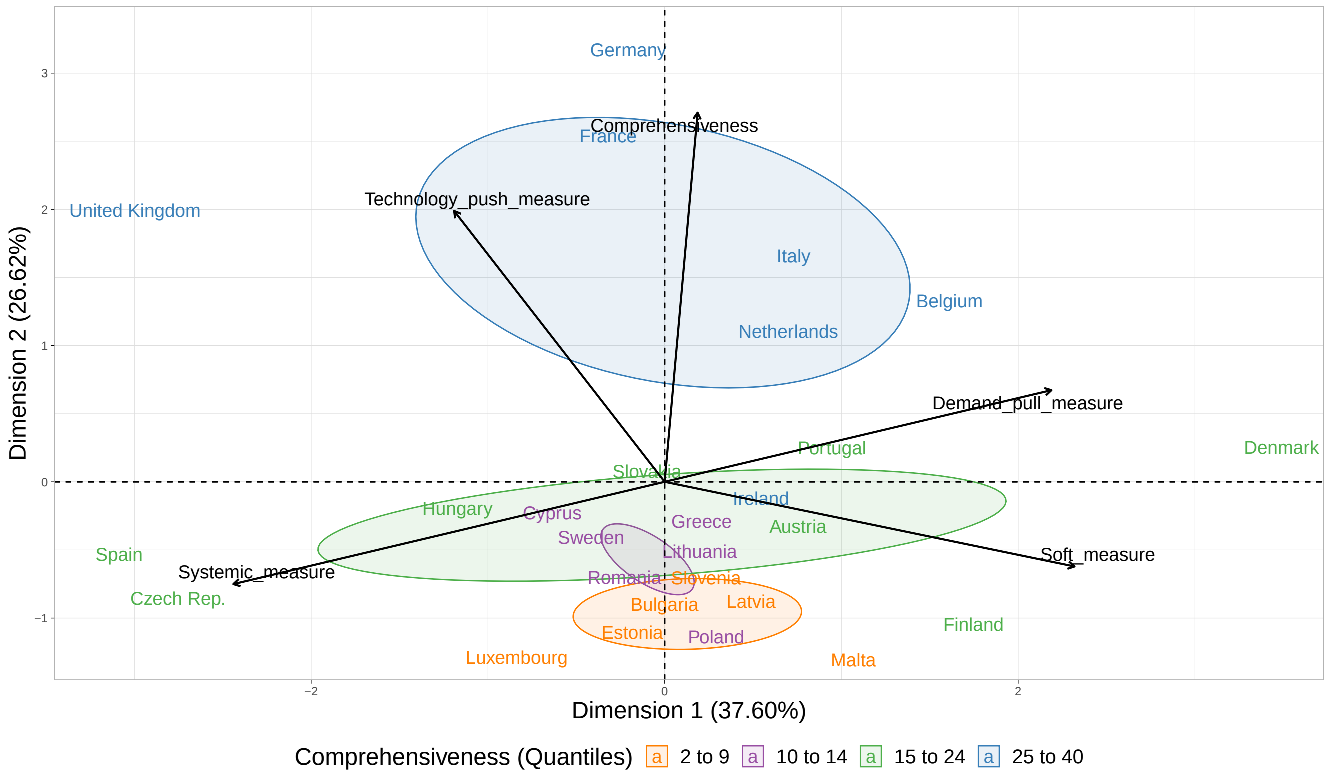

Figure 4.17: *PCA 1st & 2nd dimension - Energy Efficiency Policy mixes in the Residential Sector (2017)*

We have used two principal component analyses to examine descriptively the direction of each EU country based on policy mix orientations and comprehensiveness. The first principal component analysis (Figure 17) shows that European countries with a low level of comprehensiveness, i.e., characterised by a limited implementation of instruments or a minimal diversity of policy objectives, are not oriented and are distributed between soft and systemic measures. This low level of comprehensiveness includes countries from the first two clusters, such as Romania, Bulgaria, Poland, and Malta. Countries with a medium level of comprehensiveness (between 15 and 24) show varying degrees of orientation, either on the systemic axis or between the demand-pull and the soft axis. Spain and the Czech Republic are notable examples on the systemic axis. Portugal tends to be demand-pull, while Austria and Finland tend to be soft. Denmark is somewhere between soft and demand-pull. The most comprehensive European countries tend to favour technology-push measures or fall between technology-push and demand-pull measures. The UK, France and Germany tend towards the technology-push side, while Belgium, Italy and the Netherlands are between technology-push and demand-pull.

The first two principal components explain more variability than individual variables (eigenvalue > 1). The first dimension (38.3% of the total variance) shows a strong correlation with demand-pull, soft, and systemic measures, while the second dimension (27.68% of the total variance) is highly correlated with technology-push measure and comprehensiveness.[24]

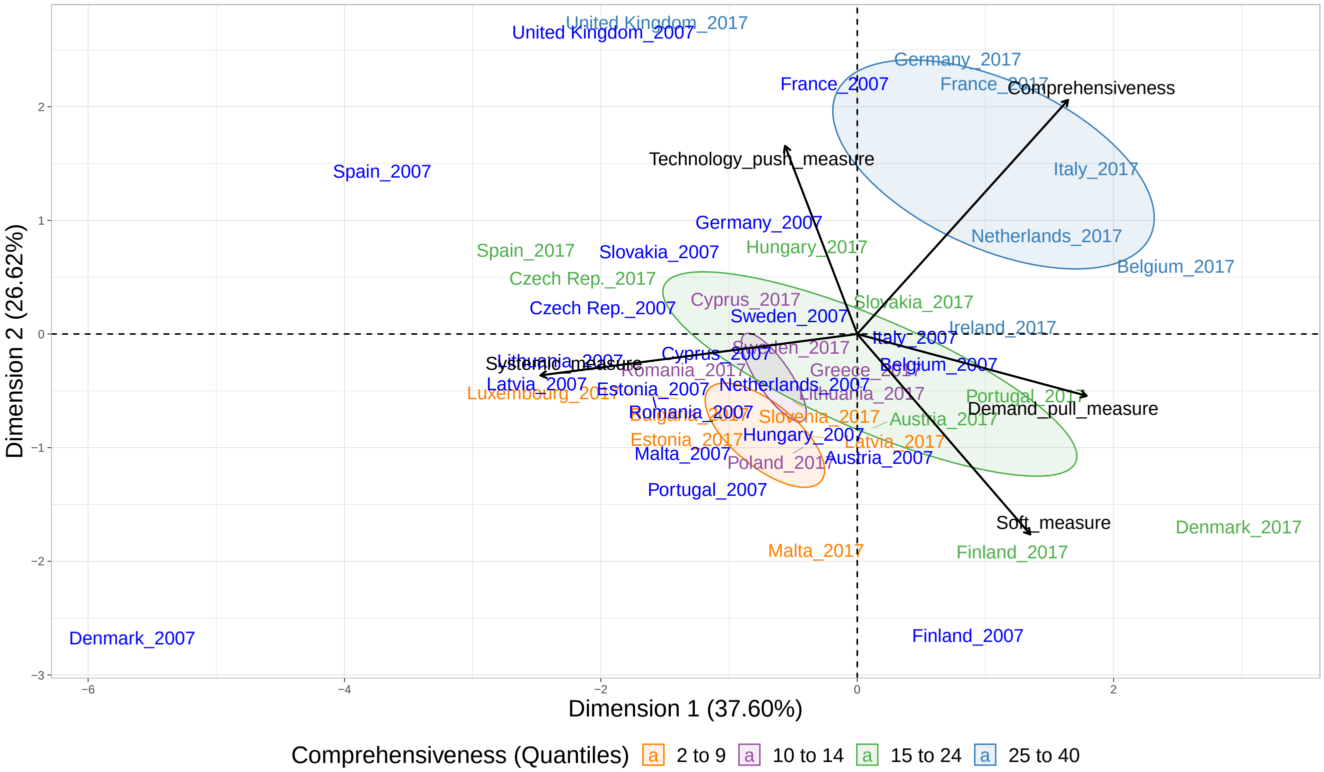

Figure 4.18: *PCA 1st & 2nd dimension including supplementary individuals - Energy Efficiency Policy mixes in the Residential Sector (2017)*

The second principal component analysis (Figure 18) provides additional information by vizualizing the policy mix orientations at a second point in time, in 2007. The additional data points (country values in 2007) shown in dark blue, are not included in the analysis, but are projected onto the principal component space computed in 2017 to examine changes in direction relative to the axes. The introduction of additional data points allows us to observe potential shifts in direction as expected from a policy mix sequence.

For instance, a significant shift is observed in Denmark: in 2007, the country tended towards the soft and

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[24] For the correlation matrix and a vizualisation of the second and third dimension space without/with supplementary individuals, refer to Appendix 5, Appendix 6 and Appendix 7 respectively.

systemic angle, before shifting towards the demand-pull and soft angle in 2017. In other words, during the decade from 2007 to 2017, the number of active policy support instruments related to residential energy efficiency in Denmark decreased, while implicit taxation of household energy consumption increased.

In 2007, Germany and France were mainly oriented towards the technology-push axis but later shifted to a more balanced position between demand-pull and technology-push measures. This is the generally expected pattern for eco-innovation, where an initial push on the technology side is needed to stimulate early-stage innovation, followed by a demand-pull orientation to support the demand side and market creation (e.g. Costantini et al., 2015; Hoppmann et al., 2013; Nemet, 2009). On the other hand, Belgium shifted away from the demand-pull axis towards a more balanced measure considering technology-push.

Italy, Germany, and the Netherlands increased their comprehensiveness. In other words, these countries not only had more active instruments, but also diversified their types of instruments, addressing a wider range of policy objectives according to the IEA taxonomy. As concrete examples, the Netherlands introduced several measures, such as the Energy Performance Certificate system in 2008 (an information and education instrument), the National Energy Saving Fund in 2014 (an economic instrument), and the Heat Distribution Act in 2014 (a regulatory instrument). On the other hand, Italy introduced the tax deduction for high efficiency appliances in 2009 (an economic instrument), created a special fund to support energy efficiency targets in 2010 (a policy support instrument), and introduced the National Building Energy Code in 2011 (a regulatory instrument).

5. Conclusions

The report provides an overview of the European environmental policy landscape and suggests ways to better measure the policy mix for sustainability transitions. Two main observations are made. First, there is considerable heterogeneity in environmental policy data sources. This makes it difficult to carry out accurate policy analysis and thus future policy evaluations, although this is crucial for promoting eco-innovation and fostering sustainability transitions. To address this issue, the report proposes a fuzzy string matching approach to consolidate multiple environmental policy databases based on common variables, while avoiding overlap between instruments. This should facilitate the development of new measures for analyzing and comparing the policy mix across European countries.

Second, the consolidated database is used to break down the policy mix into specific orientations and characteristics, as can be seen in the case study on energy efficiency in the residential sector. The analysis shows that despite common directives and regulations, European countries have different policy mix designs and sequencing patterns. Countries with a comprehensive policy mix often either prioritize technology-push measures (e.g., the UK), tend towards demand-pull measures (e.g., Belgium and Italy), or adopt a balanced approach between the two. In some cases, they follow a coherent expected shift from technology-push to demand-pull (e.g., Germany and France), but this pattern is not consistent across countries. The results also show that policy mix orientations tend to evolve over time, with some countries catching up. For example, Italy, Germany, and France have added instruments and considered a wider variety of policy objectives to their existing portfolios, thereby improving their comprehensiveness. Slovakia has strengthened its demand-pull orientation while Spain has increased its technology-push instruments. Denmark and the Netherlands have strengthened soft instruments, while the UK has increased systemic measures.

In light of the available data, it is unclear whether the current approach adequately captures the full range of soft and systemic instruments. These instruments play a pivotal role in fostering eco-innovation, as they may address stakeholder acceptability and remove systemic barriers that impede the development and diffusion of such innovations.

Two main conclusions can be drawn from the evidence presented. First, an assessment of the causal impact of the policy mix requires the consolidation and compilation of comprehensive databases on policy instruments. Second, although a comprehensive policy mix is anticipated to stimulate eco-innovation, it is currently unclear which specific gaps need to be addressed in each country. Further research is required to investigate the impacts of imbalances in the policy mix sequence. It is possible that a balanced policy mix may be most effective when preceded by an initial technology-push phase. This sequencing indicates the necessity for R&D investments at the early stages of the innovation process, with the objective of sustaining these investments while fostering demand and market creation at a subsequent stage.

The report's principal recommendation is the establishment of a centralized system for the long-term collection, harmonization, and cross-referencing of policy data related to sustainability transitions from a range of sources across Europe at various scales (e.g., national and regional). Furthermore, the system should be aligned with European directives. The effective evaluation of policy mixes, in particular with regard to policy interactions in the context of sustainability transitions, necessitates close collaboration with organizations responsible for the management of policy data.

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Appendices

Appendix 1. Distinctive features of environmental policy databases

Database	Unique Features
IEA Policy	15 subjects included (e.g., Energy Efficiency or Air Quality), as well as technologies (e.g., Solar PV or Road vehicles; 50% missing) and EndUses (e.g., Transport end-uses or Electricity end-uses; 60% missing), 75% of instruments are in force through 100 sectors (e.g., Heat generation or Industry).
EEA PaM	16 sectors (e.g., Heating and Cooling or Manufacturing) and 60 objectives (e.g., Energy Consumption: Efficiency improvements of buildings or Transport: Efficiency improvements of vehicles). In 70% of cases, the instrument is associated with a Union Policy (e.g., Energy Efficiency Directive 2012 as amended by Directive 2018/2002).
STI	Descriptive background per instrument included, 48 themes (e.g., Green energy transitions or Competitive research funding), target groups (e.g., Firms of any size or Public research institutes; 13% missing), and responsible organization(s) (e.g., European Commission or National Fund for Environmental Protection and Water Management; 22% missing).
MURE	Semi-quantitative measure of impact in terms of energy efficiency per instrument (ranging from Low, Medium to High, 1 missing). 98% of instruments are in force.

Appendix 2. Matching between instrument types (IEA PaM & MURE) based on the IEA's taxonomy

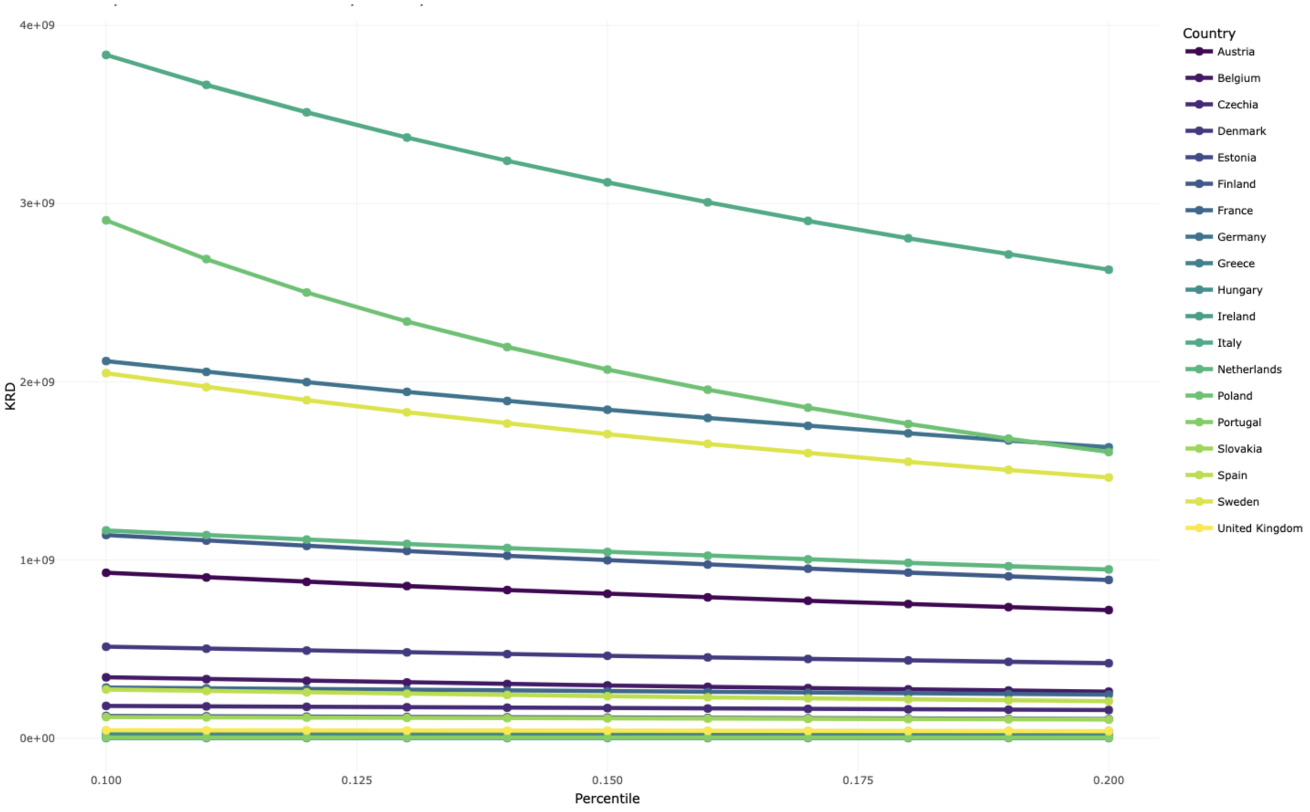
Instrument Type	IEA's Taxonomy
Capacity auction	Economic instruments
Emission Trading Scheme	Economic instruments
Feed-in tariffs/premiums	Economic instruments
Finance	Economic instruments
Financial	Economic instruments
Fiscal	Economic instruments
Funds to sub-national governments	Economic instruments
Grants	Economic instruments
Investment in assets	Economic instruments
Loan guarantee	Economic instruments
Loans (incl. concessional loans)	Economic instruments
Loans / debt finance	Economic instruments
Market-based Instruments	Economic instruments
Payments and transfers	Economic instruments
Payments, finance and taxation	Economic instruments
Performance-based payments	Economic instruments
Rebates	Economic instruments
Tax credits and exemptions	Economic instruments
Taxes, fees and charges	Economic instruments
Comparison labels	Information and education
Consumer information	Information and education
Education and training	Information and education
Endorsement labels	Information and education
Energy / CO2 performance certification	Information and education
Energy / CO2 performance labels	Information and education
Government provided advice	Information and education
Information and education	Information and education
Information campaigns	Information and education
Information/training	Information and education
Professional / Vocational training and certification	Information and education
Public information	Information and education
Compliance requirements	Policy support
Framework legislation	Policy support
Major infrastructure plan	Policy support
Mandatory reporting	Policy support
Mandatory technology use	Policy support

Continued on next page

Appendix 2 – continued from previous page

Instrument Type	IEA’s Taxonomy
Prohibition	Policy support
Public procurement	Policy support
Reporting	Policy support
Strategic plans	Policy support
Targets	Policy support
Urban planning	Policy support
Audits and inspections	Regulatory instruments
Building code (Prescriptive)	Regulatory instruments
Building codes (performance-based)	Regulatory instruments
Building codes and standards	Regulatory instruments
Codes and standards	Regulatory instruments
Mandatory energy management system	Regulatory instruments
Mandatory information	Regulatory instruments
Mandatory standards	Regulatory instruments
Minimum energy performance standards	Regulatory instruments
Monitoring	Regulatory instruments
Obligations on average types of sales / output	Regulatory instruments
Other regulatory instruments	Regulatory instruments
Performance-based policies	Regulatory instruments
Permitting processes	Regulatory instruments
Prescriptive requirements and standards	Regulatory instruments
Product certification	Regulatory instruments
Product-based MEPS	Regulatory instruments
Regulation	Regulatory instruments
Renewable / Non-fossil energy obligations	Regulatory instruments
Rights, permits and licenses	Regulatory instruments
Safety standards	Regulatory instruments
Targets, plans and framework legislation	Regulatory instruments
Inducement prizes	Research, development and deployment
Awards	Voluntary approaches
Negotiated agreements (public-private sector)	Voluntary approaches
Voluntary approaches	Voluntary approaches
Voluntary reporting	Voluntary approaches
Energy	None
Equity	None
General programme	None

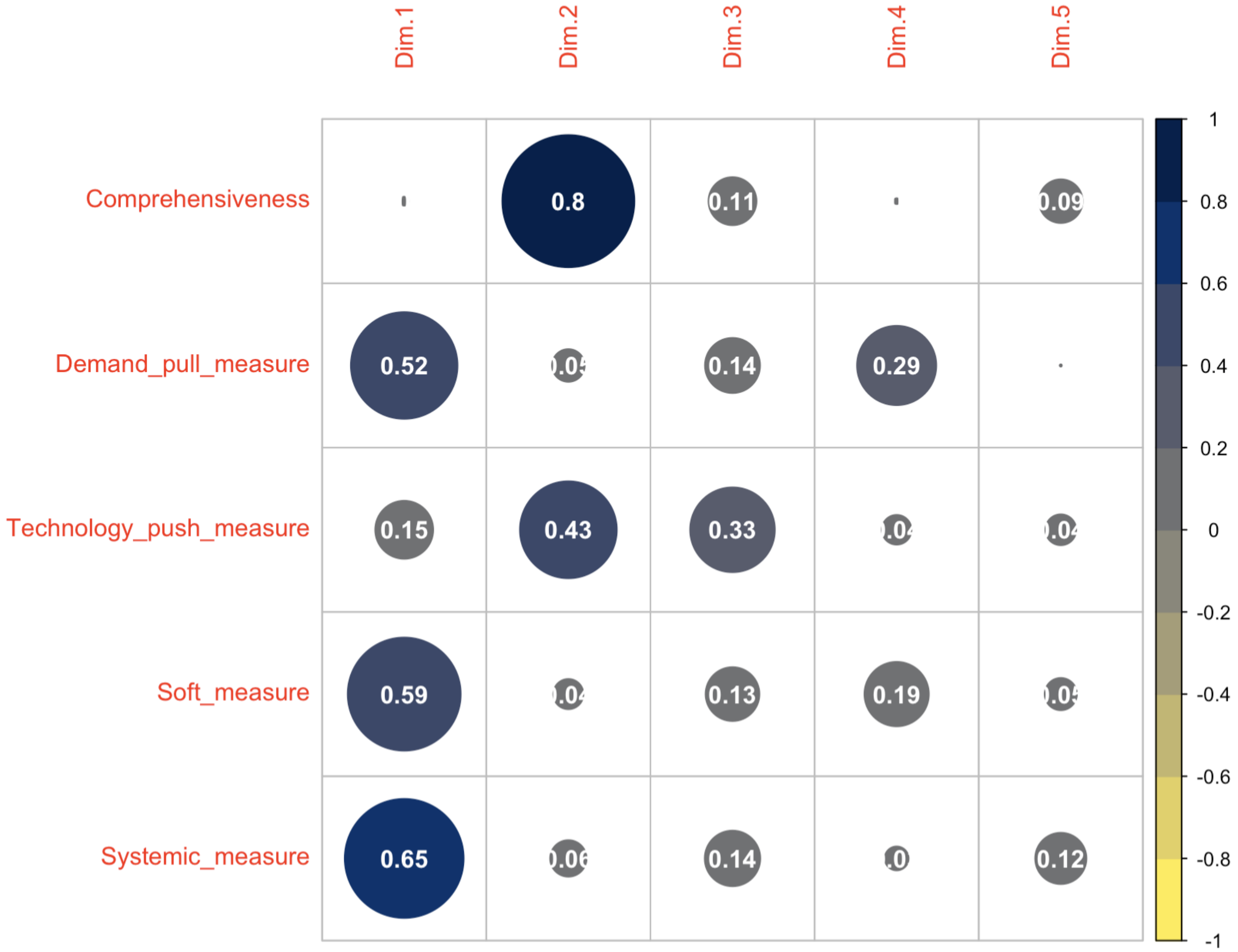
Appendix 3. Stability of KRD (domestic cumulative stock of R&D investment in energy efficiency in the building sector) per percentiles (0.1 to 0.2 by 0.01) for each EU member state



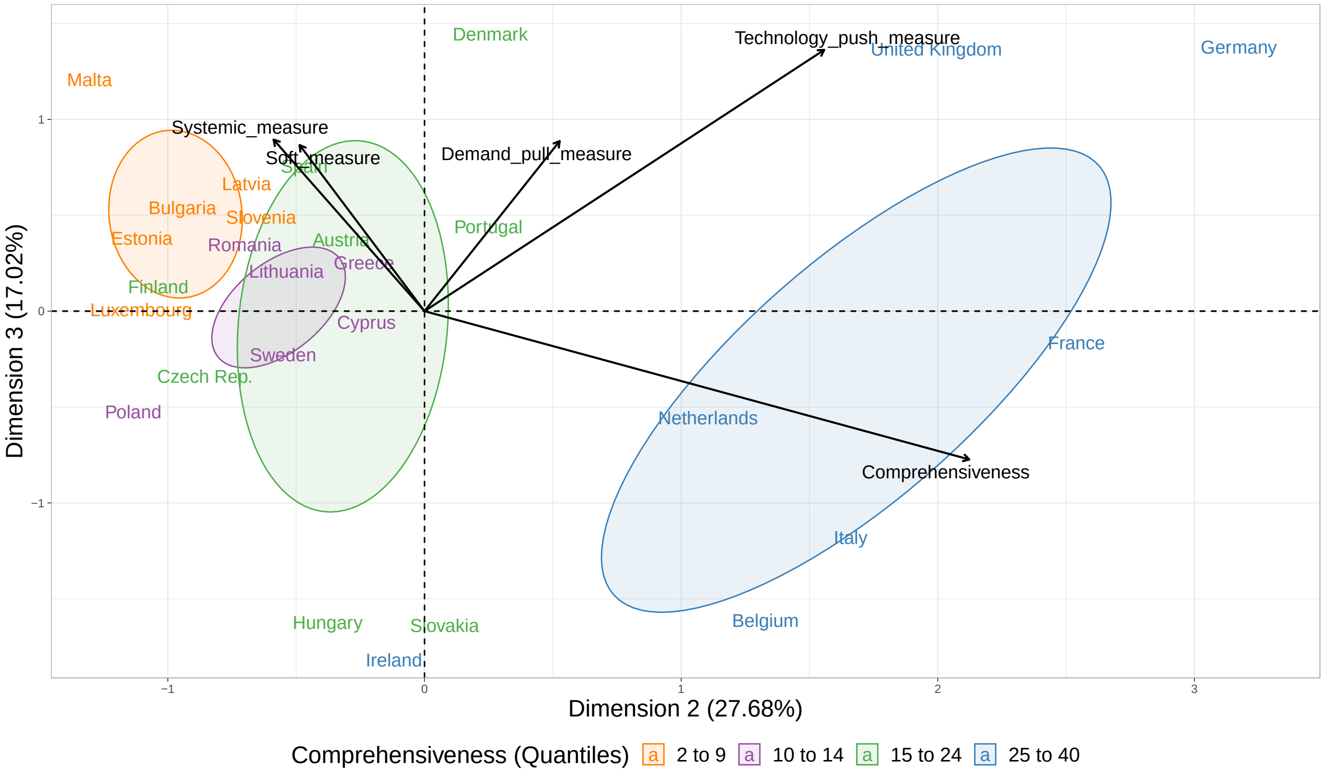
Appendix 4. International Energy Agency taxonomy *(e.g. Costantini et al., 2020,1)*

Policy Type	Instruments
Economic	• Direct investment • Fiscal/financial incentives • Market-based instruments
Information and Education	• Advice/aid in implementation • Information provision • Performance label • Professional training and qualification
Policy Support	• Institutional creation • Strategic planning
Regulatory Instruments	• Auditing • Codes and standards • Monitoring schemes • Obligation schemes • Other mandatory requirements
Research, Development and Deployment (RD&D)	• Demonstration projects • Research programmes
Voluntary Approaches	• Negotiated agreements • Public voluntary schemes • Unilateral commitments

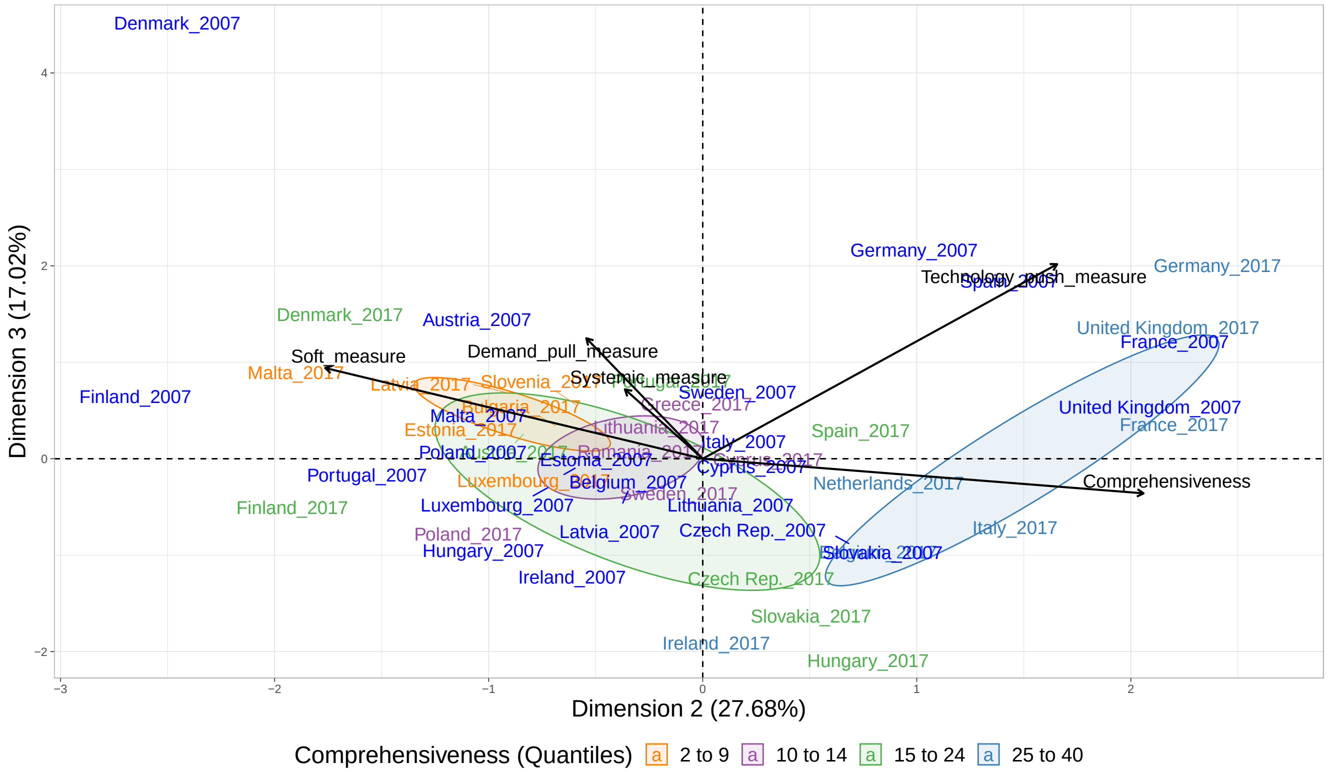
Appendix 5. Correlation matrix - dimensions of the PCA & policy mix features



Appendix 6. PCA 2nd & 3rd dimension - energy efficiency policy mixes in the residential sector (2017)



Appendix 7. PCA 2nd & 3rd dimension - including supplementary individuals - energy efficiency policy mixes in the residential sector (2017)



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