

Faculty of Engineering

University of Porto

“Analysis of energy policies: multidisciplinary, data driven tool.”

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Porto, Portugal

September 2021

Submitted to the Faculty of Engineering of the University of Porto
in fulfilment of the requirements for the degree of Doctor
of Philosophy in Sustainable Energy Systems

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Thesis developed in the frame of the MIT-Portugal Program

Acknowledgments

First, I would like to express my deepest gratitude to all the people who contributed to my learning and maturity, including the Professors of the MIT Portugal Program and from the Massachusetts Institute of Technology.

I would like to thank my supervisor Professor Vítor Leal for all his guidance, support and patience. Thanks for teaching me objectivity and precision. The insights provided by Prof. Leal were invaluable.

My grateful recognition to my co-supervisor Prof. Vera Miguéis for the constructive exchange of ideas and support, her professionalism and kindness.

Thanks must also be extended to Zenaida Zóbral for her support and discussions on particular points.

I would like to recognize the work of Célia Couto, and her support, crucial for the administrative tasks of this thesis, and her advices and support as a foreigner in Portugal.

I would like to recognize the never-ending support of my MIT Portugal program colleagues, and the community and friendship that we have made. Thanks Kashif, Aqsa, Fátima. I am deeply indebted to all the people who provided valuable content and references for this thesis and participated in the stages of planning and modeling.

I also acknowledge the Consejo Nacional de Ciencia y Tecnología (CONACYT), as my granting institution.

My grateful thanks to my family, to my parents: Georgina & Jorge, my uncles: Paty, Jose Luis & Javier and my siblings: Geor & Jorgito for their constant support and care, and their unconditional love.

My deepest gratitude to all the people in the European and American continent who supported me along this process, thanks for your friendship!

Finally, I would like to thank Jörg-Michael and my family in Germany that have been to my side, boosting my energies and lifting my spirit. Thanks for being an inspiration, your never-ending positivity and love.

Abstract

A decision-making support tool is proposed based on a data-driven methodology through energy policy analysis.

The methodology relies on an energy policy effectiveness characterization through multidisciplinary characteristics. Several concerns have been identified under four categories: Economic, Environmental, Social and Institutional. They have been grouped into eight condensed concerns, according to their ends objective, with the purpose of keeping the essence behind all the concerns and include them in the proposed assessment. For each of the condensed concerns, at least one indicator has been identified as an assessment metric. As the following step in the structuring of a policy decision-making process, the policy options, in the form of technical measures and instruments, have been identified and organized by their characteristics. At this stage, there was a focus on Domestic Water Heating policies.

As to select the methodology that better suits the elaboration of a support tool based on the analysis of past data, qualitative and quantitative methodologies were reviewed. Machine Learning (Decision Tree) was selected to be used.

Decision Trees techniques were applied to the dataset conformed by the predictors (including the effectiveness concerns and the policy options) of Renewable Energy support policy mixes in the European Union from the year 2004 to 2018.

A policy effectiveness index has been elaborated as a complementary work as the data gathered and structured enables its calculation.

Machine Learning results provides granulated information (including visual representations, classification rules, policy profiles, significant variables identification). The index results include the ranking of countries performances.

Sumário

É proposto um instrumento de apoio à tomada de decisões baseado numa metodologia orientada por dados através da análise da política energética.

A metodologia baseia-se numa caracterização da eficácia da política energética através de características multidisciplinares. Foram identificadas várias preocupações em quatro categorias: Económica, Ambiental, Social e Institucional. Foram agrupadas em oito preocupações condensadas, de acordo com o seu objetivo final, com a finalidade de manter a essência por detrás de todas as preocupações e de as incluir na avaliação proposta. Para cada uma das preocupações condensadas, foi identificado pelo menos um indicador como métrica de avaliação.

Como passo seguinte na estruturação de um processo de decisão política, as opções políticas, sob a forma de medidas e instrumentos técnicos, foram identificadas e organizadas de acordo com as suas características. Nesta fase, foi dada ênfase às políticas de Aquecimento Doméstico da Água.

Quanto à seleção da metodologia que melhor se adequa à elaboração de um instrumento de apoio baseado na análise de dados anteriores, foram revistas metodologias qualitativas e quantitativas. Foi selecionada a Machine Learning (Árvore de Decisão).

As técnicas de Árvore de Decisão foram aplicadas ao conjunto de dados conformados pelos preditores (incluindo as preocupações de eficácia e as opções políticas) das combinações de políticas de apoio às Energias Renováveis na União Europeia desde o ano de 2004 até 2018. Foi elaborado um índice de eficácia das políticas como trabalho complementar, uma vez que os dados recolhidos e estruturados permitem o seu cálculo.

Os resultados de Machine Learning fornecem informação granulada (incluindo representações visuais, regras de classificação, perfis de políticas, identificação de variáveis significativas). Os resultados do índice incluem a classificação do desempenho dos países.

List of Abbreviations

AI	Artificial Intelligence
BASE	Bielefeld Academic Search Engine
CBA	Cost-Benefit Analysis
CHAID	Chi-squared Automatic Interaction Detection
CHP	Combined Heat and Power
CLM	Institutions and Measures
DHC	District Heating and Cooling
DHW	Domestic Hot Water
DOAJ	Directory of Open Access Journals
DT	Decision Tree
EAPI	Energy Architecture Performance Index
EP	Energy Policy
EPEI	Energy Policy Effectiveness Index
FAO	Food and Agriculture Organization
FN	False Negative
FP	False Positive
FIT	Feed in Tariff
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GJ	Gigajoules
GHDI	Human Development Index
HDM	Hierarchical Decision Model
HICP	Harmonised Indices of Consumer Prices
IEA	International Energy Agency
ISE	Index of Sustainable Energy
kgoe	Kilograms of oil equivalent
kWh	Kilowatt hour
MCDA	Multi Criteria Decision Analysis
MCDM	Multi-criteria Decision Making
MEPS	Minimum Energy Performance Standard
Mtoe	Million tonnes of oil equivalent
ML	Machine Learning
NGO	Non-Governmental Organization
NN	Neural Networks
OLS	Ordinary Least Squares
QCA	Qualitative Content Assessment
RE	Renewable Energy
RES	Renewable Energy Sources
RF	Random Forest
ROA	Real Options Analysis
ROA	Return on Assets

SMART	Specificity, Measurability, Attainability, Reliability and Time-bound
SPSS	Statistical Package for the Social Sciences
SSRN	Social Science Research Network
STO	Strategic, Tactical, and Operational
STW	Solar Thermal World
SVM	Support Vector Machine
SWH	Solar Water Heater
TES	Total Energy Supply
TN	True Negative
toe	tonnes oil equivalent
TP	True Postive
WHS	Water Heating Systems

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Chapter 1 Introduction

1.1 Context & Motivation

Energy Policies (EP) aim to generate solutions in which an equilibrium of security of supply, economic competitiveness and environmental compatibility is achieved. In addition, environmental governance has become one of the major drivers of countries' international and local agendas and a shared task among international organizations to define their strategies. This situation has resulted in continuous efforts on the creation and implementation of policies to mitigate and reduce climate change.

This evolution has had some disruptive moments as the Kyoto Protocol and the Paris Agreement (UNFCCC, 2018), where countries settle common and individual goals to improve the present and future environmental situation. The adaptation from the countries to reach the settled goals can vary considerably, depending on their country characteristics (industrial needs, economy, climate and weather conditions among other criteria). Countries select their own energy strategies through policies and plans to achieve their goals.

The available policy alternatives can vary in not only the time scope and place of their application, but also their type, resources, orientation, among other resources. Nevertheless, time, money, and other valuable resources (as the non-reduction of Greenhouse Gas emissions) are invested in the application of energy policies, where not all of them have the objective achievement that is intended. This last is the major motivation of this research, aiming to enhance the objective achievement of energy policies through their analysis.

This research will develop a support tool for decision-makers at different scopes and places to promote the adjustment or elaboration of more effective energy policies. This assessment tool will allow to analyze policies from a multidisciplinary perspective using predictive analytics.

Even as every country has very particular needs and features from the energy perspective, the proposed characterization may ease to countries that share similarities to learn from other experiences, letting countries explore synergies with regions that have similar characteristics. Similarly, the learning curve from past experiences within the same country is expected to be supported.

The support tool developed will be tested for Renewable Energies (RE) support policies, due to their importance for sustainable energy systems and availability of data.

To fully understand the energy policy process, a list of questions is now presented that establish the context for the subsequent formulation of the research objectives and questions. In order to organize the information that is related to these questions, relevant examples that were found have been summarized.

1.1.1 What is energy planning?

Finding a specific definition for energy planning in the literature can result very challenging; even if there is a considerable amount of available information related to it, there is not an explicit definition of it. The importance that the topic has gained in different contexts (public and private), magnitudes (national, regional, and urban), and subtopics

(transportation, buildings, industry, etc...) can be perceived through the increasing amount of entities elaborating their energy plans.

As referred by some authors, there is a lack of common agreement on the energy planning definition (Prasad et al., 2014). Energy planning can be considered as the way for determining the optimal mix of energy sources to satisfy a given energy demand (Thery and Zarate, 2009), or as the way to balance the spatially localized energy supply and demand of a given area (Keirstead et al., 2012). In any case, energy planning involves the organization of the resources to comply with the energy needs in an area.

From an energy-institutional perspective (by an institution is understood as an organized and formal entity, foundation, or the like), there is not an exact or standardized description for the concept of energy planning.

Energy plans act as the execution documents of energy planning. They cover different subtopics (e.g. Housing, Waste Management, Regional Spatial Strategies, etc...). Intending to complete the understanding of energy planning, energy plans examples are now presented in Table 1. The documents here presented are just a representative sample of the examples available in the literature. No specific criteria or search procedure was followed at this point yet.

Table 1 Examples of Energy Plans and their objectives

Document Name	Reference	Observations	Scope
Minnesota Local Government Project for Energy Planning	(Minnesota Local Government, 2018)	Differentiation by city type. Energy planning templates for use in the 2040 comprehensive planning process	Local
Ontario's Long-Term Energy Plan	(Ontario Authority, 2018)	Document under development, but it highlights the feedback input from people across Ontario.	Local
Community Energy Plan	(Region of Waterloo, 2018)	It is influenced by the Official Plans, Climate Action Plans and Economic development ones.	Communal
County Energy Planning in Kenya: Local participation & solutions in Migori County	(Stockholm Environment Institute, 2018)	Considers citizen participation	National
New York State Energy Plan	(NASEO 2018)	An integral scope is considered (coordinating every State agency and authority regarding energy).	State
Vermont Comprehensive Energy Plan and Electric Plan	(Vermont Department of Public Service, 2018)	Comprehensive approach for all the Stakeholders	Local
Sustainable Integrated Urban & Energy Planning	(The Centre for Urban Energy Ryerson University, 2018)	Lessons learned from 'mega cities' around the world	Local

Document Name	Reference	Observations	Scope
Low Carbon Energy Plan	(Greater Birmingham and Solihull Local Enterprise Partnership's, 2018)	Particular focus on investment and funding	Local

1.1.2 What is an energy policy?

Energy Policies represent the alternatives and actions to execute an energy planning strategy. Even if energy policies accounts as one of the cornerstones of any energy plan, it was also challenging to find their definition in the literature. It was necessary to clear the term of policy itself. Policy is defined as a set of ideas or a plan of what to do in particular situations that have been agreed officially by a group of people, a business organization, a government, or a political party (Cambridge Dictionary, 2019).

From the wide concept that the term “policy” encompasses, it can be said that a policy is not just an independent decision; it is a set of coherent decisions with a common long-term purpose (FAO, 2017).

Policy mix is another relevant component present in the regulatory strategy of a country. They account for the interactions and interdependencies between different policies as they affect the extent to which policy goals are realized (Flanagan et al.2020).

Energy policies can fall into one or more categories (types). Some examples include (Bajay, 2004):

1. Energy security: different policies can be included under the security topic, addressing the short term and long-term availability of resources. For the short-term, the risk of physical unavailability in case of a supply disruption includes not only the resources themselves, but the grid infrastructure or issues as smart grids and remote connection. While the long-term, is more related to improve energy security, through better resources and technologies, therefore can include subtopics as renewable energy, geopolitical relationships, energy efficiency, among others.
2. Energy economics: the policies that are normally found under this topic are under the regulation related with the design and functioning of the energy market, as prices and subsidies, investment frameworks, financial mechanisms, taxation, together with the interest and welfare of the different participants involved.
3. Energy environmental: about the environmental related policies, not only the Greenhouse Gas (GHG) emissions related issues are normally included in this area, but also the overall environmental resources management, energy wastes and their relationship.

Naturally, energy policies can also consider in conjunction some or all of the categories above.

Policies are normally executed through instruments or mechanisms that enable the implementation of the technical measures. Technical measures refer to the actions that imply an actual change in the energy system and are implemented with the goal of achieving the established policy objectives. Policy instruments are tools of governance to influence targeted individuals or a group's behavior in order to achieve strategic public objective

(Howlett & Howlett, 2017). Policy instruments can be considered as mechanisms that promote or support the implementation of the technical measures.

1.1.3 Who are the Energy Policy stakeholders?

Stakeholders refer to individuals, groups, or institutions with interests or concerns in an organized state of affairs, and can be impacted by the organization's activities, targets or policies (Yudha & Tjahjono, 2019). Stakeholders can be organized into the next three categories, according to their level of impact (Miron & Preda, 2014):

1. Key stakeholders: they have a significant influence on the project and can be important to the success of the project.
2. Primary stakeholders: individuals, groups, or a combination of both that can be affected positively or negatively by a project who has an impact on them.
3. Secondary stakeholders: entities in the process of delivering the activities comprising the project. They can be influenced positively or negatively. Sometimes they take part in the decision-making process.

When identifying the energy system stakeholders according to their legal identity, five categories of actors can be identified (Dallamaggiore et al., 2015):

1. Private organization: company, professional organizations, etc.
2. Public organization: central and local governments, justice authority, university, etc.
3. Private-public organization: private-public company etc.
4. Other organizations and associations: Non-Governmental Organization (NGO), consumer association, think tank, lobby, etc.
5. Individuals: individual politicians, religious leaders, social media users, etc.

It was identified a classification according to the stakeholder's functions (WBCSD, 2012):

1. Share knowledge and build trust: Academia, School, Community & NGO.
2. Receive electricity & Gas: residential, individual and industrial customers.
3. Procure services: contractors.
4. Purchase Fuel Materials & Equipment: suppliers.
5. Provide License to Operate: regulators.
6. Deliver Investments & Results: investors/shareholders, partners, lenders, insurers.
7. Energy utilities and prosumers: produce energy.

The previous identified stakeholders' types have been applied to the examples of energy plans (presented in Table 2).

It is worth saying that when classifying the stakeholders by type, the category can vary depending on the project or, in this case, on what are the objectives, different tasks and therefore roles to be taken by each stakeholder.

Regarding the functions, additional functions as the ones provided by the selected classification can be added. The energy authorities and governmental authorities do not only provide the license to operate, but they regulate and implement policies. Similarly, International agencies share knowledge, but also observe, evaluate and do recommendations over policies. Direct cross-sectorial authorities (e.g. Sustainability/Climate change/Environment authorities) can observe, evaluate and recommend, but they can also be part of the implementation of the policy. Non-direct cross-sectorial authorities like from health, agriculture and other topics can also give their opinions and recommendations.

Table 2 Examples of stakeholders participating in energy plans

Stakeholder	Level of impact	Legal identity	Functions
Energy authorities	Key	Public	Provide License to operate
Other governmental institutions	Key	Public	Regulate and implement policies
International agencies	Secondary	Public	Observe, evaluate and recommend
Energy efficiency commission	Primary	Public	Regulate and implement policies
Energy utilities and prosumers	Primary	Public, private or private-public	Supply energy
Consumers	Primary	Private	Utilize electricity & gas
Academia (Universities, RD&I)	Secondary	Public or private	Share knowledge and build trust
NGOs	Secondary	Other organizations and associations	Share knowledge and build trust
Civil Society	Primary	Other organizations and associations or individuals	Share knowledge and build trust
Consultancy groups	Secondary	Private	Share knowledge and build trust
Labour markets representatives	Secondary	Other organizations and associations	Share knowledge and build trust
Other participants of the energy chain	Primary	Private	Procure or purchase services or goods
Cross-sectorial authorities (direct and indirect)	Secondary	Public	Observe, evaluate and recommend

1.1.4 Who participates in the energy policy process?

Different actors (from the stakeholders) can be accounted across the different stages of the energy policy process. Even during each stage of the process, a variety of participants can be mentioned. A search of the agents that can participate as direct decision-makers in the policy creation stage (and specifically related to the creation of energy plans) has been done. This has been done with the aim to identify the main users of the support tool in which this thesis is focused, the most popular participants include:

1. International, national and local authorities with direct responsibility in energy strategies.
2. National and local authorities from non-direct energy areas (mainly health, agriculture, transportation).

3. Energy/Sustainability/Climate change/Environment authorities.

As mentioned, the participants vary widely across the energy plans. However, a constant that can be noted in some energy plans and that is translated into participants that can be considered in the energy planning process, is civil society. Even if they do not directly participate as decision-makers, consultancy of civil society can be observed across documents. Some other stakeholders that may participate in the energy plans are private energy consultants, company strategic planners, and urban development planners.

About the link between urban planning and energy planning, the connection among them occurs in a bidirectional way, emphasizing the inextricable link between these areas (Madlener & Sunak, 2011). This situation recalls the importance of urban development planners, as participants.

Regarding the level of administration, state, regional and national levels can be seen. The national and regional ones are often coordinated with the national authorities. Some subtopics and their policies are normally in the hands of state government e.g. urban transport, city planning, building codes, etc... It requires to be consistent with the overall energy policy strategy of a country (Office of the Indian Energy Policy and Programs, 2014).

Some authors agree that the transition towards renewable energy sources requires a stronger involvement of municipalities in the energy planning process, arguing that municipalities should be recognized as official energy planning authorities (Sperling et al., 2011).

As one of the energy plans reviewed, the New York State Energy Plan (New York State's Energy Planning Board, 2016) was coordinated by the State's Energy Planning Board, whose members belong to different sectors and whose participation aims to provide a multi-sectoral perspective to the project (as energy connected agencies). Some of its participant members are the Department of Transportation, the Department of Health, the Department of State, the Department of Labor, the Division of Homeland Security and Emergency Services, the Agriculture and Markets.

Overall, there is not a rule about the participants of the policy process, the policy creation or policy plans, varying widely across the world. Some examples of energy planning participant organizations are given in Table 3.

Table 3. Examples of organizations participating in energy planning

Organization or agent	Document/Webpage Name	Observations	Reference
Department of Energy-South Africa	Integrated Energy Planning Process	Use of scenarios assessment	(South African Department of Energy, 2013)
United Nations Food and Agriculture Organization(FAO)	Methodology and design for integrated energy planning for sustainable agriculture and rural development	Proposes a methodology for rural communities in developing countries with a multidimensional perspective	(FAO,2018)

Organization or agent	Document/Webpage Name	Observations	Reference
Office of Indian Energy Policy and Programs	Office of Indian Energy Policy and Programs	It gives insight into efficiency and conservation strategies and identifies valuable opportunities to further reduce future energy costs through new programs and activities	(Department of Energy, 2018)
Enervision	Total Energy Planning	Incorporates energy innovation, renewable energy and traditional generation resources in defining	(EnerVison, 2018)
New York State's Energy Planning Board	New York State Energy Plan	Focuses on meeting projected future energy demands, keeping a balance with economic development, climate change, environmental quality, health, among other elements.	(NYSEPB, 2018)
Queensland Government, Department of Infrastructure, Local Government and Planning	State Planning Policy- State interest guideline Energy and water supply	Define the specific matters of state interest in land use planning and development.	(State of Queensland, 2017)

1.1.5 What decisions are made for the energy plans' design?

The methodology of the creation of an energy plan varies from one source to the other, and further analysis is required to detail the process itself. For the different documents that have been reviewed, some common approaches, similarities and differences can be highlighted.

In most of the included examples, it is easy to identify the consideration of main drivers and aims, as the framework providers to develop the energy plan. Driver's definition can act as the cornerstone for the objectives and purpose articulation of energy planning, leading to a prioritization of expected impact, and therefore influencing the selection of energy policies and their instruments.

Another feature to be mentioned that is crucial for the development of a plan is the scope definition, as the range (national, local, municipal or other) of the expected impacts of the defined mechanisms and instruments, whereas its main variation relies on the purpose of the project.

The time scope is another relevant feature to be categorized, where a medium to long-term perspectives tends more frequently to be applied than short-term ones. This is probably explained that policies and their instruments are the tools to execute the actions of a strategical perspective, where the decisions taken will be normally reflected in a longer period than the present.

Finally, deciding the policies themselves (through the policy programs) becomes the center of the decision. It includes the definition of the instruments and measures to be implemented. It is crucial to be matched with the needs, constraints and requirements of the objectives of the energy policies. The focus of this thesis is to support the policy decisions.

1.1.6 What drivers influence the policy choices to be taken during the decision-making processes?

The policy choice is normally located at the beginning of the policy process, most of the time after the problem and goal definition. For some policy structures, it can happen as a subsequent step of the continuation or modification of a policy (not starting from scratch), whereas, an existing policy has been evaluated and adjustments are to be done (European Commission, 2017). An ex-ante policy evaluation (conducted before the policy implementation) is another moment in which the policy choices analysis are normally considered (Nispen, 2011).

A relevant aspect behind the policy choice is the policy participants of the process. The decision-maker is in charge of including or not certain opinions and needs. The literature on policy instrument selection describes a linear process taken by rational policymakers (Weimer and Vining, 2004). In addition, the policy choice can happen at different decision-making levels (Hansson et al., 2011).

Very different factors can drive the choice of policy instruments. The policy selection will vary according to the criteria selected by the policymakers, influenced by their values, priorities, and other considerations.

The choice enables to include the constraints and opportunities around a circumstance (Haddad, 1995). A careful choice of instrument to fit the circumstances in the best possible way should weigh the pros, cons, costs, and benefits of each option. The assessments can include from the general concerns like natural conditions and country-specific factors (Gawel et al., 2016), to the market characteristic and other considerations. Detail on policy choices are given in the following paragraphs.

In the literature, some interest has been given to the problem definition as a core decision driver, where the issue nature is one of the choice focus (Oosterhuis, 2006) (Pegels et al., 2018), together with the changing needs derived from the problem features (Dimitriou, 2015) and the changing needs of the system as a whole (Borrás & Edquist, 2013). This approach relies on the consideration of the problem as the cornerstone for the choice.

Another approach, instead of focusing on the problem, relies on the policy instrument nature (Dimitriou, 2015) (Howlett et al., 2015). It has also been found that the evolution of the policy instrument can be considered for the choice process (European Commission, 2017) (Gawel et al., 2016). By evolution, it is meant the consideration of the previous instruments used to tackle the targeted issue but could also refer to a continued plan or strategy that will include different stages, and selecting the most suitable option for each stage. For a policy evolution approach, considering long-and short-term processes of the policy change can be done (Rao & Woolcock, 2003).

Policy efficiency as another large assessment concept has also been identified as a driver, and it relates the resources used for achieving some targets (Prontera, 2016) (Persson, 2007).

Some instruments can be chosen with the aim of promoting innovation and technological stimulation (Oosterhuis, 2006) (Goulder & Parry, 2008). Under this example, the policy choice will be influenced by the stage where the innovation process is

selecting the most suitable option for the different stages. Disruptive technologies normally require some type of instruments, compared to other stages of the technology where other policy options may be required to achieve the stage objectives. Some policies may directly promote new technologies' invention, while others can be focused on promoting their deployment. This approach includes the technical elements involved in a policy (European Commission, 2017).

The cost consideration has also been found in several documents, either specified as cost-effectiveness (Kotchen et al., 2011) (Goulder & Parry, 2008) or as budgetary constraints around a policy or a country. Both policy budgets and countries' socio-economic contexts are big drivers that enable the consideration of the policy implications for the economy and different social and economic groups within the territory.

With an economic and equity base, considering energy security, through both energy intensity and dependency reduction, is another driver to be considered for the instrument selection (Hansson et al., 2011).

Regardless of the costs behind a policy instrument, some policymakers will be guided by a broader goal, as could be meeting emissions targets invariant to the instrument choice and their costs (Kotchen et al., 2011).

Stakeholder's consideration has been found in many documents, however, two larger trends have been observed. The first approach is related to the equity of the choices, as the distribution of impacts, cost, and benefits (Dimitriou, 2015) (Goulder & Parry, 2008) (Hansson et al., 2011). The second approach, about the maximization of Stakeholders' benefit, aiming to increase Political support and acceptability from them (Persson, 2007) (Bouwma et al., 2015). This last alternative enhances the decision maker's interests that may also, drive the political behavior behind the choice process, and is closely related to benefiting certain stakeholders group.

Some Policymakers will consider the reaction of interest groups to various policy proposals. Known as behavioral considerations, the concept involves the reactions that the target groups can have (European Commission, 2017). The consideration of actors can consider the needs of large industrial clients and lobbies (Prontera, 2016) (Gawel et al., 2016). For the energy sector, the industrial clients and their representatives can be influential actors, because of their large use of energy in their production processes, becoming relevant actors around an instrument decision. Whenever it is aimed to benefit or not a group of stakeholders, some biases for the instrument choice can be created, strengthening or weakening the position of an actor (Nispen, 2011).

The institutional framework includes different concerns regarding the context of an instrument and its political and institutional actors and context. In the institutional framework, regulatory interactions are included (Dimitriou, 2015); they can focus linking and relating the flexibility trade-off among policies and their interconnection across jurisdictions (Dimitriou, 2015) (Prontera, 2016) (Goulder & Parry, 2008).

What can be named as Network attributes, meaning the actor's structure in which a policy will be designed and implemented may be relevant as the context for the policy implementation (Bressers & O'Toole Jr., 1998). Besides the implementation requirements,

and as another way to consider stakeholders, weighting and prioritizing the policy compliance by the participating actors and ensuring the implementation of the instruments through the actor's capabilities can be crucial for the instrument choice (Bouwma et al., 2015).

The political feasibility, as the condition of the policy for being supportable by existing institutions, involves the legal system, the human capital and the infrastructure (Persson, 2007). It can also include the consideration of the Governmental level of policy implementation (Oosterhuis, 2006), being National, International, or Local, a single approach or the combination of them is feasible.

Another element under the Institutional framework is what is known as political style (Bressers & O'Toole Jr., 1998), emerging from the policymakers' values and political ideology (Nispen, 2011). Additionally, the institutional framework refers to the capability, as the institution's capacity, experience, and familiarity with the issued topic (Borrás & Edquist, 2013) (Peters & Nispen, 1998). Policy choice requires a certain degree of adaptation to the circumstances of public administrators.

Externalities influence the policy choice (Goulder & Parry, 2008) (Gawel et al., 2016). Externalities are the representation of the market defects and the best way to regulate them is through their consideration in the policy choice. Externalities, as a type of market failure, can cover different areas, referring to the monetization of the costs behind a policy; these involve environmental, social or other costs. Some stakeholders can be reluctant to externality consideration as often the costs to comply are paid by the involved actors (Bouwma et al., 2015).

Climate change through different parameters is a strong driver for the policy choice (Houle & Macdonald, 2009), particularly differences in the policy choice can be taken as how climate change is considered, from an environmental threat perspective, the focus on its mitigation, or even considering it as offering economic development opportunities (Houle & Macdonald, 2009). A wide variety is available, as an answer to these variations, from market base instruments to coercive policy instruments. Climate change could be held under a local, regional, national or international framework, options that will also influence the instrument choice.

GHG emission reductions, explicitly as a significant driver, have also been found (Houle & Macdonald, 2009) (Goulder & Parry, 2008) (Kotchen et al, 2011).

The International environment as an influence driver has also been present in the reviewed literature (Houle & Macdonald, 2009), whereas international agreements and regulation act as the umbrella to provide direction to the policymakers and their choices, e.g. the Kyoto protocol was found to be considered as the main guideline to define instruments for different industries while the protocol was active (Prontera, 2016). The international environment is important for the international interconnection, through the relationships existing between states, markets and civil society organizations (Howlett et al., 2015).

The opposite of an international approach may focus on the country context, meaning giving a country an internal approach to the process. This situation may recall to the focus

on the domestic nature of the concerns that enable to select one option instead of other available options (Persson, 2007) (Pegels, et al., 2018) (Goulder & Parry, 2008) (Prontera, 2016) (Hansson et al., 2011) (Gawel et al., 2016).

Independently of an international or country prioritization, both approaches can still be combined in a unique approach; nevertheless, the weights given to each may differ.

1.1.7 What support tools are available to contribute to the decision-making processes?

By tools, in general it is understood as something that helps to do a particular activity (Cambridge Dictionaryb, 2018). In the case of Energy policy design, tools can serve e.g. to model possible outcomes from different policy options or study the application of policy options in different places or time-periods. The use of tools contributes to the achievement of energy policies’ objectives (whether or not explicitly defined in the energy plans).

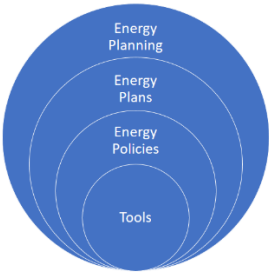


Figure 1 Scope of Energy Planning, Plans, Policies and Tools.

Two broad support tool categories can be mentioned. First, the models to analyze energy policies, normally based in a methodology for assessing the technical options under selected attributes and in some cases the incorporation of weights (e.g. models that use Multi Criteria Decision Analysis). Second, policy guidelines and handbooks that act as framework support documents to support the creation of energy plans. Models are often used to support a guideline elaboration, creating a mixed approach (Figure 2).

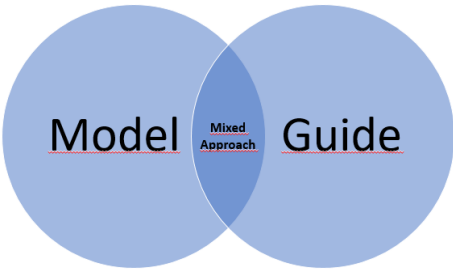


Figure 2. Energy planning tool types

The first tools examples enlisted by the search engine Google (Google, 2018), under the key words of “Energy Planning tools” are presented in Table 4.

Table 4. Examples of energy planning guidelines and tools

Document Name	Reference	Observations
State Energy Planning Guidelines	(National Association of State Energy Officials, 2018)	A guide to develop a comprehensive State Energy Plan plus supplemental policy and program options.
Municipal Energy Planning An Energy Efficiency Workbook	(University of Wisconsin-Extension, 2017)	Organized as a workbook, it provides a blueprint for developing an energy efficiency plan.
Guidance for Municipal Enhanced Energy Planning Standards	(Vermont Natural Resources Council, 2017)	It is a tool for decision making on practical steps to accomplish our goals.
City-Level Energy Decision Making: Data Use in Energy Planning, Implementation, and Evaluation in U.S. Cities	(National laboratory of the U.S. Department of Energy, 2015)	It aims to enable cities to lead clean energy innovation and integrate strategic energy analysis into decisions by providing standardized, localized energy data and analysis.
Planning for Renewable Energy: A Companion Guide to PPS22	(UK Government, 2004)	Offers practical advice as to how policies can be implemented.
Policy Guide on Energy	(American Planning Association, 2018)	Orientation document; it focuses on energy economy and resilience.
Cornwall Renewable Energy Planning Advice	(Cornwall Council, 2016)	Advice provision platform, from general to specific guidance.
Community Energy: Planning, Development and Delivery	(Combined Heat and Power Association & other associations, 2010)	Developed to support energy project developers.
Low Carbon Neighborhood Planning	(Centre for Sustainable Energy, 2010)	This guidebook has been developed to help communities develop a neighborhood plan.
Methodological guidelines for the development of Sustainable Energy Communities and Systems in urban decentralized areas of the Mediterranean Region	(European Commission, 2014).	The document recognizes similarities among the communities in the Mediterranean area intending to ease the replication of the suggested policies within the locations that share geographical and ethnographic characteristics.
Community Energy: Planning, Development and Delivery	(International Energy District Association, 2018).	This guide aims to help planners and project developers understanding the creative process of energy maps to be included in master plans or development plans. It also eases the identification and translation of energy opportunities into viable projects.

1.2 Research objectives

The main objective of this research is to create a tool that makes more objective and efficient the decision-making processes for energy policies at different levels. An “effectiveness in mind” approach is sought to be promoted through this thesis. To do so, policies from the past are analyzed to support the design of new ones, focused in the improvement of policies target achievement. To do so, the proposal of a novel technique for policy analysis is sought, additionally to a multidisciplinary perspective, it is of interest to

use a technique in which the results from previous policy results and data management are included, serving as a base for further applications of data-driven solutions for decision-making.

The key research question underlying this thesis is: *How to develop a data-driven multidisciplinary support tool for energy policy analysis that incorporates previous policies information and is based in a data-driven methodology?*

The new support tool should consider:

Impact. How much would the tool lead to the improvement of the achievements in policy goal achievement?

Beyond the improvement in reduction of the greatest amount of GHG, by incorporating learnings from past implementations, the new tool should lead to programs that have more probability of success, and therefore real impact.

Cost-effectiveness. How much will each policy option cost?

When policy options can be quantified in monetary terms, it becomes possible to select an option according to economic resources and constraints.

Other areas besides economic costs are interesting to be explored for their quantification as amount of human capital invested, amount of GHG saved, time-quantification, etc...

Equity/Distributional Fairness. Bearing in mind that every analyzed policy option will affect differently the related groups of people; the question becomes which option leads to the most equitable distribution of the benefits?

Participatory. It is different from the principle above, as not only fair distribution of results is sought, but to be able to directly incorporate the participation and views of stakeholders. The main question is: does the tool allow the participation of the stakeholders?

1.3 Research structure

1.3.1 Research scope and methodology

The objective of this thesis is to create a support tool that can act as an integral orientation mechanism, easing the creation or adjustment of energy policies. As a crucial step for the model development, a review that aims to characterize the policy evaluation practices regarding the public policies on energy, with a focus on the metrics: concerns, objectives, and indicators was done. As a key novelty, emphasis was put into finding attributes and metrics that can be used to assess effectiveness, not only efficacy or efficiency. The concerns and objectives were organized into four categories: Institutional, Environmental, Economic, and Social.

For every category, detailed and condensed concerns were identified. It was attempted to find indicators for every condensed concern, which resulted in core indicators.

To characterize policies by their typology, a review on technical measures and policy instruments was elaborated.

These two reviews were the first step towards the creation of a framework for the application of the support tool.

Quantitative and qualitative techniques for energy policy evaluation have been organized to identify the methodology that better suits the specific objectives and resources of this research.

Machine Learning (ML) techniques were selected to be applied in the development of the analysis methodology here presented. The search for the best-performing decision tree was done. The data extracted through the identified concerns of the conceptual framework was used as the variables of the model. Policy recommendations are presented in the results.

The database that has been generated has been used as inspiration for the application of another technique: index elaboration (as a complementary work). The research methodology structure can be seen in figure 3.

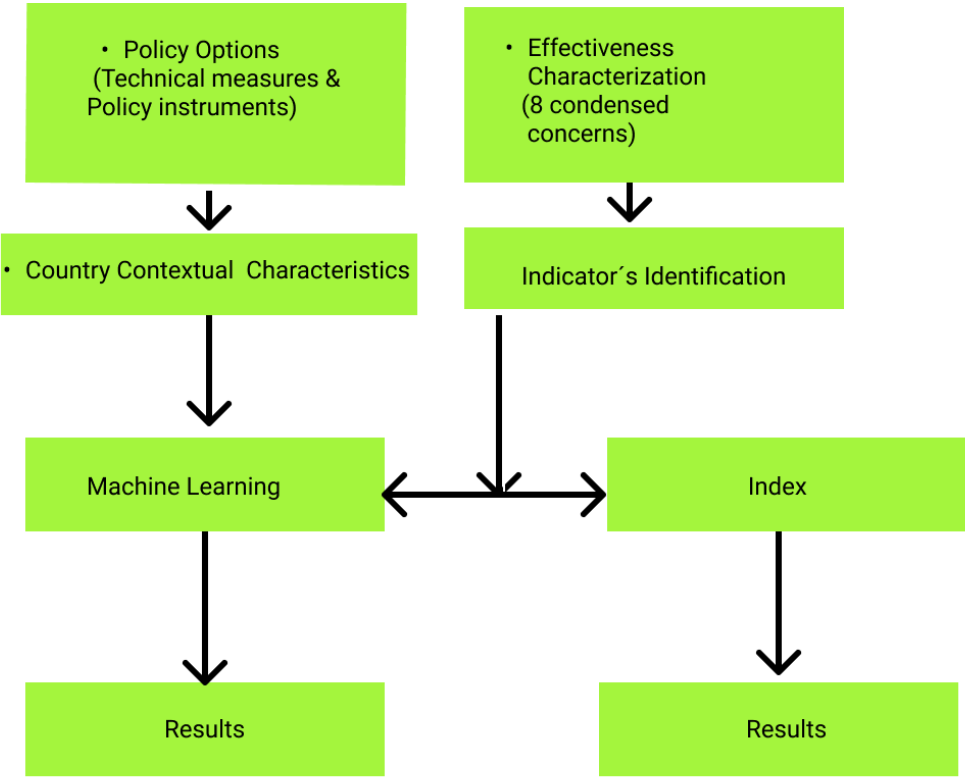


Figure 3. Research methodology structure

1.4 Thesis roadmap

This thesis has gone through the organization of contextual questions in Chapter 1 with the aim to introduce relevant concepts for the understanding of the energy planning decision making support tool proposed.

Chapter 2 organized the literature review done for energy policy evaluation methodologies, covering quantitative and qualitative ones.

In Chapter 3, as part of the methodology for the support tool developed, the effectiveness concerns have been identified and condensed via the identification of their end objective into condensed concerns. In addition, representative indicators have been identified and matched for the condensed concerns.

A synthesis of technical measures and policy instruments for Domestic Water Heating (DWH) is presented in Chapter 4, in which they have been organized to express the different policy choices available in the matter. DWH policies were selected to be analyzed as for their energy efficiency potential. Nevertheless, it was required to select policies from another energy topic due to the data unavailability of the initial policy topic. Renewable Energy policies have been selected to be analyzed.

Chapter 5 focuses on the application of Machine Learning methods via Decision Trees to the data recovered after the organization of the concerns.

With the purpose of using the information gathered and structured in Chapter 3, a policy effectiveness index is proposed in Chapter 6.

Chapter 7 organizes the conclusions, contributions and future work of this research.

Chapter 2: Literature review on Energy Policy Evaluation Methodologies

2.1 Introduction

The methodologies to evaluate Energy Policy (EP) vary considerably. As will be shown through this chapter different approaches have been used in the literature.

A general analysis that accounts for characteristics perceived in the documents retrieved will be shown. The characteristics include the time-frame and the stakeholder participation.

Priority characteristics sought in the selected methodology will be detailed further in this chapter. Afterwards, a comparison against the characteristics and methodologies will be done with the purpose of clarifying which methodology is better to select as the base of the proposed decision-making support tool of this thesis.

2.2 Identification of sources

The search engines Sciencedirect (Sciencedirect, 2019), Google Scholar (Google Scholar, 2019) and JSTOR (JSTOR, 2019), also known as research databases, together with the open-source browser Google (Google, 2019) were used for gathering documents. The expressions under which the search was done were “Energy policy evaluation” (academic and open-source); “Energy policy effectiveness” (academic source); “Energy policy assessment” (academic source); “Energy policy efficiency” (academic source). The selection of the documents to be reviewed was done by their title, abstract content, and keywords. After doing so, the criteria for the document selection for the analysis was having at least one concern that assesses energy policies. A summary of this process is presented in Table 5.

The detail of each search source is presented in Appendix A (Tables A1 to A8), for which order numbers are provided.

Table 5. Search terms by source and documents reviewed and adopted by each

Search Term	Search Engine	Documents Reviewed	Documents Adopted	Detailed List
Energy Policy Evaluation	Sciencedirect	18	9	Table A1
Energy Policy Evaluation	Google	17	10	Table A2
Energy Policy Assessment	Sciencedirect	16	10	Table A3
Energy Policy Effectiveness	Sciencedirect	9	5	Table A4
Energy Policy Effectiveness	Google Scholar	20 (3 repeated)	15	Table A5
Energy Policy Effectiveness	JSTOR	5	3	Table A6
Energy Policy Evaluation	Google Scholar	19 (3 repeated)	13	Table A7
Energy Policy Evaluation	JSTOR	5 (1 repeated)	1	Table A8

The search considered the key search engines Elsevier, Google, Google Scholar, and JSTOR, so in principle; all major publications obeying the criteria were covered. However, theoretically, it could happen that the consideration of additional databases (e.g. CORE, Bielefeld Academic Search Engine (BASE), Directory of Open Access Journals (DOAJ), Social Science Research Network (SSRN), World Wide Science, Semantic Scholar, etc.) could provide some additional results. In addition, the non-published documents (studies non-accepted for publication) have not been considered. This situation does not pose a threat to

the validity of the review. The search protocol applied has a reasonable degree of easiness and reachability, resulting in a sound number of documents that could be gathered. Other methodologies suitable for the task are available, but have not been identified.

2.3 Methodological approaches

The classification here presented separates qualitative vs quantitative techniques. It regards the process as numerical or non-numerical based. The terms “qualitative” and “quantitative” do not refer to the type of data generated in the evaluation, but the methodology process itself. However, there is a strong relationship between the type of data generated and the process. This general typology includes qualitative, quantitative and mixed-methods.

The use of qualitative research methods to evaluate a policy can provide a unique and valuable insight that could otherwise be ignored. Qualitative analysis can help to integrate individual perspectives and collective ones. These methods are popularly used when there is an interest in obtaining detailed and rich knowledge of the assessed phenomenon (Miller and Salkind, 2002). Qualitative methodologies can contribute to better understand how the studied policy inserts into the policy framework contexts (e.g. social or economic).

While qualitative techniques base their estimation on analytical processes, quantitative techniques are based on estimations that use a mathematical relation (Marhavilas et al., 2011). Their results tend to be numerical.

Even if a purely quantitative methodology is selected to be applied, some subparts of the process may require understanding via qualitative approaches.

As just mentioned, quantitative research data can result in a numerical form, while qualitative research tends to produce results in textual forms. Therefore, the conjunction of both practices may bring the analysis to a more integrative form, instead of selecting one approach or the other. Beyond the type of results, by mixing methodologies, a combined approach may integrate what can be useful to create a new set of characteristics. (Garbarino & Holland, 2009a). The types and subtypes identified under each category are presented in Table 6.

Table 6. Types and sub-types of methodological techniques/approaches

Type	Sub-type	Technique/approach
Qualitative	- Qualitative: assess information through qualitatively data organization processes.	Qualitative Content Assessment (QCA)
		Strategic, Tactical, and Operational (STO) framework
		Four paradigm model
Quantitative	-Statistical: deals with the collection, analysis, and interpretation of numerical data.	Linear regression model
		Ordinary Least Squares (OLS) regressions
	-Multi Criteria: evaluates possibilities under different criteria	Multi Criteria Decision Analysis (MCDA)

Type	Sub-type	Technique/approach
		Hierarchical Decision Model (HDM)
	-Financial: focuses on the monetary range of the analyzed options and uses monetary-oriented processes	Real Options Analysis (ROA)
		Cost-Benefit Analysis
		Partial Equilibrium models
	-Behavioral: enables the assessment of behaviors and preferences	Discrete choice analysis (using Random Utility Theory)
		Ramsey curves
Mixed methods	-Other: combined methods have been classified under this category	Indicators
		Scenario Analysis/Modelling

A description of the key information is provided, helping to clarify the different reported options under each group. An example of each methodological approach has been given.

2.4 Qualitative approaches

2.4.1 Qualitative Content Assessment (QCA)

QCA is commonly used for analyzing qualitative data and it regards the conceptual analysis of a subject via the information assessment through the data organization. To have a valid evaluation, researchers may consider their own experience of the phenomenon to be studied, leading to the minimization of possible biases (Bengtsson, 2016).

QCA process can be applied to identify policy objectives, barriers and any other element of the policy framework. For every assessed policy, through QCA the governance, policy processes and sustainability priorities can be identified (A. J. Chapman et al., 2016).

Similar to the QCA, some qualitative-based approaches that use the conceptualization of a phenomenon include analytical framework, Conceptual framework and Descriptive framework. The results produced are most likely to be qualitative.

These qualitative approaches can be combined with other methodologies, as can be weighting systems (factors), by doing so, the initial approach is translated into a mixed-method (generating quantitative and qualitative results).

For example, in A. Chapman et al., 2016, a country comparison using QCA has been done, for which energy policies in eight OECD members have been analyzed. Qualitative findings of the policies have resulted, highlighting the suggestion of doing policy evaluation in process, instead of ex-post.

2.4.2 Strategic, Tactical, and Operational (STO) framework

The STO framework is used to describe the assessed phenomena structure from different levels. Therefore, it is an alternative to evaluate policies and their effectiveness from different structural angles. The levels of planning horizons are categorized into three levels: Strategic decision, Tactical decision and Operational decision (Misni & Lee, 2017). When evaluating from top-bottom approach, commonly, the strategic level focus on the national

level, the tactical to the territory level and the operational to the local level. The STO framework is useful to evaluate energy policies, as the objective achievement can be analyzed by the level of jurisdiction, together with other concerns, all disaggregated by level.

For example, in Arababadi et al., 2017, a multi-unit analysis has been taken. The assessment has been implemented at different levels for each evaluated policy for further comparison to the ex-means and the existing effectiveness assessments for the policies.

2.4.3 Four paradigm model

The four paradigm model is a managerial methodology used to understand how consumers evaluate a phenomenon through two dimensions: importance and satisfaction. The four paradigm model is a qualitative research method that was initially introduced by Martilla and James in 1977 (Martilla & James, 1977). It is closely connected to marketing research. This technique incorporates the analysis of the consumers' evaluation of each policy in terms of perceptions.

For example, W. Li, Long, & Chen, 2016 assesses the consumers' perceptions of the new energy vehicle-related policies. It calculated the importance and satisfaction perception value around the policies. The calculated value contributes to position the evaluated policies in an assessment quadrant.

2.5 Quantitative approaches

2.5.1 Regression modeling

Regression is a quantitative technique based on statistical analysis. These types of techniques run different series of regressions to assess the relationships between the evaluated variables. The variable definition is a crucial step of the methodology, where some variables will serve as explanatory and others as control variables. They are a possibility to study the impact factors of policies. Different computational programs are available to develop the regressions automatically.

There are different types of regression models. It is considered a simple linear regression model when only one independent variable is considered; it is a multiple linear regression model when there are two or more independent variables considered in the model (Hutcheson, 2011). Some factors often seen as variables in energy modeling are the price of energy and levels of economic development (Garbarino & Holland, 2009b).

For example, in García-Álvarez et al., 2018, the control variables refer to five multidisciplinary concerns: state trends of security of energy supply, environmental concern, conventional energy trends, electricity price trends, and economic situation. The study leads to analyze how the Solar PV Capacity has increased with and without them.

Regression using Ordinary Least Squares (OLS)

OLS regression is the way for estimating the unknown parameters in a linear regression model. The estimation is done by minimizing the sum of the squares in the difference between the observed and predicted values of the dependent variable configured as a straight line.

For example, in Theel & Westgaard, 2017, the OLS regressions are used to evaluate energy efficiency policies, including information regarding the energy consumption per residential customer (for more than 10 years).

Regression models using Panel Data

Panel data is a technique that is also known as longitudinal or cross-sectional time-series data. It allows the inclusion of behavioral elements. The estimation of social interactions and their influence on the assessed elements can be modeled. Its application includes different sectors, from policy evaluation to estimation of medical treatment effects (McManus, 2015). The frequency of the information recovery varies according to the study topic, panels with a shorter period are needed to monitor small changes e.g. health studies (Hsiao, 2007). Panel data is a dataset in which the behavior of entities can be observed across time (Torres-reyna, 2007). Panel data gives the possibility to control variables that can be difficult to be quantified and variables that change over time. An advantage of this approach is the suitability for multilevel analysis and the heterogeneity provided (Torres-reyna, 2007).

For example, in X. Zhao et al., 2016 a mixed regression model with provincial panel data is presented. Environmental and economic variables have been modeled. As a result, the more suitable policies per resource area and policy recommendations were generated.

2.5.2 Multi Criteria Decision Analysis (MCDA)

The MCDA is a widely used technique as can be used in different sectors and allows the consideration of technical, economic, social and environmental concerns (or any other desired) for each option (Russi, 2007). MCDA enables the assessment of the distribution of costs and benefits across different types of stakeholders (Commission, 2015), being concerns of interest from a social perspective.

MCDA techniques can provide different alternatives for the results. These alternatives include identifying a single preferred option, ranking options, short-listing the options, or categorizing the options as acceptable and unacceptable (London, 2009). For EP evaluation, MCDA through the selected variables allows the evaluation of possible trade-offs between the selected variables, enabling the comparison of the policy options, under the policymaker's preferences.

For example, in Nikolaev & Konidari, 2017, the multi-criteria evaluation method is used as the research methodology, for which three different RES targets for 2030 scenarios were developed. For each scenario, different policy mixes were assessed. The modeling resulted

in the most suitable policy mixture for the promotion of renewables and for achieving the expected targets.

2.5.3 Hierarchical Decision Model (HDM)

The Hierarchical Decision Model (HDM) is a well-known multi-criteria decision-making tool (Abbas, 2013). The technique requires an initial structuration of the problem into objectives and their criteria. This initial structuration allows decomposing the problem into a hierarchy of sub-problems to analyze them independently. The hierarchy is organized into levels that integrate the decision elements (criteria) (Lingga, 2016). An interesting characteristic of the technique is that the objectives behind a policy can be translated into quantifying elements. Besides, the most suitable solution defragmentation, some alternative solution may be provided. HDM normally involves expert qualitative judgments quantification by using a pair-wise comparison method (Abotah, 2015). HDM besides being used as an assessment tool to analyze policy instruments, it can also generate an optimal energy policy portfolio.

For example, in Theel & Westgaard, 2017, the research objective has been to test policy instruments. The results have shown that renewable portfolio standards and tax credits are the two most effective instruments among the alternatives assessed for the selected geographical area.

2.5.4 Real Options Analysis (ROA)

ROA is based on an option valuation technique to evaluate physical or real assets (Mun, 2002). It has been popularly used to support decisions regarding capital budget, therefore is a well-known tool to evaluate projects. The technique highlights that the fundamental aspect for the realization of a project is its economic value (Anderloni, 2011).

About the applications of the ROA, it has been used in the financial markets to gain insight into the risks associated with the investment. ROA can be an interesting technique in the energy planning area, particularly, for renewable energy project evaluation.

For evaluating projects that include climate risk information, ROA is a useful alternative as it has the potential to incorporate it directly (Tröltzsch et al., 2016).

For example, in Lee & Shih, 2010, the analysis includes the forecast of installed capacities and international oil prices. A policy benefit evaluation model based on a binomial real options pricing model was developed to assess the benefits of policies for developing RE in Taiwan.

2.5.5 Cost-Benefit Analysis (CBA)

The CBA, as a financial-based technique, is often used to evaluate projects in both the Public and Private sectors. CBA is a widely used approach for guiding public sector decisions (Crespi, 2011). One purpose of the technique is to facilitate the best allocation of society's resources (Crouch, 2012). It is based on a systematic evaluation that allows valuing the gains and losses in monetary terms (Boardman & Columbia, 2015). The technique allows

creating a framework for the decision-maker, in which a variety of impacts that occur in different periods can be assessed (as they are converted into present value terms).

CBA can be sometimes inadequate to meet assessment needs that go beyond the economic spectrum. For which other types of evaluation may be applied in order to fully explain the policy implications of an issue (Crouch, 2012). Cost-benefit analysis is a common decision-making tool in the electricity industry. By building several models, CBA will allow comparing different channels, options technologies and other variables (Energy and Environmental Economics, 2014).

For example, in Energy and Environmental Economics, 2014, the analysis compared various renewable resources through their overall value. Net cost or net value analysis is used comparing the cost of bringing up a resource to the total renewable source benefits.

2.5.6 *Partial equilibrium models*

The Partial equilibrium models have been used to investigate markets and market-related issues since the second decade of the 1900s (Canova, 1994). They enable information provision about policy measures and the relationship with supply-demand behavior, therefore is a good alternative when the preferences of the consumers want to be included.

It is a practical tool to recover information about new products in a market. Some assumptions are typically done as that the markets to be stable and constant (Sacchelli et al., 2014).

For example, in Liu et al., 2018, seven renewable energy generation policies of China have been tested. The model has taken an economic, environmental and social effectiveness orientation, for which the differences in the areas, before and after the policy have been analyzed. The comparison has been done through selected indicators.

2.5.7 *Ramsey curves*

The Ramsey-Cass-Koopmans Model (popularly known as the Ramsey model or curves) allows for the integration of microeconomic level information, including data from firms (supply) and households (demand) and their corresponding behaviors (as the optimal consumption/saving decisions) (Gourinchas, 2014). The Ramsey model can be applied to do a Welfare analysis, which deals with welfare issues, being an alternative for governments to regulate the markets based on maximizing the social welfare (Barkley, 2019). Ramsey curves can also be used to evaluate the impacts of taxes and price ceilings (Stiglitz, 2015).

For example, in Atalla et al., 2018, an analysis to differentiate taxation using Ramsey curves by applying demand elasticity values was carried out. An optimal pricing schedule has resulted.

2.5.8 *Discrete choice analysis*

Discrete choice models base their simulation on the utility function of discrete alternatives (non-continuous). These alternatives can be part of a choice set (multinomial) or just a pair (binary choice). This analysis relies upon two tasks: the behavioral model

definition and the estimation of the parameters. This analysis can result in challenging econometric calculations, as discrete analysis reveals less information than continuous choices (Train, 2002).

As part of the choice modeling, Random utility theory can be incorporated, used when the preferences on alternatives can be ranked according to scores. It is based on the assumption that the individual selects the highest utility option, but as the utilities are not known with certainty (by the analyst) are treated as random variables (Horowitz et al., 2014).

For example, in N. Wang et al., 2017, behavioral research was done, leading to know the main drivers that influence the choice of new passenger vehicles (purchase price, cruise range, operating cost fuel availability and emissions). Through a questionnaire, the customer's vehicle preferences were revealed, together with their understanding of the policy measures.

2.5.9 Scenario Analysis and modeling

Through scenarios, different frameworks can be tested to best achieve policy goals. They can consider the preferences, priorities and constraints, and evaluate the different choice options (A. J. Chapman, 2016). Scenarios are not a methodology themselves, as they serve as a tool to show the results from applying different methodologies (and illustrate different possibilities). Therefore, it is normal to see the use of scenarios for the comparison of available alternatives, under different methodologies.

Scenario Analysis allows to learn about potential future alternatives, present a range of possible outcomes (Holroyd et al., 2007). It has been used in both the private and public sector, as they are tools to develop strategic plans and manage risk in the face of the uncertainties of the future (particularly for medium- to long-term strategic planning). Scenarios have been also used as a national policy-planning tool to assess the opportunities, risks, and trade-offs (Maack, 2001).

For example, in Qiang et al., 2016, an Energy Policy Simulator (EPS) has been developed. Through the simulation, the effects and interactions of more than 30 energy and environmental policies were tested. As output, the simulator generates metrics on emissions of pollutants, various fuels by sector use, electricity capacity and generation, capital and operation changes, maintenance expenditures, etc...

One characteristic of this simulator is the feasibility to track the social benefits, done through the monetized value of avoided pollution-induced premature mortality (from fine particulates and climate damages from CO₂e).

2.5.10 Machine Learning (ML)

Evaluations using Index and Machine Learning have not been found in the retrieved literature. Some techniques are now described for their data analysis capability and characteristics.

Machine Learning refers to tasks associated with Artificial Intelligence (AI). It involves recognition, planning, prediction, and other tasks (Harmelink et al., 2006). In ML, predictive

models are developed and trained with specific purposes, providing data-driven solutions to different contexts (Frank et al., 2020).

Data combined with ML techniques can have a great potential to tackle different multidisciplinary problems (Buchanan & Miller, 2017). As a data-driven analysis approach, ML has over some decades in practice; however, its techniques have been boosted in the last years (Smola & Vishwanathan, 2008). ML has been applied to different areas. One of the areas where it has been less applied is Economics, explained by the lack of accumulated data in some subtopics (Kreif & DiazOrdaz, 2020). Some available examples in economics and quantitative social science include pure prediction problems (e.g. demand estimations) (Bajari et al., 2015). ML includes different techniques, such as Support Vector Machine (SVM), Neural Network (ANN), Random Forest (RF), Decision Trees (DT) (Nitze et al., 2012). Some of the algorithms of these techniques relies on regressions and other statistical methods.

Decision Tree (DT)

DT is a procedure to create a tree-based classification model, classifying the records in the sample. Decision trees are well-known prediction and data mining tools (Hoeschele et al., 2015). Through the tree paths that a DT creates, the prediction of future events or trends can be done. This has made DT a popular method used for problem structuring, and a suitable technique for decision-making (Analytics, 2021). Decision trees go from simple to complex multi-stage problem structuring (Rokach & Maimon, 2005). One of their contributions to problem solving, relies upon the definition of possible courses of action, structuring the alternatives for decision-making (Song & Lu, 2150).

The decision tree consists of nodes that advance downwards to form a rooted tree. The nodes originate in the root node (i.e. a node with no incoming edges). The nodes can have or not outgoing edges; if they continue the tree growth, they are called internal or test nodes, if there is not an outgoing edge, they are called leaves nodes (also terminal or decision nodes) (Rokach & Maimon, 2005).

Random Forest (RF)

RF consists of a tree partitioning method, supported by several decision trees, based on different samples of data variables (Zekić-Sušaca et al., 2020). As a popular general-purpose algorithm, RF can be applied to a wide range of modeling tasks (IMF, 2015). Aiming to identify the variable with the strongest explanatory power, the importance of the variables can be identified (E. S. Kim et al., 2020; Menze et al., 2009).

Neural Networks (NN)

Neural networks are composed by neurons that receive inputs from other neurons and send information to other neurons; each neuron is a function of weighted inputs, which will be used in a subsequent function that converge to calculate the final output (Steinkraus, 2017). The comparison of the output values to the true ones is what gives the characteristic

of the NN of learning. These neurons or nodes are organized by layers. Each layer has a different task, where the final layer will compute the final prediction value.

There are various functions used for activation across the neurons. One of the most commonly used activation functions is the sigmoid function. The other functions that are used are the Step function, Linear function, Ramp function, Hyperbolic tangent function (Kukreja et al., 2017).

2.5.11 Indicators & Indexes

As will be detailed in Chapter 3, indicators represent a well-known instrument to organize information. Information that can be produced by the application of a certain methodology. Among the types of indicators, performance indicators are able to measure different features of a policy or project (as the impacts, outcomes, outputs, and inputs). Indicators give the possibility to monitor the assessed element towards its objectives. Indicators generate information to be evaluated itself, or can be a compliment for other methodologies, contributing to organize the data and requiring further analysis.

Some indicators use weighting for their application, and if summed up, they become an index. Weighting factors allows giving more importance to certain elements in a set, and according to the defined criterion. The definition of the criterion depends on the priorities and preferences of the decision-makers. There are different methods to calculate weighting factors and alternatives to assess the robustness of the results (Sala & Cerutti, 2018).

For example, in Collado & Díaz, 2017, it is used an index to test policy measures effectiveness around final energy savings achieved. The analysis covers efficiency policies from different sectors (Transport, Building, Industry, Public Services and Equipment).

2.6 Methodologies quantification

The methodologies identified through the analyzed documents have been quantified under their Geographical scope, Time-frame, Stakeholder participation, among other relevant criteria.

The quantifications are presented in Table 7. As expected, very diverse approaches were found. The qualitative-based methodology type was found as the most popular approach (19 documents). Descriptive and qualitative analysis methods have been considered as qualitative-based. The second more frequent approach is statistical (17 documents). Scenario and modeling techniques have also been identified (12 documents). The category others include the approaches that were found only once e.g., Cost–Benefit Analysis (CBA), Return On Assets (ROA), etc.

Table 7. Documents found per methodological approach

Methodology	Quantity	Documents Numbers (from Tables in Appendix A)
Statistical	17	10; 14; 20; 27; 32; 33; 36; 38; 39; 42–44; 48; 52; 56; 61; 63.
Scenario	12	1; 5; 9; 16; 18; 21; 22; 34; 53; 60; 65; 66.
Qualitative-based approach	19	2–4; 11; 13; 17; 23–25; 28; 31; 37; 40; 41; 45; 46; 57; 58; 64.
Index (indicators)	4	8; 12; 35; 59.
Others	14	6; 7; 15; 19; 26; 29; 30; 47; 49–51; 54; 56; 63.

When analyzing the scope or level of application of the energy policies evaluations (local, regional, national, international, or a combination among them), it is noted in Table 8 that the highest number of the reviewed documents regards the national level (with 40 documents), with a considerable difference above the other alternatives. The national scope is followed by the international scope (with eleven documents). Some documents regard all the levels of application or a combination of more than one level. Another observation is that only three locally focused documents were found.

Concerning the time frame shown in Table 9, almost all of the retrieved documents state or enabled us to infer the period of the evaluation (summing 53 documents), against 13 documents where that was not possible. The time framing of the process, according to the reviewed documents, can be ex-ante, in-progress, or ex-post. The ex-post energy policy evaluation approach was the most often found (34 documents), followed by the ex-ante approach (10 documents). It can be noticed that only two of the reviewed documents (“Moving Toward Energy Efficiency: A Results—Driven Analysis of Utility-Based Energy Efficiency Policies” Theel & Westgaard, 2017 and “Evaluating Consistency in Environmental Policy Mixes through Policy, Stakeholder, and Contextual Interactions Lieu et al., 2018) declared a combined approach (with more than one possible timing period).

Table 10 shows the participation of stakeholders in the EP evaluation. Stakeholder participation is related to the involvement of actors along the evaluation process. Less than one-third of the documents retrieved report some form of participation from stakeholders (19 out of 66 documents).

Table 8. Documents found per geographical level of analysis

Level	Quantity	Document Numbers (from Tables in Appendix A)
National	40	1–4; 6–11; 13; 16–18; 20; 21; 24–26; 28; 30–32; 34; 35; 45; 46; 50; 52; 53–55; 58–64; 66.
Regional (State)	9	14; 15; 19; 27; 36; 38; 39; 47; 56.
International	11	29; 33; 37; 40; 41; 43; 44; 49; 51; 57; 65.
Combined	3	12; 23; 22.
Local	3	5; 42; 48.

Table 9. Documents found per time-frame.

Time Framing of the Process	Quantity	Documents Numbers (from Tables in Appendix A)
Ex-ante	10	1; 5; 15; 22; 23; 29; 31; 40; 47; 51.
Ex-post	34	4; 8–10; 18; 21; 27; 32; 33; 35; 36; 38; 39; 41–63; 65; 66.
In-progress	7	19; 28; 30; 34; 46; 48; 64.
Combined	2	14; 17.
Not inferred	13	2; 3; 6; 7; 11–13; 16; 20; 24–26; 37.

Table 10. Documents found per stakeholder participation.

Stakeholder Participation	Quantity	Documents Numbers (from Tables in Appendix A)
Yes	19	3–6; 13; 14; 17; 20; 23; 29; 30; 37; 40; 53; 54; 58; 59, 64.
No	47	1; 2; 5–12; 16; 18; 19; 21; 22; 24–28; 31–36; 38; 39; 41–52; 55–57; 60–63; 65; 66.

In Table 11, it can be seen that when analyzing the motivation stated in the reviewed documents, the most common one is to conduct a policy evaluation itself, observed in 34 documents. Four documents clearly defined their interest in supporting policymakers, while 16 documents target the evaluation of policy success. It can be noted the interrelation between the identified motivations.

Table 11. Documents per expressed objectives of the review.

Motivation	Quantity	Documents Numbers (from Tables in Appendix A)
Policy evaluation	34	6–8; 13–16; 18–22; 27; 30; 32–34; 37; 39; 40; 45; 46; 49; 53–55; 57–62; 64–66.
Policy review	7	23; 24; 26; 29; 35; 36; 51.
Support policy makers	4	3; 5; 17; 20.
Evaluate policy success	16	1; 9–12; 38; 41–44; 47; 48; 50; 52; 56; 63.
Creation of a methodology/framework	5	2; 4; 25; 28; 31.

2.7 Comparison of the Methodologies in view of a tool design

For defining the evaluation methodology to serve as the base for the development of the decision-making support tool subject to this thesis, four priority characteristics have been defined as criteria for the selection: a multidisciplinary approach, in which concerns under different dimensions can be assessed; the inclusion of stakeholders; a data-driven approach, enabling the quantitative incorporation of the characterization of policy effectiveness characterization; and that overall it represents a novel form of energy policy analysis.

The quantitative methodologies reported in this chapter are now contrasted against the previous characteristics. From the alternatives that had better complied with the priority characteristics, one main methodology was selected. A second-best option was also chosen to be used as a complementary work.

Table 12. Methodologies comparison against priority characteristics

Methodology	Multidisciplinary evaluation	Stakeholder's inclusion	Data-driven	Novelty to energy policy	Possible results
Multi Criteria Decision Analysis (MCDA)	X	X	X		Single option, rank options, short-lists, or categories
Discrete choice analysis	X	X	X		Main drivers that influence a choice

Methodology	Multidisciplinary evaluation	Stakeholder's inclusion	Data-driven	Novelty to energy policy	Possible results
Four paradigm		X	X		Quadrant with the perceived value of policies
Partial Equilibrium		X	X		Information about new elements (policies, products, services)
Ramsey curves		X	X		Optimal decision
Hierarchical Decision Model (HDM)	X	X	X		Optimal energy portfolio
Index Elaboration	X	X	X		Easy to compare results (1 or 2 digits)
Machine Learning techniques	X	X	X	X	Profiles (categories) with certain characteristics; the significance of variables analysis, etc.

Observations on the classification above presented are now described, highlighting the focus characteristics of each methodology:

1. Multi Criteria Decision Analysis (MCDA) can be applied for different orientations, with an interdisciplinary approach and across diverse stakeholders. Nevertheless, they do not represent a novelty to the energy policy evaluation.
2. Discrete Choice models include preferences and alternatives in the assessment. Questionnaires are required to reveal the customer's preferences. It performs well for a set or binary choices; however, it only applies to discrete alternatives.
3. The four paradigm assesses only two dimensions, incorporating them in terms of perceptions from consumers' evaluation of each policy.
4. The Partial Equilibrium models perform well in the incorporation of consumer perspectives, being useful for the study of policy measures and the relationship with supply-demand behaviors, it is a methodology focused on the social dimension.
5. Ramsey curves are focused on the economic and social dimensions of a phenomenon, via the microeconomic level information and a social welfare analysis.
6. Hierarchical Decision Model (HDM) involves qualitative judgments quantification, from which the perspective of stakeholders' inclusion is covered, nevertheless, to do so a complicated pair-wise comparison method needs to be applied.
7. Index are practical tools to organize data and that can include multidisciplinary approaches and stakeholders participation. Different indexing systems related to energy are available.
8. Machine Learning (ML) includes different techniques; all of them allow a multidisciplinary evaluation. Not all of the techniques allow the participation of stakeholders directly. A notable fortress of Machine Learning relies on its novelty to the energy policy evaluation and its practicability for data management. DT and RF

are data mining techniques that can be used to operate on large volumes of data, discovering hidden patterns and relationships (Magesh et al., 2013).

2.8 Conclusions of the Chapter

As shown through the chapter, both qualitative and quantitative methods include a wide variety of methodological options. A combination of methods is possible via mixed methods and through the application or development of different frameworks, completed with numerical data analysis, or the way around via the calculation and estimation of numerical data with a strong base on a conceptual framework.

Undoubtedly, there are certain characteristics of each technique that directly align with the priority characteristics sought in the chosen methodology. First, as a data-driven methodology, quantitative techniques are preferred over qualitative ones. Not only because they tend to produce quantitative results, but the application of a methodology supported by mathematical calculations that ease its application under different circumstances is preferred.

The stakeholder involvement that is sought can be reached via the approaches that model behaviors and allow the incorporation of stakeholders' participation (e.g. Partial Equilibrium and Four Paradigm). They have a participatory component, characterized by stakeholder involvement in the evaluation process. These techniques bring the opportunity to enhance the social perspective of the stakeholders, making them active participants instead of passive subjects. Through the stakeholders' inclusion, this analysis incorporates the evaluation of the social and institutional dimensions of a policy.

As a multidisciplinary approach is sought, techniques like CBA or ROA are not of interest, since they focus on only one area of knowledge. On the other hand, techniques like Partial Equilibrium allows the incorporation of different dimensions. In general, most of the approaches here presented allow an interdisciplinary evaluation.

Machine Learning techniques have been selected as the most interesting methodology for their possibility to incorporate interdisciplinary data and the novelty of the methods themselves for energy policy analysis. Regarding the incorporation of stakeholder's perspective, there are different techniques included in ML, in which some of them allow the incorporation weights.

Complementing the ML, the elaboration of an index has been identified as the second most interesting approach. It is a well-known data-driven methodology, in which the incorporation of stakeholders' consideration and multidisciplinary perspective is feasible. It does not has a high novelty degree, nevertheless it has been selected above the other alternatives (like Hierarchical Decision Model (HDM) or Multi Criteria Decision Analysis (MCDA)) because it can measure current conditions and track the changes of a policy or program, while forecasting trends. Additionally, indicators can answer to key policy questions.

Chapter 3: Synthesis of Energy Policy concerns and objectives

3.1. Introduction

As an intended contribution to the planning and management of energy action plans, this chapter addresses the second part of the problem of EP evaluation, with a focus on effectiveness. It starts with the conceptual differences between effectiveness, efficiency, and efficacy, and then moves on to find specific indicators for a comprehensive assessment. Such a set would be useful for ex-post evaluations, but in some cases, it could also be useful for ex-ante evaluations and thus assist the design of better policy programs. Therefore the main motivations of this chapter have been to create a support document that enables a more structured and comprehensive planning process (and that does not leave important aspects forgotten); planning programs that have a higher chance of succeeding, in practice; and supporting the good use of resources (public and/or private).

With the aim of evaluating EP and provide information that facilitates their adjustment to distinctive characteristics, a set of concerns was intended to be identified through this chapter. The concerns were organized under the different proposed categories and subcategories. These concerns were then organized under condensed concerns, by identifying their final objective.

An indicator identification process was followed. Indicators were selected as the assessment metrics that can provide a comparison between the policies defined objectives and their achievement, therefore selected as an effectiveness measurement instrument. The identification of concerns ends objectives has also been done, serving as cornerstones for the identification of indicators.

3.2 Policy Success: Efficacy, Efficiency and Effectiveness

A sensible goal of policy evaluation is to assess whether or not they are “successful”. “Success” is defined as “the accomplishment of an aim or purpose” (Cambridge Dictionary, 2019). This is very much in line with the definition of “efficacy”, which is defined as “the ability, especially of a medicine or a method of achieving something, to produce the intended result” (Cambridge Dictionary, 2019).

A strict or “hard” approach to the evaluation of “success” or “efficacy” could therefore rely on the comparison between what is achieved and what was the target or goal; e.g., a program that has the target of promoting the installation of 80,000 solar collectors would be “successful” or “efficacious” if it achieves 80,000 or more installations, while it would be “unsuccessful” if it achieves equal or less than 79,999 installations.

The example above illustrates as well that such a “hard” approach to success evaluation is probably too strict. Under this approach, failing by a large amount or by a small amount is put under the same label. It could also serve as a stimulus to establish artificial and sometimes counter-productive low targets, to increase the probability of achieving the results.

Therefore, more flexible and comprehensive metrics are needed to assess policy success. This is where the concept of “effectiveness” may come into play. Although sometimes seen

as equivalent to “success”, it is formally defined as “the degree to which something is successful in producing a desired result” (Cambridge Dictionary, 2019). The word “degree” opens room for a more gradual evaluation, clearly allowing for differentiation between failing by a large amount vs. failing by a small amount, as well as for succeeding by a small amount vs succeeding by a large amount.

Furthermore, “effective” has already been used, e.g., in the field of medicine as different from “effective” in the sense that it is something that is evaluated from the real-world use or implementation, including informal feedback from doctors and patients, rather than from controlled experiments alone (Ernst & Pittler, 2006).

It may be of interest to bring into consideration also the concept of “efficiency”. This is distinct from both efficacy as from effectiveness, assessing what was achieved concerning the means that were put into the program. While of course being efficacious is more important than being efficient, being efficient is also important. It implies that resources (e.g., funding to investments), which typically are limited, are being well used. By being efficient, more effect can be achieved from a given amount of resources.

As a more nuanced concept than efficacy, effectiveness thus has the potential to encompass the components of taking into consideration contextual variables and of assessing “success” in a quite modulated manner. It can even be advocated that, while privileging the evaluation of the achievement of results, a truly effective program should assess those results concerning the contextual variables (geographical, economic, and cultural) rather than by just comparing it to the initial goals of the program. This is so because these often are not declared and, even when they are, their choice is inherently somewhat arbitrary. Effectiveness can thus incorporate some dimension of efficiency into the assessment.

3.3 Energy Policy Concerns and Objectives

The term *concern* is defined as “something that is important to someone, or the fact of being important” (Cambridge Dictionary, 2021). This definition can be very general, nevertheless it involves the sense of importance on a matter. The importance notion that a concern can reflect will be reflected in the concerns’ organization presented in the following sections. The identification of the concerns included in the Literature led to forming a list of more than 60 concerns. That process will be described in detail in this chapter. They have been classified into four broader categories (Environmental, Economic, Social and Institutional), and some subcategories have been formed: Environmental-GHG, Other Environmental Impacts, Economic-General, Competitiveness, Equity, Employment and Governance.

3.3.1 Environmental Concerns

Table 13 shows the concerns identified regarding the environment. Two subcategories were defined: “Greenhouse gas” (GHG) and “Other environmental impacts”. The border among the categories could be very thin, as some concerns can be related to both. That is the case e.g. of Renewable Energy (RE) sources related concerns (e.g., RE standards, RE Deployment and RE Tech Efficiency).

Greenhouse Gas (GHG) emissions reduction was found as the predominant concern for evaluating energy policies under an environmental perspective and gathered under the subcategory Environmental GHG. The appearance of the GHG emissions concern has been increased by the continuous and reinforced definition of international agendas, national targets, agreements, and other efforts to reduce GHG emissions and minimize climate change.

The category Other Impact on the environment includes the concerns that assess the conservation and improvement of the environment, excepting GHG. Renewable Energy (RE) related concerns (e.g., RE standards, RE Deployment and RE Tech Efficiency) have been included in this subcategory.

Table 13. Environmental concerns found.

Document	Environmental GHG	Other impact on the environment
Lieu et al., 2018	-	Environmental pressure
Abotah, 2015	Low carbon economy	Environmental protection
Chapman et al., 2016a	GHG emissions	RE Deployment, RE Tech Efficiency
Chapman et al, 2016b	GHG emissions	-
Chen, 2011	-	Ecological awareness
Alyamani et al., 2016	GHG emissions	-
Lee & Shih, 2010	-	Environmental protection
Nikolaev & Konidari, 2017	GHG emissions	-
Hafeznia et al., 2017	-	Consideration of climate and weather
S. J. Li et al., 2017	-	RE energy production
Yu et al., 2015	CO2 emissions	Energy savings
Aized et al., 2018	GHG emissions	-
Arababadi et al., 2017	GHG emissions	-
Burke & Stephens, 2017	-	RE minimum requirements
Chang & Fang, 2017	-	Sustainability in energy supply
García-Álvarez et al., 2018	-	General environmental awareness
Mirjat et al., 2017	-	General environmental awareness
Atalla et al., 2018	Climate change mitigation	-
Delmas & Montes-sancho, 2011	GHG emissions	Renewable resources
Menz & Vachon, 2006	-	Resources capacity and quality
Arbolino et al., 2019	GHG emissions	Renewable share
Thornley & Cooper, 2008	-	Resource capacity
Jenner et al. 2013	-	Resources share
Dong, 2012	GHG emissions	-
Sancho, 2010	GHG emissions	-
Bersalli,et al., 2020	GHG emissions	-
Stagl, 2006	Global warming and climate change	Renewable energy use; Less-pollutant transportation
Hoffman et al., 1977	GHG emissions	Environmental impact, energy resources
Carley, 2009	-	Natural resource endowments, RE share
Kilinc-Ata, 2016	GHG emissions	-

3.3.2 Economic Concerns

A large set of concerns was found under the economic category, as shown in Table 14. Almost all the reviewed documents included at least one aspect under this category. The

economic dimension regards all the concerns that assess policies in monetary terms, from which two subcategories were formed: Cost and Competitiveness.

The Cost subcategory includes the concerns related to direct monetary influence, particularly related to costs and expenses. Both levels, macroeconomic and microeconomic, have been assessed; e.g., the energy price is included, referring to the economic aspects in a micro economical view. The Gross Domestic Product (GDP) impacts of energy decisions refer to the macro level of an economy.

Regarding Competitiveness, this subcategory brings together market orientation concerns (e.g., attractiveness of investment, market growth and market maturity aspects).

Table 14. Economic concerns found.

Document	Cost	Competitiveness
Chapman et al., 2016a	Energy price performance	Market growth and maturity
Theel & Westgaard, 2017	Energy price and demand	GDP
Abotah, 2015	Economic feasibility	-
Qiang et al., 2016	Cost-Effectiveness	-
Lieu et al., 2018	Supply chain and Service providers	-
Chapman et al., 2016b	Generation Cost, Levelized cost of electricity (LCOE)	GDP Impact and Market Impact
Energy and Environmental Economics, 2014	Energy generation net cost	-
Chen, 2011	Energy demand, energy price	-
Bukarica & Tomšić, 2017	-	Market barriers
Alyamani et al., 2016	Energy demand, cost, and price	Utility profits and revenue
Lee & Shih, 2010	-	Macroeconomic parameters
Collado & Díaz, 2017	Energy savings	-
Nikolaev & Konidari, 2017	Internalized total cost	Attractiveness in RES investment
A.J. Chapman	Generation Cost, Electricity Price	GDP Impact and Market Impact
X. Zhao et al., 2016	Power demand, energy substitution alternatives, technological change	-
S. J. Li et al., 2017	Macroeconomic context	-
S. Ma et al., 2020	Carrier price, demand	Patents
Shrimali et al., 2017	Cost-effectiveness potential	Investment incentives
Aized et al., 2018	Costs, supply, and demand	-
Burke & Stephens, 2017	Macroeconomic context	-
Chang & Fang, 2017	Macroeconomic context	-
Liu et al., 2018	Costs and profits	-
García-Álvarez et al., 2018	Electricity price trends, economic situation, security of supply	-
Mirjat et al., 2017	Economic efficiency	-
Atalla et al., 2018	Micro economic impact	-
Lund, 2007	Cost-effectiveness	Market State
Dong, 2012	GDP per capita, Oil imports, electricity consumption	-
Agnolucci, 2007	Financial support	-
Mitchell et al., 2006	Risk reduction	-
Sancho, 2010	GDP	-
Qiu et al., 2019	City Infrastructure	-
Bersalli et al., 2020	Energy generation, Energy dependence rate	Access to domestic credit, Income per capita

Document	Cost	Competitiveness
Economics, 2011	Cost-effectiveness	-
Yuan et al., 2011	Cost-effectiveness	-
Rosenow 2016	Energy Savings	-
Nicholson-crotty & Carley, 2016	Energy generation costs	-
Stagl, 2006	Energy efficiency; energy costs	-
Zhang et al., 2014	Energy costs, renewable energy costs (and subsidies), Carbon prices	-
Hoffman et al., 1977	Energy costs, dependence on imports	-
Carley, 2009	Gross state product per capita, electricity use, electricity price	-
Neij & Kerstin, 2006	Electricity costs	-
J. Zhao et al., 2011	Technology payback period	-
Kilinc-Ata, 2016	Carrier prices, imports, GDP growth, electricity consumption	-
Verbruggen, 2009	Cost-effectiveness	-
Banerjee & Solomon, 2003	-	Consumer response and manufacturer/marketer response
Kim & Lee, 2012	-	Consumer choice, technology, and location characteristics

3.3.3 Social Concerns

Concerns with a social orientation have been gathered in Table 15. Two sub-categories were defined. Firstly, Equity include concerns related to social sustainability factors, as the acceptance of certain energy technologies and the impacts of subsidies on energy bills. It can be noticed how equity has been considered in several documents, being a key component of energy distribution. Some other stated concerns include energy democracy and consumer surplus. This last is an important reference to measure the welfare of consumers (García-Álvarez et al., 2018).

The second subcategory, Employment, as can be inferred from its name, is the subcategory to account for the employment rates affected by the energy policies. The knowledge and skills (expertise) of the workforce have also been included in this subcategory.

Table 15. Social concerns found.

Document	Equity	Employment
A. J. Chapman et al., 2016a	Health, subsidy allocation, costumer's participation	Employment
Rogge et al., 2017	Distribution of energy costs (equity)	-
IRENA et al., 2014	Equity (Consumer's impact)	-
Abotah, 2015	Customer interaction and satisfaction	-
A.J. Chapman, 2016b	Impact of subsidies in energy prices, distribution of costs and benefits	Employment
W. Li et al., 2016	Perceptions of importance and satisfaction	-
Nikolaev & Konidari, 2017	Energy equity	Employment
Wang et al., 2017	Consumers' preferences, vehicle acceptance, and Willingness To Pay	-

Document	Equity	Employment
Hafeznia et al.	Social acceptance of RE technologies	Knowledge and skill of workforce (expertise)
Enzensberger	Stakeholder's consideration	-
Edwards, 2018	Social acceptance	-
Burke & Stephens, 2017	Energy democracy	-
Chang & Fang, 2017	Equity among households: Energy elasticity	-
Liu et al., 2018	Consumer surplus	-
Mirjat et al., 2017	Socio demographic information	-
Atalla et al., 2018	Electricity price elasticity (Household behavior)	-
Delmas & Montes-sancho, 2011	Customers, Renewable preferences	Unemployment
Arbolino et al., 2019	Health	-
Harmelink et al., 2006	Acceptance by the actors	-
Yao et al., 2014	Socio demographic Information	-
Qiu et al., 2019	Socio demographic information	-
Ling-yun & Jia-jia, 2016	Public health and people's welfare	-
Bürer & Rolf, 2009	Stakeholder's consideration	-
J. Zhao et al., 2011	Household income, Neighborhood characteristics	-
Stagl, 2006	Warm spaces	-
Neij & Kerstin, 2006	Participation and Commitment of actors	-

3.3.4 Institutional Concerns

There is a recent recognition of the importance of the institutional context. Concerns like political commitment, policy choice, and citizen engagement characterize policies from an institutional perspective.

The variety of concerns found in this category was larger than in the previous categories (Table 16); however, no subcategories were created, due to a lack of a clear structure. The identified concerns describe the policy institutional framework, including concerns as flexibility with policy instruments, actors, and institutional environment, among others.

Even if the institutional performance does not measure policy success itself, it contributes to explain the policy environment. Institutional context tends to be assessed qualitatively rather than quantitatively. The lack of quantitative procedures to evaluate some dimensions of the institutional context provides the opportunity to develop scientific-based methodology proposals that enable to evaluate the concerns found under this category.

Table 16. Institutional concerns found.

Document	Concern
Rogge et al., 2017	Actor's and institution's participation
IRENA et al., 2014	Political accountability, source of finance and regulatory simplicity
A. J. Chapman et al., 2016c	Governance, government priorities
Theel & Westgaard, 2017	Policy Environment
Abotah, 2015	Institutional and Government support
Bukarica & Tomšić, 2017	Political will, public participation, public dialogue, regulatory framework
Yoon & Sim, 2015	Policy framework (policy environment and policy process)
Nikolaev & Konidari, 2017	Administrative and financial capacity, Feasibility of implementation

Document	Concern
Arababadi et al., 2017	Policy budget
Burke & Stephens, 2017	Policy implementation mechanisms
Liu et al., 2018	Government fiscal revenue
García-Álvarez et al., 2018	Policy Environment
Mirjat et al., 2017	Policy Environment
Delmas & Montes-sancho, 2011	Type of Governor
Menz & Vachon, 2006	Policy environment
Dong, 2012	Other policies (number)
Agnolucci, 2007	Policy certainty and planning constraints
Qiu et al., 2019	Policy options
Rosenow et al., 2016	Policy environment
Carley, 2009	Political institutions, other policies (presence)
Harmelink et al., 2008	Policy implementation
J. Zhao et al., 2011	Advertisement
S. Ma et al., 2020	Policy budget
Verbruggen, 2009	Robustness, efficiency

Table 17 shows the number of appearances per concern by subcategory. It is noted that Economic-cost is the subcategory that was found more often in the reviewed documents, reflecting the importance given to it by the consulted sources. The second most popular subcategories are Governance and Social equity, which regards the energy impacts on society and energy distributional impacts.

Table 18 shows an analysis of the categories. It was noted that most documents mention more than one category (42 documents). From the remaining 24 documents (single category approach), 12 documents report an Economic orientation, being the largest one.

Table 17. Number of appearances per concern by subcategory.

Category	Quantity of Documents	Documents Numbers (from Tables in Appendix A)
Environmental-others	14	2, 7, 15, 17, 18, 21, 24, 25–29, 31, 33
Environmental GHG	14	1, 5, 9, 15, 18, 21–23, 36, 38, 39, 44, 47, 49
Economic-cost	36	1, 2, 5, 8–10, 14–19, 22, 24–29, 31, 32–36, 39, 40, 42–49, 60
Economic-competitiveness	15	1, 3, 5, 7, 9, 10, 14, 18, 31, 34–37, 49, 62
Social Equity	25	1, 6, 9, 11, 12, 15, 18, 20, 24–26, 28, 29, 31, 36, 37, 39, 40, 42, 48, 52, 53, 58, 60, 66
Social-Employment	7	1, 9, 10, 18, 31, 36, 47
Governance	26	3, 4, 9–15, 23, 24, 26–28, 36, 38, 40, 44, 45, 48, 51, 56, 57, 60, 62, 63, 65

Table 18. Single vs. multi-category orientation.

Category	Quantity of Documents	Documents numbers (from Tables in Appendix A)
Single	24	4, 6–8, 13, 16, 19–21, 30, 32, 34, 37, 41, 42, 46, 50, 52, 54, 57, 58, 61, 64, 66
Multi-category	42	1–3, 5, 9, 10–12, 14, 15, 17, 18, 22, 23, 24–29, 31, 33, 35, 36, 38–40, 43–45, 47–49, 51–53, 55, 56, 59, 60, 62, 63, 65
Environmental	2	21, 41
Economic	12	7, 8, 16, 19, 32, 34, 46, 50, 52, 54, 61, 64
Social	7	6, 20, 30, 37, 42, 58, 66
Institutional	3	4, 13, 57

3.4 Identification of Gaps

After the review of the concerns that have been used to characterize the effectiveness of the energy policies, some areas have been identified as not fully covered regarding an integral review of EP effectiveness characterization.

A list of concerns missing, as judged by this author, has been elaborated and is presented in Table 19. The criterion followed to add concerns was if the impacts of the concern could be modified by a policy, and their relevance for the EP effectiveness characterization.

Not all the subcategories needed extra concerns. e.g., the Social subcategories (Social-Equity and Social-Employment) were considered as complete, as the concerns identified through the review do provide a comprehensive perspective of the social approach.

Under the environmental category, the concern of environmental protection has been often found through the revised documents. However, it has been considered relevant to detail it through more specific concerns (as water and land resources) to be able to better measure them.

The externalities pricing is a concern that can be reported under the environmental or economic category, being a mixture of both areas. For the monetarization process that externalities involve, it has been decided to keep this concern under the economic category.

It was found a lack of consideration of some aspects that may be relevant for the policy appraisal, as available funds (for technology, innovation, and infrastructure investment), the economic context of the private sector, and the economic situation by regions, economic and fiscal parameters (like inflation, escalation, exchange rates, and taxes). All these concerns can be gathered as economic background. Additionally, the grid state is a relevant concern for its relation to the energy service provision.

Finally, the concern under the institutional category (Amount and quality of Staff) intends to involve a relevant aspect of the institutional framework: the governing human resources. They differ from Knowledge and skill of the workforce (reported in the Social concerns), as this last regards the technical workforce involved in the policy implementation, while the second one, regards the governance-related workforce.

Table 19. Additional concerns by category.

Environmental Concerns	Economic Concern	Institutional Concern
Water resources	Externalities pricing	Amount and quality of Staff
Land resources	Economic background	
Waste Management	Grid state	

3.5 Inferred Energy Policy Objectives and Condensed Concerns

With the intention of better organizing the concerns and facilitating the identification of their evaluation metrics, a condensation process was taken to eliminate redundancies, conglomerating them into condensed concerns. The condensed concerns have been

identified after questioning where there could be an impact if the extracted concern does not comply. In addition, for every condensed concern, its end objective has been identified (as shown in Table 20). The identification of the ends objective aims to put the review more in line with the typical Multi-criteria Decision Making (MCDM) language and to ease the further identification of indicators. In addition, though the identification of the ends objective, a systematic approach to structure complex decisions is provided (Keeney, R.L. 1992).

The economic extracted concerns are the largest in number when compared with other categories. It was possible to narrow down the initial list to three condensed concerns: affordability, accessibility, and economic competitiveness.

Affordability includes all the concerns that may affect the state of being cheap enough for people to be able to pay for electricity or other forms of energy (Cambridge Dictionaryf, 2019). Accessibility refers to the fact of energy or electricity being able to be reached or obtained easily (Cambridge Dictionaryg, 2019).

Competitiveness brings together the concerns that relate to being able to compete successfully with other companies, countries, organizations, etc... (Cambridge Dictionaryh, 2019).

The concerns under the environmental spectrum have been condensed through two concerns. The first one reflects the policy's impact on the environment. Its ends objective relates to environmental sustainability, defined as the quality of causing little or no damage to the environment and therefore able to continue for a long time (Cambridge Dictionaryi, 2019). The second condensed concern denotes the impacts on climate change.

In the social category, Equity, as the situation in which everyone is treated fairly and equally (Cambridge Dictionaryj, 2019), gathers the majority of the social concerns. Health is however kept as a separated condensed concern.

Governance effectiveness and efficacy as a single condensed concern included all the concerns under the institutional perspective. Governance is defined as how an organization is managed at the highest level and the systems for doing so (Cambridge Dictionaryk, 2019). and assessed through its effectiveness and efficacy.

The organization of the extracted and condensed concerns is documented in Table 20. The economic, environmental, and social categories include more than one condensed concern. The end objective used for each condensed concern can be seen in each column.

Table 20. Extracted and condensed concerns per ends objective.

Economic			Institutional
Affordability	Accessibility	Economic Competitiveness	Governance effectiveness and efficacy
END OBJECTIVE: <u>Maximize the capability of energy payment</u>	END OBJECTIVE: <u>Maximize the access to energy</u>	END OBJECTIVE: <u>Maximize economic competitiveness</u>	END OBJECTIVE: <u>Maximize the policy effectiveness</u>
Energy Price, Elasticity, Cost-Effectiveness, Generation Cost, Net Cost,	Energy demand, Security of energy supply, Incorporation of climatic data, Grid Expansion,	Market growth and maturity, Market barriers, Attractiveness in RES investment,	Actor's and institution's participation Political accountability Source of finance and regulatory simplicity

Economic			Institutional
Affordability	Accessibility	Economic Competitiveness	Governance effectiveness and efficacy
Levelised cost of electricity (LCOE), Technological change, Technological characteristics, Carrier Price	Electricity/Resources Imports/Exports, Geopolitical situation, Energy substitution	Investment incentives, Market Impact, Utility profits and revenue, Profit Ratios Economic feasibility, Macro economic data, Energy savings, GDP Impact, Patent	Governance Government priorities Policy Environment Institutional and Government support Political will Regulatory framework Policy framework Administrative and financial capacity Feasibility of implementation Policy budget Policy implementation mechanisms Government fiscal revenue Type of Governor Policy environment Other policies Policy certainty and planning constraints Policy options Political institutions Robustness, efficiency
Social		Environmental	
Equity	Health impact	Impact on climate change	Impact on the environment
<u>END OBJECTIVE: Maximize social equity</u> Distribution of energy costs, Energy Impact Subsidies allocation Energy Democracy Consumer surplus Welfare and Economic impact Employment Demographic information Knowledge and skill of workforce (expertise) Consumer's acceptance Consumer's preferences Social acceptance of RE technologies Customer satisfaction Perceptions of importance Externalities pricing Macroeconomic context Microeconomic context	<u>END OBJECTIVE: Minimize the health impacts</u> Health Warm spaces	<u>END OBJECTIVE: Minimize the climate change impact</u> Global warming and climate change GHG emissions reduction Low carbon economy	<u>END OBJECTIVE: Minimize the environmental impact/maximize the environmental sustainability</u> Environmental pressure Environmental protection RE Deployment, RE Tech Efficiency Ecological awareness Environmental protection Consideration of climate and weather RE energy production Energy savings RE minimum requirements Sustainability in energy supply General environmental awareness Renewable resources Resources capacity and quality RE share Renewable energy use Less-pollutant transportation Environmental impact Energy resources Natural resource endowments

3.6 Contributions of the Review

Wide variety of documents (66 documents) that meet the eligibility criteria have been analyzed. Each of them presents an alternative to characterize energy policies. The data

gathered derives from multiple sources that attempt to give a solution to the same question: how to evaluate energy policy effectiveness?

It was found that five documents of the review [21,27,30,32,52] consider at least one extracted concern under each of the four core categories, being the most complete documents presented in this review. Nevertheless, no single document covered the eight condensed concerns that have been identified. Therefore, our results are an expansion of those approaches, giving the possibility to apply a more integral analysis.

The results generated a wider perspective on the different concerns that assess energy policy effectiveness. Four core categories (Economic, Environmental, Social, and Institutional) were organized and synthesized through more specific categories (eight condensed concerns organized by their ends objective), presented in Figure 4.



Figure 4. Condensed concerns (inner layer), end-objectives (middle layer) and examples of extracted concerns (outer layer)

3.7 Indicators for Energy Policy Effectiveness Assessment

Indicators have been selected as the metrics to assess the identified concerns. For the data-driven support tool development, translating the identified concerns in the previous section into metrics will now be done.

All the extracted concerns were already organized into condensed concerns, for which the indicator identification process is now followed, identifying, at least one indicator for every condensed concern. The end objective of each concern has been enlisted to ease this purpose.

When observing the concerns not in their condensed form, but their extracted one, more detailed indicators can be seen.

Indicators' Relevance and Types

The relevance of indicators has been recognized in the energy field (Sustainable Energy Authority of Ireland, 2018, IAEA et al., 2007, Eurostat, 2017, OPEC, 2018). Agents have created ways to assess different dimensions of the energy industry through indicators, giving them several functions and purposes (CEDREN, 2012, Global CCS Institute, 2018, World Energy Council, 2018, IEA, 2014).

They can be used as assessment metrics, providing a comparison between the defined objectives and their achievement, therefore assessing the effectiveness of the state of systems, which can be applied to assess the success of policies.

At the beginning of the policy cycle, in ex-ante assessment, indicators can provide a deeper orientation of where to add more resources or where to focus while designing a policy. They may allow a deeper understanding of some elements and even help to identify relations that may not be shown through basic statistics or data. Indicators, as communication instruments, can be useful tools for policymakers to express elaborated ideas or concepts to other relevant stakeholders of the sector or out of it; e.g., the indicators issued by national governments to inform regional or local authorities.

Indicators can be differentiated by function, serving as monitoring, guideline, or communication instruments. With a monitoring purpose, indicators evaluate the policy progress towards their objective's achievement. When indicators are used to monitor the status of an energy policy, they can be helpful for the improvement of the policy. An in-progress evaluation enables the identification of the need for modifying the track to achieve the settled objectives in case the progress is not fully satisfactory.

Indicators can also be differentiated by whether they are individual or composite (also known as aggregated). The first ones are commonly used to show the presence or state of a situation or condition individually for a topic (Ycharts, 2018). Despite the usefulness of individual indicators, sometimes the information provided may not be enough for the purposes of the evaluation or an integrative assessment of more than one element. Hence, the condition of the state of a topic may require the evaluation of more than one criterion, requiring the use of composite indicators. For some interrelated information, composite indicators are a feasible alternative. They are the result of individual indicators being compiled into a single index to summarize complex and multi-dimensional situations (Business & Employment, 2016) (Business & Employment, 2016). Some well-known examples of composite indicators in the energy field are energy poverty and energy access indicators. For energy deployment decisions, policymakers

require to know the state of the energy sources, which involves different concerns. That may require an aggregated indicator. For this example, aggregated and individual indicators may be required to contribute to providing information about the energy sources, including why and how they were successful, the social perceptions around them, together with the economic details and other relevant concerns (Yu et al., 2015).

3.8 Indicators Review Methodology

The search for indicators in documents was initially done in the search engine Google (Google, 2018). The first 50 results of the search under “energy policy indicators” were reviewed in detail. Many of them were directly about energy or indicators; however, they either analyzed or proposed indicators related to buildings, utilities or other very specific topics of the energy sector or were not related to energy policies. Therefore, only the documents with general energy policy goals were considered, resulting in the 23 documents listed in Appendix B.

Subsequently, a complementary search was done on the academic database Sciencedirect (Sciencedirect, 2019). From the first 50 documents retrieved under “Energy Policy Indicators”, most of the documents retrieved do not propose new sets of indicators (from the ones previously identified). The majority of the related documents focus on analyzing the indicators proposals done by international organizations or governments (identified through the open sources search) or documents that focus on the analysis of the implementation of the indicators in a particular country or region.

When searching the corresponding indicators for every condensed concern through the retrieved documents, some concerns could not be matched through the recovered documents. A more detailed search was done to find at least one indicator for the concerns. This led to searching and finding additional documents, listed in table B2 of Appendix B. For this search, the names of the concerns were used as keywords, together with the terms “indicator”, “assessment” and “evaluation”.

Indicator’s Identification

As part of the indicator’s identification process, relevant examples or conceptual clarifications of the extracted concerns are presented at the beginning of each table (Table 21 to 24).

3.8.1 Economic concerns

Table 21 shows the indicators deemed as suitable each condensed concern with an economic orientation. For every concern more than one indicator has been identified.

To measure Affordability, the “Willingness to Pay for energy” (WTP) indicator was found. It is defined as the amount of money that the consumer is willing to pay (estimation of the demand for the electricity function) (Choynowski, 2002). The WTP for energy can be applied in more detailed forms to specific concepts; detailing helps to relate the behavior around the price for energy under specific forms like WTP for renewable energy, WTP for using a particular fuel, WTP for the avoidance of service disruptions or WTP for rural supply. The process normally followed to obtain the WTP is through data recovery (survey) from the targeted audience. Some of the

specific factors that influence WTP include the consumers' socio-economic profile and the consumers' energy consumption patterns (Ma et al., 2016).

Three concerns had been identified under the economic-competitiveness subcategory (with their corresponding indicators). The idea behind these concerns and indicators is to be able to assess information about the market state (e.g. potential market threats and obstacles), providing market signals that allow a wide-ranging status evaluation of the market. Several indicators have been identified in this subcategory, situation that reflects a certain recognition from the literature of providing information about the market status. The indicators found provide data not only for policymakers but also to other stakeholders and decision-makers (as could be the case of private investors and other market participants).

The generation of information for different participants is supported in the interest of policymakers to enhance policies that better equilibrate the outcomes of the policies for all the participants. Particularly, for renewable sources deployment projects, it is of big relevance to know the profitability for energy utilities. In addition, market growth and maturity information provide relevant data and help to reduce project risk (IRENA, 2018).

The indicators in this subcategory can also act as compasses to provide information regarding the degree and form of liberalization of the energy sector in the measured country or region (IRENA et al., 2014). It is also a way to assess the market readiness or organizational characteristics of the industry or type of technology in a country or region.

Table 21. Condensed Economic concerns and identified indicators.

Concern	End Objective	Indicator	Units	Source	Definition
Affordability	Max. the capability of energy payment	Willingness to Pay	Numerical value	Measuring Willingness to Pay for Electricity (Choynowski, 2002)	Indicator of how much personal satisfaction or well-being individuals derive from different outcomes
		Spending on energy as a proportion of the household income	Percentage	Assessing the performance of renewable energy support policies with quantitative indicators (Held et al., 2014)	Percentage of income destined to pay electric energy
Accessibility	Max. the capability of energy provision	Energy access	Aggregated value	Energy Sustainability Index (WEC, 2013)	Dimension part of the Energy Trilemma Index, assessment of Security of Supply and Energy Delivery
Economic competitiveness	Max. the economic competitiveness	Harmonised Competitiveness	Numerical value	Harmonised competitiveness indicators (Harmonized Competitiveness)	Indicators that include price and cost competitiveness

Concern	End Objective	Indicator	Units	Source	Definition
				Indicators, 2018)(HCI, 2018)	
		Competitiveness Index	Aggregated value	The Global Competitiveness Report (GCR al., 2018)	Index that analyzes competitiveness along 12 pillars by country, including market size; and business dynamism

3.8.2 Environmental concerns

Table 22 shows the selected indicators for the condensed concerns with environmental orientation: Environmental sustainability and Climate change.

Several indicators have been found as general environmental indicators, reporting very different aspects of Environmental Sustainability. It has been decided to pick only the more general indicators as to be the ones that directly correspond to the concern as a whole (condensed concern). On the other hand, acknowledging that Environmental Sustainability in energy supply presents a very broad concept, a more detailed definition of the specific aspects to be assessed under sustainability in energy supply is recommended to be done for a more meticulous analysis by the users of this support tool.

It is noted that for the “Impact on climate change” concern, besides the identified indicator, detailed assessment metrics or tools were found. Nevertheless, they were under the form of standards or inventories. They do not account as indicators, therefore they have not been reported. The different metrics available for this concern could be explained by the relevance given to the topic, leading different agents to propose solutions and ways to assess this concern.

Table 22. Condensed Environmental concerns and identified indicators.

Concern	End Objective	Indicator	Units	Source	Definition
Environmental sustainability	Min. the environmental impacts	Environmental Sustainability Indicators	Aggregated value	Environmental Sustainability Indicator (Government of Canada, 2016)	Indicators on air, climate, water, nature, and human influence
		Environmental Performance Index	Aggregated value	Environmental Performance Index(Yale, 2019)	Includes 32 performance indicators across 11 categories covering environmental health and ecosystem vitality
		Environmental impact of a	Aggregated value	Energy Sustainability	Includes the assessment of Energy resource

Concern	End Objective	Indicator	Units	Source	Definition
		country's energy use		Index (WEC, 2013)	productivity, GHG emission and CO2 emissions
Impact on climate change	Min. the impact on climate change	GHG emissions from energy use per unit of GDP	GHG/GDP (CO2/economic unit)	Indicators for Energy Sustainable Development (OPEC, 2017)	Composed by GHG emissions from energy production over GDP

3.8.3 Social concerns

The proposed indicators for the two condensed concerns with social orientation are shown in Table 23. Under the Social equity category, the indicators seem to be a mixture of economic, institutional and social elements, which makes sense as the social aspects are a wide and integrative subject, with different subtopics influence. The majority of the topics covered appear to belong to more than one category. After double-checking the ends objective of these indicators, it was confirmed their closeness to the social category.

If the equity indicators may be too general for the user's need, a more detailed approach in the extracted policies is suggested for the policy analysis e.g. consumer's surplus was reported as a concern itself, but it was later found to be the metric to assess the consumer welfare and a metric for welfare and economic impact. Consumer welfare can be used to assess the effectiveness of policies, through the comparison of the change brought by policies and their benefit and social welfare (Liu et al., 2018). The consumer surplus indicator is a metric for consumers' welfare, defined as the excess of social valuation of product over the price paid (OECD, 1993). In other words, it is the difference between what the consumer is willing to pay and what they actually do pay. Consumer welfare is closely related to WTP, as both include consumer's behavioral aspects, and their measurement requires information about individual and group preferences.

The approaches reported in Table 23, conglomerate the concerns above mentioned and other details into single metrics.

Table 23. Condensed Social concerns and identified indicators.

Concern	End Objective	Indicator	Units	Source	Definition
Equity	Max. the consumer's welfare	Energy Equity Indicators	Aggregated value	Energy Equity Indicators (California Energy Commission, 2019)	Set of indicators that evaluate access, investment and resilience
		Population unable to keep home adequately warm	Percentage	Eurostat (Eurostat, 2019)	Population unable to keep home adequately warm by poverty status

Concern	End Objective	Indicator	Units	Source	Definition
		Energy Equity	Aggregated value	Energy Trilemma Index (WEC, 2013)	Includes the assessment of access, and quality of supply
Health's impacts	Min. The energy impact on health	Accident fatalities per energy produced by fuel chain	Number of fatalities by fuel chains per energy or electricity produced annually	Energy indicators for sustainable development (IAEA et al., 2007)	Annual fatalities by fuel chain

3.8.4 Institutional

The indicators for the Governance effectiveness and efficacy condensed concern are shown in Table 24. Some of the extracted concerns covered by them are described in the next paragraphs.

Most of the indicators presented so far across the previous categories belong more directly to the energy subject; however, most of the indicators within this condensed concern do not belong to the energy field directly. Most of them have not been initially found in the documents analyzed (requiring a more specific search), identifying them from documents that belong to general policy indicators topics.

When going on the detail of the extracted concerns included, some of the detailed concerns under this category include the policy acceptance (credibility of the policy), stakeholder's participation and public dialogue concerns throughout the policy process.

Actors and institutions representativeness across the policy process are brought together with the Stakeholder's participation, as a way to understand the whole policy ecosystem, through its participants.

Institutional feasibility, as another extracted concern is defined as the magnitude of the legitimization, acceptance and capability to be accepted and adopted of a policy or its instruments to which a policy or policy instrument is seen as legitimate, gaining acceptance for its adoption and implementation (IRENA et al., 2014). Measuring institutional feasibility can be challenging, as it is not easily quantifiable. However, efforts can be seen through the development of different metrics around it (OECD, 2015). The literature on institutional feasibility metrics is concerned about the administrative factors that support a policy, which results in indicators that measure the policy's capability and help to relate the available resources and comparing them with the needs. It directly relates to the policy administrative capability situation, having the right institutions to execute a policy, but also to the financial capability.

Policy budget can be seen to belong to both, the economic and institutional categories; however, it is more closely related to the institutional context, as it refers to the policy resource capability itself. Therefore, it was decided to be kept in the institutional category. The Policy budget concern can be partially assessed through the institutional feasibility metric, yet, a more specific assessment indicator is available: Access to budget.

Policy synergy can be closely related to policy coherence, as both work in favor of the coordination of policies and their incorporation into other policy sectors. They can also be found as policy integration and it occurs when policy instruments have a cumulative or reinforcing impact to pursue a common goal or overarching policy aspiration (OECD et al. 2015). For the assessment of policy synergy and coherence, an integrative approach has been identified, which considers the coordination across levels of government (authorities), actors, actions, targets or even among policies. All of the possible alternatives regard coordination that translates into maximizing the benefits of a policy; synergies can be described as win-win strategies or winning strategies (Luukkanen et al., 2012).

Table 24. Condensed Institutional concerns and identified indicators.

Concern	End Objective	Indicator	Units	Source	Definition
Governance effectiveness and efficacy	Max. the policy effectiveness	Government effectiveness index	Aggregated Value	World Bank Group (WBG, 2019)	It covers dimensions like Government Effectiveness; Regulatory Quality
		Worldwide Governance Indicators	Percentile Rank (0 to 100)	Worldwide Governance Indicators (OECD, 2017)	Indicators on the quality of governance, including Government Effectiveness, Regulatory Quality

3.8.5 Additional concerns from Review

The concerns that were identified as missing in the subsection “Identification of Gaps” were tried to be matched with a corresponding indicator. The same methodology was followed as for the identification of the previous indicators.

All the concerns were matched with an indicator excepting Externalities pricing and are presented in Table 25.

Table 25. Additional concerns by category and identified indicators

Concern	Objective	Indicator	Units	Source	Definition
Water and Land resources	Max. the environmental sustainability	Environmental Protection Indicators for California (EPIC)	Different units	California Environmental Protection Agency(California Environmental Protection Agency (Cal/EPA, 2004)	Set of indicators that measures land, water, air quality and waste management
Waste Management	Max. the environmental sustainability	Generation of waste by waste category	Tonnes	Eurostat (Eusorstat,2019)	Data on the generation and treatment of waste based on the annual average of the population.

Concern	Objective	Indicator	Units	Source	Definition
Grid State	Max. the energy accessibility	Grid Electrification indicator	Aggregated Value	RISE(WBG, 2017)	Includes 3 subindicators (Funding support for grid electrification, for consumer connections and standards of performance on quality of supply)
Amount and quality of staff	Max. the quality of staff	Education, experience and skills of staff	Not available	IRENA (IEA, IRENA, 2018)	Education, experience and skills of staff at different levels
		Amount of staff	Number of staff	IRENA (IEA, IRENA, 2018)	Number of staff by organization

3.9 Conclusions of the Chapter

This review aimed to characterize the policy evaluation practices in the Energy field, with a focus on the metrics: concerns, objectives, and indicators. In addition to efficacy and efficiency, an emphasis was put into trying to find indicators that can assess effectiveness. Effectiveness enables a more holistic, field-tested, and modulated assessment of the achievements.

It was found that from the different categories (Environmental, Economic, Social, and Institutional), the Economic category is the one most often included, being present in nearly all documents (36 out of 66). Ex-post is the most frequent evaluation type in terms of the moment (34 out of 66). Regarding the level of disaggregation reported for EP evaluations, local studies were found in three documents, while the national ones had the lead (40 out of 66). Considerations like the stakeholder's participation, evaluation motivation, and methodological approach varied with less focus across the gathered documents.

The extracted concerns were condensed in a more compact list that eliminated redundancies, organizing them by their end objective. This resulted in eight condensed concerns: accessibility; affordability; competitiveness; impact on climate change; impacts on the environment; equity; and health.

The identification of the core metrics of the concerns was also done, leading to the exploration of the energy policy indicators spectrum. A total of 15 indicators were identified as possible alternatives to fully characterize the concerns: 2 for affordability, 1 for accessibility, 2 for economic competitiveness, 3 for impacts on the environment, 1 for climate change impact, 3 for equity, 1 for health, and 2 for governance effectiveness and efficacy. This list is a considerable expansion from what could be found in any single previous document. It is proposed as a holistic assessment of the effectiveness of energy policies.

The main contribution of this review is the organization of attributes focused on assessing energy policy effectiveness in a more detailed way. The Energy Trilemma (Wyman, 2018) metrics have been very useful to identify options to assess some of the identified condensed concerns;

however, the Trilemma lacks the consideration of one of the core categories resulting from this review: the Institutional one.

The potential of the data from this review gives the possibility to construct more complete and integral assessment procedures and to reframe already existing energy policy evaluation methodologies with the addition of new attributes (and its metrics).

This review can be directly useful for the national and international current governance situation, in which different levels of authority are implementing approaches for climate change mitigation, whereas EP evaluation is required, e.g., for the SDGs achievement assessment, a set of indicators currently exists (UNFCCC, 2020). However, a policy effectiveness evaluation tool or methodology (in coherence with the SDGs) may contribute to assess in more detail every policy. Therefore, this report contributes to establishing a base for the future development of a policy effectiveness evaluation methodology that supports the alignment of policies to achieve the SDGs or any other international, national, or local frameworks targets.

Chapter 4. Synthesis of Technical Measures and Policy Instruments for Domestic Water Heating

Different energy policies are available to promote energy efficiency and the use of renewable sources for electricity generation. Each policy subject may involve several types of technical measures and policy instruments.

As a way of better characterizing and understanding the policy instruments, a detailed analysis of Domestic Hot Water (DHW) support policies was performed, including the most frequent types of technical measures and policy instrument.

Water heating is one of the most basic energy services. Heating water for domestic activities comprises approximately 25% of households' energy use in Australia (Arbor, 2020), 20% in Canada (City, 2017), 14% in the European Union (EU) (Climate Neutral City, 2020), and 13.2% in US (UNFCCC, 2020). It is the second largest energy use segment in the residential sector, accounting for 4% to 10% of the total energy used in developed economies (DNV, 2017). The importance of guaranteeing access to hot water and the weight of this service in the overall energy use in the residential sector make the achievement of more efficient and sustainable production and use of domestic hot water a global policy objective.

The residential sector constitutes one of the greatest sources of untapped potential for energy efficiency improvements and reduction of GHG emissions. The CO₂ emissions reduction potential for the building stock in 2020 is estimated at 21%–54% in developed economies, 26%–46% in economies in transition and 18%–41% in developing countries (Novikova, 2010).

The socio-economic benefits of energy efficiency improvements associated with DHW are widely recognized, including the reduction of energy costs and the increase of wellbeing. Over the last decades, several governments have aimed for a better management of hot water use and promoted the use of renewable sources and/or more energy efficient systems.

Currently, the main challenge is to fulfill the sector needs with the most sustainable alternatives. Despite the large untapped potential for reduction of GHG emissions associated with DHW and the demonstrated political will to achieve it, there is still a lack of scaling-up of both technological and non-technological opportunities for improvement (Novikova, 2010). Among the existing works, a thorough review on possible technical measures that may lead to the reduction of GHG emissions associated with DHW (through increase energy efficiency and/or the use of renewable energy sources) and the policy instruments that are more adequate for the respective implementation is still lacking and this gap may be hampering policy makers from taking informed decisions. Indeed, the identification of the technical measures to be promoted and the choice of policy instruments with which the later are promoted are key for a successful policy-making process (Figure 5).

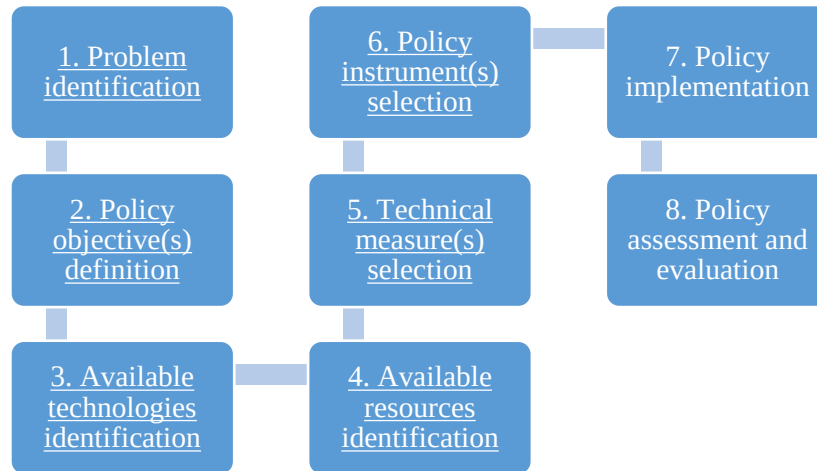


Figure 5. Water Heating System (WHS) Policy Process

This chapter aims to support WHS policy decision makers, with a focus on steps 5 and 6 as the steps where technical measures and policy instruments are to be selected, considering the WHS policy process described in Figure 6.

4.1 Domestic Hot Water Situation across the World

Water heating energy use varies across countries and regions, but, in general, it is associated with a high share of energy use. More than 50% of the residential energy use corresponds to thermal use, with a considerable contribution from water heating usage. For the year 2000, the energy use associated with water heating in the residential sector corresponded to 480 Mtoe and reached 580 Mtoe in 2017 (IEA, 2012). The increase in energy use can be associated with the increased use of hot water, which is not sufficiently counteracted by energy efficiency improvements.

Moreover, future projections point to a significant increase of the associated energy use in the following years, especially in developing countries. Indeed, the growth in hot water use may imply a significant increase in the associated energy use or, on the other hand, reducing the hot water use would result in direct energy savings with their associated CO₂ reductions. For example, reducing the use of hot water in approximately 20% in the United States could lead to a reduction of 41 million MWh of electricity consumption and 240 billion cubic feet in the use of natural gas, corresponding to a reduction of about 38.3 million tons of CO₂ emissions (IEA, 2019).

Nowadays, the dominant technologies in the production of domestic hot water in buildings are either fossil fuels based or low-efficiency electrical technologies, with the exception of some developing economies where the traditional use of solid biomass is predominant (IEA, 2019) (Parsons, 2013).

Given the low-efficiency or carbon-intensive technologies, and the projected increase in the use of hot water, DWH comprises a large potential for energy efficiency improvements, and the reduction of GHG emission (IEA, 2012). The average level of emissions associated with the production of hot water varies significantly among the different DHW technologies, ranging from

0.02 mtCO₂ eq./Yr with a heat pump to 0.06 mtCO₂ eq./Yr with an electric water heater and to 0.87 mtCO₂ eq./Yr with a gas water heater (EWEB, 2020).

Currently, the promotion of both energy efficiency and renewable energy use for water heating within the residential sector is already one of the priorities in energy policy at different governance levels. The set of solutions that can be promoted is large, given the wide variety of technologies available. The potential for reducing the GHG emissions associated with the production of hot water with the use of natural gas is estimated to be around 25.8 million tons of CO₂, while the adoption of electrical SWH technologies could lead to a reduction from 20.9 to 45.0 million tons (Denholm, 2007).

4.2 Materials and Methods

In this paper, the identification and characterization of both technical measures and policy instruments used to promote energy efficiency and renewable energy use in DHW is based on an extensive literature review, identifying the WHS-related policies across the world.

Policy instruments can be considered as mechanisms that promote or support the implementation of the technical measures. Policies are normally executed through instruments or mechanisms that enable the implementation of the technical measures. Most of the instruments have been gathered from the policies where the technical measures were identified.

For the review, two databases on energy efficiency policies were taken as the starting point:

1. The energy efficiency policies and programs database published by the International Energy Agency and retrieved from IEA (AIE, 2017). The list of policies was obtained by selecting the following filters: “heating and cooling” as sector and “Renewable Energy and Energy Efficiency” as topic.
2. The solar thermal incentive database organized by and retrieved from the website Solarthermalworld (Solar thermal world, 2018).

The selection of the two databases was based on the fact that these comprise a collection of several DHW policies, gathered from different national and international studies. They gather detailed information concerning several DHW policies, including location, timeframe, responsible authority, etc. More than 30 WHS policies across the world were retrieved from this review, including their correspondent technical measures and policy instruments.

To guarantee a more comprehensive review, an additional search was performed in the open browser Google (Google, 2019), under the expression “water heating efficiency technical measures”. The first 50 sources displayed under this search were reviewed. This number was considered as a reasonable compromise between comprehensiveness and feasibility. The search lead to the identification of additional measures and consequently to the identification of additional policy instruments.

Finally, additional measures and instruments not found in the reviewed documents (e.g., prizes and awards, fines and tax increase, technology phase-out) were added to the list, supported by specific search based on personal experience and experts’ opinions.

The review resulted in the identification of individual technical measures and policy instruments previously adopted in the promotion of energy efficiency and renewable energy use for domestic hot water. The identification of the combination of technical measures the policy

instrument(s) used for their implementation was also performed. The results were organized in a table and are presented in Appendix C (Table C1).

4.3 Results

4.3.1 Identification of Technical Measures

The review of the energy efficiency policies led to the identification of a wide variety of technical measures, which were organized by type. Most of the reviewed policies promote a single technical measure, with only a few opting for the combination of several measures.

Measure 1: Adjusting the scale of the water heating system

1.1. Replacing collective system with individual WHS

Independent water heating systems (as opposed to collective) provide individuals with the possibility of controlling the devices' maintenance and operation, allowing them to make technical improvements when required. Moreover, individual metering allows for a detailed monitoring of the consumption pattern of each user, leading to a better identification of inefficiencies (technical or behavioral).

1.2. Installation of a collective WHS (building or district systems) in substitution of individual systems

Moving from individual to collective WHS is also feasible and may have advantages, depending on the context. The most adequate solution may vary depending on the characteristics of each building, but also criterion like the geographical location and the energy sources. A collective system could refer to a WHS which provides several dwellings in the same building or even several buildings. District heating is an example of a collective heating system (WHS included). The choice for a collective system may allow for the transition to more efficient and less carbon-intensive technologies that can only be effective in large-scale system. This could include the incorporation of renewable energy or excess heat.

Measure 2: Replacement of water heating technologies for more efficient or less-carbon intensive ones

Technology replacement is one of the most straightforward measures, as the replacement will normally imply the installation of a "better" technology (more efficient or cleaner technology). Differences in fuels, together with technical characteristics can be seen among the wide spectrum of options, varying from renewable energy systems, to electrical input devices and hybrid systems, existing in various configurations. The replacement trends vary from country to country, probably due to the context specificities as the benefits of the different technologies depend on the local conditions. The most common technology replacements identified through the revision of the different WHS energy efficiency policies are presented in Table 26. In general, electric and gas-based devices are replaced by cleaner source-powered technologies, as solar-powered devices.

Table 26. Most common DHW technology replacements.

Initial Technology				
		Natural gas water heater	Natural gas central boiler	Solar water heater
	Fossil fuel water heater	X		X
	Electric tankless water heater	X		
	Electric storage water heater	X		X
	Fossil fuel central heater		X	X
	Electric heat pump			X

*Renewable water heater includes District Heating and Cooling (DHC) networks and small-scale Combined Heat and Power (CHP) units. It does not include solar water heaters (Source: own elaboration).

Measure 3: Installation of solar thermal technologies (to complement WHS)

This measure corresponds to the installation of solar thermal panels to be combined with the already existing water heating device. This is an alternative to the replacement of the whole system, comprising the addition of the solar thermal system to the WHS already installed, reducing the use of energy by the later.

Measure 4: Insulation of boilers

Adding new or improving existing boilers' insulation can lead to energy savings. The insulation of already installed boilers can reduce the heat losses, and it may be a cheaper option than replacing the whole device.

Measure 5: Insulation of heating pipes

The piping system that is used in the distribution of the hot water by the different usage points can also be insulated, leading to a decrease in the heat losses of the whole WHS. The impact of this measure may depend on several factors, ranging from the outdoor temperature to the material of the pipes and the length of the distribution system.

Measure 6: Installation of (or replacement for) efficient water appliances

Water heating systems are combined with other appliances to provide end-use service, as could be the showerheads or the bathroom and kitchen taps. Thus, the installation of efficient (water saving or energy saving) devices may lead to a better use of the hot water. For instance, the installation of devices that reduce the water flow may lead to significant reductions of the total water use and, consequently, of the associated energy use.

Measure 7: Regular maintenance of Water Heating Systems

The performance of regular inspections may improve the daily operation of the hot water system and accelerate the identification and correction of malfunctions, and even the replacement of the devices (when necessary). The benefits of performing regular maintenance of the heating devices are numerous, including: to prevent system irregularities and cope with them opportunely, to guarantee that the energy performance does not get degraded faster than it should and to increase lifetime of the equipment.

Measure 8: Installation of smart systems

Nowadays, smart systems are available to improve the management of WHS at different scales (both individual and collective systems). These systems can include wireless monitoring and data collection systems. They could improve the monitoring of the heaters' operation status, allow for automatic temperature control and to program schedules and other timing functionalities (tele control). In addition, monitoring functionalities can also comprise performance and malfunctions identification. Furthermore, some of the smart systems currently available allow for the automation of the WHS to turn on and off according to the individuals' preferences, as the hourly energy price or the availability of renewable energy sources (solar and wind).

Measure 9: Reduction in the use of hot water

Aiming to lower the water and energy consumption, actions like taking shorter showers or cleaning (dishes or clothes) with cold water can directly decrease DHW demand.

The technical measures retrieved from the literature are shown in Table 27.

Table 27. List of technical measures, type and source of identification.

Source	Program Description		Implementation on Timeframe	Technical Measure(s) Promoted	Type of Technical Measure(s)
	Name	Country/ Region			
(Saskenergy, 2019)	Energy Star Loan Program	Canada	2015	Device change (from fuel to gas)	Replacement of water heating technologies for more efficient ones
(FortisBC, 2019)	British Columbia Energy Star Water Heater Program + Furnace and Boiler Replacement Program	Canada	2014		
(Energywise, 2019)	Warm Up New Zealand: Heat Smart	New Zealand	2009	Device change (from oil boiler; Gas or propane furnace/boiler to more efficient ones)	Installation of solar thermal technologies
(Energywise, 2019)	Insulation Programmes 2009–2018	New Zealand	2009		
(Domácnostiam, 2019)	Slovakian Green Homes incentive programme	Slovakia	2019	Installation of renewable-based systems (SWH, photovoltaics, heat pumps, small wind-mills)	Installation of solar thermal technologies
(Enova, 2016)	“Enovatilskuddet” (Enova grants)	Norway	2015	Installation of solar water heaters, pellet boilers and heat pumps	

Source	Program Description		Implementation on Timeframe	Technical Measure(s) Promoted	Type of Technical Measure(s)
	Name	Country/ Region			
(BAFA, 2019.)	Market Rebate Programme for Renewable Energy	Germany	2012	Installation of SWH systems, heat pumps, pellets tanks, woodchip equipment	Installation of solar thermal technologies (to complement WHS)
(Services, 2019)	Solar water heaters	Malta	2010	Installation of solar water heaters and heat pumps	
(Sklad, 2019)	Eco Fund, Slovenian Environmental Public Fund	Slovenia	2009	Installation of Solar water heating systems and other renewable technologies	
(Bydlení, 2019)	Nova Zelena Usporám	Czech Republic	2013	Installation Solar thermal systems, biomass boilers and heat pumps	
(Klima- und Energiefonds, 2019)	Demoprojekte Solarhaus	Austria	2017	Solar thermal systems addition	
(WBSEFF, 2014)	Western Balkan Sustainable Energy Financing Facility II	The Western Balkan countries*	2013		
(Ministerio de Industria, 2014)	Tax Rebate	Chile	2016		
(ANME, 2019)	Prosol II	Tunisia	2005		
(Conservation, 2018)	The National Financing Mechanism for Solar Water Heaters	Lebanon	2010		
(Ministerio de Industria, 2014)	Solar Plan	Uruguay	2012		
(Economy Ministry, 2019)	Programme for partial subsidising of purchased and installed solar water heaters for households	Macedonia	2017		
(Residential Energy Efficiency Credit Line, 2019)	Residential Energy Efficiency Credit Line 3	Bulgaria	2016		
(California Solar Initiative, 2019)	California Solar Initiative Thermal Program	California	2017	Installation of solar WHS (for new construction buildings)	
(Agencia Andaluza de la Energía, 2019)	Andalusia: Sustainable Construction Incentive Programme	Andalusia	2017		

Source	Program Description			Technical Measure(s) Promoted	Type of Technical Measure(s)
	Name	Country/ Region	Implementati on Timeframe		
(Arctic Energy Alliance, 2019.)	Northwest Territories Energy Efficiency Incentive Program	Canada	2014	Electric hot water cylinder wraps installation	Insulation of boilers
(Aranda et al., 2017)	Analysis of energy efficiency measures and retrofitting solutions for social housing buildings in Spain as a way to mitigate energy poverty	Spain	2017	Installation of efficient taps and showerheads	Installation of (or replacement by) efficient water appliances
(Savickas & Bielskus, 2015)	Technical measures to decrease heat energy consumption of final customer in multi-apartment buildings according to Energy Efficiency	Lithuania	2015	Independent heat substation for heat and hot water preparation; Hot water system balancing; Hot water metering for each final customer of the building; Smart intelligent wireless monitoring and data collection system	Individual/collective optimization of the water heating system. Installation of smart systems
(Poortinga & Steg, 2002)	Viable behavioral and technological energy-saving measures	The Netherlands	2002	Rinsing dishes with cold water; shorter showers; Insulation of heating pipes	Reduction in the use of hot water. Insulation of heating pipes

4.3.2 Characterization of technical measures

In order to facilitate the assessment of the technical measures identified in the review process, these were characterized according to the following features: level of transformation; level of energy savings; scope (single vs. multi-apartment solution) and need for technical/specialized intervention (organized in Table 28).

3. **Level of transformation** refers to the degree of change in the WHS due to the technical measure implementation. “Marginal” refers to small changes in the WHS, while “transformative” refers to significant interventions or changes. For example, the installation of more efficient appliances, as showerheads, can be considered a marginal transformation, while the installation of a solar thermal system to complement already existing WHS is a transformative measure. The analysis of this feature is important to understand if the measure can be implemented without a significant burden for the users, and without significant changes in the WHS system.

4. **Level of energy savings** measures the energy efficiency improvements and it is classified as high or low, referring to the degree of energy-saving potential behind each measure, implying a change or considerable reduction in the fuel used, e.g., changing the shower head for more efficient ones saves up to 30% (low level of energy savings), while replacing technologies for efficient technologies can reach up to 90% (high level of energy savings) (Itard, 2016).
5. **Scope** assesses if the measure can be applied to a single apartment and/or in a multi-apartment. This is important as it allows to identify the adequacy of the measures according to the dwelling typology.
6. **Need for technical/specialized intervention** refers to how the measure implementation requires technical assistance or can be implemented directly by the final user. Its relevance relies on understanding if the measure requires specific workforce or skills for it to be implemented.

Table 28. Characterization of the technical measures.

Technical Measure	Level of Transformation	Level of Energy Savings	Scope	Requirement of Trained Technician
1. Adjusting the scale of the water heating system.	Transformative	High Impact	Multi-apartment /Single apartment	Yes
2. Replacement of water heating technologies by more efficient or less-carbon intensive ones	Transformative	High Impact	Multi-apartment/Single apartment	No
3. Installation of solar thermal technologies (to complement WHS)	Transformative	High Impact	Multi-apartment/Single apartment	Yes
4. Insulation of boilers	Marginal	Low Impact	Multi-apartment/Single apartment	No
5. Heating pipes insulation	Marginal	Low Impact	Multi-apartment/Single apartment	No
6. Installation of (or replacement by) efficient water appliances	Marginal	Low Impact	Multi-apartment/Single apartment	Yes
7. Regular maintenance of water heating systems	Marginal	Low Impact	Multi-apartment/Single apartment	Yes
8. Installation of smart systems	Marginal	Low Impact	Multi-apartment/Single apartment	Yes
9. Reduction in the use of hot water	Marginal	Low Impact	Single apartment	No

4.3.3 Identification of policy instruments

The policy instruments retrieved from the literature were organized by type. They are briefly described in the following paragraphs, and also presented in Table 29.

Policy Instrument 1: Minimum Energy Performance Standard (MEPS)

As a well-developed energy efficiency standard, MEPS establishes the minimum level of performance that a device must have to be sold in the market. With the aim of defining the required performance levels, standby losses are generally considered, for which testing procedures including standing loss tests are carried out (Johnson et al., 2013). MEPS normally lead consecutively to selling and installing products that are at least as efficient as defined in the standards. The use of energy standards is widely spread, whereas international agencies have participated through the creation of international references. The definition of standards can also happen by geographical areas, as has happened in North America (Canada, USA and Mexico) and in Australia and New Zealand (Turriel, 2000). The first standard creation for WHS in the EU was established in 1998 for gas boilers (Dungen, 2011). International standards have served as tools for national governments to base some regulations and achieve objectives (UNFSS, 2013). Depending on the objectives, standards can be mandatory or voluntary.

Other standards: Voluntary Standards

Out coming as best practice from industry guidelines, voluntary standards can address a diversity of products. Standards may benefit final consumers by raising the quality or any other product characteristic. The application of voluntary standards is not exclusive to the industrial sector.

Policy Instrument 2: Technology phase-out

Prohibit the installation of certain technologies represents another measure to cope with the energy-inefficient technologies, leading to ban the production and/or distribution of certain devices or systems with certain characteristics (Hohne et al., 2019).

Policy Instrument 3: Rating System/ Building Index

Rating systems as evaluation tools, can serve to create a benchmark among buildings, providing an alternative for evaluating and comparing criteria (e.g., efficiency, use, costs). Different scales can be used through the ratings; the National Energy Performance rating system in the US uses a 1 to 100 scale, whereas the higher the score, the better energy performer the evaluated facility is (Reed, 2002). One of the purposes of rating systems is to provide practical information to stakeholders and decision makers about the efficiency and inefficiency of buildings ((IMT), 2009). Building index is an organized form of building evaluation, whereas a score is given to every evaluated facility. They both can serve as a basis to building certification.

Policy Instrument 4: Labelling

Energy labelling, as the way to categorize products under certain characteristics, provide information regarding the product technical data (e.g., efficiency). By labelling, the energy efficiency requirements in the manufacture of the product is promoted, leading to impulse market

take-up of certain products or technologies. A labelling system can be used to express the results of a rating system or building index.

Policy Instrument 5: Certification

Certificating certain type(s) of equipment (boilers and WHS) may include the compliance of MEPS, minimum device age or any other characteristic validated under the regulation or market criteria. For WHS, some examples include minimum efficiency levels.

Policy Instrument 6: Information, education and awareness campaigns

Education and awareness campaigns provide information to consumers, service providers and/or any other targeted stakeholders. Information aimed to be communicated to the targeted audience may comprise the potential for energy savings, available WHS devices and appliances. It is frequent, through this instrument, to inform the final consumer on the benefits and drawbacks associated with the different WHS technologies available in the market and advise them on how to improve their own performance. The provision of more specific information through training or workshops is another option, usually targeting a more specific audience as technicians and other service providers. In general, this type of instrument is relatively easy to implement and does not require significant investments (Santiago, 2011).

Policy Instrument 7: Grants and Subsidies

Subsidies, as a financial support, aim to reduce the capital cost of a technology, enabling the market growth of the technology. These instruments have widely been used across the countries, and most of the times, the incentives become unnecessary, after the market has been developed (Schaefer, et al., 2000).

Policy Instrument 8: Tax credits/tax incentives

This type of instruments corresponds to a positive financial incentive, meaning that incentivizes consumers (or other stakeholders) with actions that benefit the final user as tax rebates or tax exemptions. These aim to reduce the total investment of the WHS acquisition.

Policy Instrument 9: Fines and tax increases

As a negative form of incentive, fines and tax increase are used to penalize the non-compliance or abuse of certain actions (Fraunhofer Institute for Systems and Innovation et al., 2016).

Policy Instrument 10: Low-interest loans/third-party financing

Another financial aid suitable for the acquisition of solar water heater (SWH) is to facilitate the access to credit. This option can be complemented with other policy instruments.

Policy Instrument 11: Prizes and Awards

This corresponds to the identification and recognition of best practices or any desired parameters through a prize or award. The prize could be economic or not (WEC, 2016)

All these types of instruments can be used alone or combined. The combinations of instruments is worth mentioning, whereas more than one instrument is applied, and it has been identified in different documents of this review.

The instruments have been organized in Table 29 by the details of the policy program or document where they were identified, their detailed instrument and type. Most of the instruments have been gathered from the same policies where the technical measures were identified.

Table 29. Policy Instruments list.

Reference	Policy	Country	Year	Detailed Policy Instrument	Policy Instruments Type
(Saskenergy, 2019)	Energy Star Loan Program (SaskEnergy/SaskPower)	Canada	2015	Fiscal incentives	Tax credits/tax incentives
(FortisBC, 2019)	British Columbia Energy Star Water Heater Program + Furnace and Boiler Replacement Program	Canada	2014		
(Arctic Energy Alliance, 2019)	Northwest Territories Energy Efficiency Incentive Program	Canada	2014		
(Ministerio de Industria, 2014)	Tax Rebate	Chile	2016	Tax relief	
(Energywise, 2019)	Warm Up New Zealand: Heat Smart	New Zealand	2009	Grants and subsidies	Grants and Subsidies
(Energywise, 2019)	Insulation Programmes 2009–2018	New Zealand	2009		
(California Solar Initiative, 2019)	California Solar Initiative (CSI)—Thermal Program	California	2017	Rebate	
(Regulator for Energy and Water, 2019)	Solar water heaters	Malta	2010		
(ANME, 2019)	Prosol II	Tunisia	2005	Grant or reimbursable credit	
(Agencia Andaluza de la Energía, 2019)	Andalusia: Sustainable Construction Incentive Programme	Andalusia	2017	Economic Subsidy	
(Enova, 2016)	“Enovatilskuddet” (Enova grants)	Norway	2015		
(BAFA, 2019)	Market Rebate Programme for Renewable Energy	Germany	2012		
(Bydlení, 2019)	Nova Zelena Usporám (New Green Savings/New Greenlight to Savings)	Czech Republic	2013	Subsidy for investment	
(Economy Ministry, 2019)	Programme for partial subsidising of purchased and installed solar water heaters for households	Macedonia	2017		
(Domácnostiam, 2019)	Slovakian incentive programme Green Homes	Slovakia	2019		
(Klima-und Energiefonds, 2019)	Demoprojekte Solarhaus (Demo Projects Solar House)	Austria	2017		

Reference	Policy	Country	Year	Detailed Policy Instrument	Policy Instruments Type
(Residential Energy Efficiency Credit Line, 2019)	Residential Energy Efficiency Credit Line 3 (REECL 3)	Bulgaria	2016	Loan and investment grants	
(Lviv Regional State Administration , 2019)	Energy Saving programme for residents of the Lviv region for the year 2013–2016	Ukraine	2013	Low-interest loans	
(Csobod et al., 2009)	Overview and Analysis of Public Awareness Raising Strategies and action on energy savings	Central and Eastern Europe (CEECE)	2009	Informative campaigns	Information, education and awareness campaigns
(IMT), 2009)	A roadmap for creating building energy rating systems in Central Asia	Central Asia	2009	Rating systems	Rating systems
(D’Agostino & Mazzarella, 2019)	What is a Nearly zero energy building? Overview, implementation and comparison of definitions	Europe	2018	Building Index	Building Index
(Dungen, 2011)	Energy Performance Standards How does New Zealand compare with other countries?	New Zealand	2011	Minimum Energy Performance Standard (MEPS)	Standards
(Johnson et al., 2013)	An International Survey of Electric Storage Tank Water Heater Efficiency and Standards	New Zealand	2013	Minimum Energy Performance Standard (MEPS)	
(Turiel, 2000)	Present status of residential appliance energy efficiency standards—an international review	International	2000	Other Standards	
(Pusok & Morris, 2018) .	Voluntary Energy Standards: ISO 50001 and the superior energy standards	International	2018	Other Standards	
(Reed, 2002)	National Energy Performance Rating System	USA	2002	Rating System	Rating System
(UNECE, 2018) [53]	Mapping of Existing Energy Efficiency Standards and Technologies in Buildings in the UNECE Region	UNECE Region	2018	Building energy codes; Energy Performance Certification; Labelling	Combined (more than one instrument)
(WEC, 2016)	Energy Efficiency Policies around the World: Review and Evaluation	International	2008	Labelling, Codes & Standards	

Reference	Policy	Country	Year	Detailed Policy Instrument	Policy Instruments Type
(Government of Australia, 2019)	Water Heating Energy Rating	International	2019	Labelling, Codes & Standards	
(Norden, 2015)	Nordsyn—energy labelling requirements for packages of water heaters and solar devices	International	2015	Labelling, Codes & Standards	
(National Housing Bank, 2015)	Capital subsidy scheme for installation of solar thermal systems	India	2014		
(Ministerio de Industria, 2014)	Solar Plan	Uruguay	2012	Soft Loans + Subsidy	
(Conservation, 2019)	The National Financing Mechanism for Solar Water Heaters	Lebanon	2010		
(WBSEFF, 2014)	Western Balkan Sustainable Energy Financing Facility II (WEBSEFF II)	The Western Balkan countries*	2013	Loans and Grants	
(Sklad, 2019)	Eco Fund, Slovenian Environmental Public Fund	Slovenia	2009		

4.3.4 Characterization of Policy Instruments

The identified instruments have been characterized regarding five major aspects and organized in Table 30.

- (i) **Required competences** refers to the regulatory competences required to policy makers for the instrument implementation (buildings, technology development, market development and taxation definition).
- (ii) **Target group** refers to the actors that are most commonly targeted by the different policy instruments (e.g., installers, construction sector and final consumer, technology developers or industry, etc.).
- (iii) Most common **levels of implementation** correspond to the governance level(s) the different policy instruments are commonly implemented, including local, national and international approach.
- (iv) Major or key **challenges and barriers** related to each policy instrument (either recognized in the literature or proposed through the characterization)
- (v) **Category of Instrument:** The policy instruments retrieved have also been classified in three categories: (a) regulating; (b) informative; and (c) incentivizing. By “regulating” it is meant those instruments that are normally used to formally implement an action, normally through a binding status, compared with informative, whose aim is to provide information to different stakeholders. The instruments enlisted as incentivizing relate to the provision of stimulus (commonly economically) for the measure to be implemented.

Table 30. Policy instruments characterization.

Policy Instruments	Required Competences	Target Group	Levels of Implementation	Challenges/Barriers	Category of Instrument
1. Minimum Energy Performance Standard (MEPS)	Communication with customers	Technology developers (industry), final consumers	Regional/National	Industry (manufacturers) capability (Johnson et al., 2013); clients or other stakeholders' disapproval	Regulating
2. Technology Phase-out	Market organization and regulation	Final Consumers	Local, National	Industry and other stakeholders' disapproval	Regulating
3. Rating System/Building Index	Expert qualification & planning	Construction sector	National	Info availability Public's general environmental ignorance and low awareness of social and economic benefits of energy efficiency (IMT, 2009) Financial costs (D'Agostino and Mazzarella, 2019)	Informative
4. Labelling	Information provision	Final Consumers	Regional/National	Lack of understanding by targeted audience	Informative
5. Certification	Planning	Technology developers (Industry), Final Consumers	National	High demand volume	Informative
6. Information, Education and awareness	Communication with customers	Installers, Construction Sector and Final Consumers	National, Regional, Local	Lack of interest from targeted audience	Informative
7. Grants and Subsidies	Communication with customers	Installers and Final Consumers	National, Regional, Local	Attraction of wrong audience Fiscal Costs (IMF, 2015) private-sector under-investment,	Incentivizing
8. Tax credits/tax incentives	Regulation; Proximity and communication with customers	Installers and Final Consumers	National/Regional	Attraction of wrong audience Market failure and negative effects private-sector under-investment,	Incentivizing
9. Fines and tax increase.	Regulation and planning	Installers and Final Consumers	National, Regional, Local	Not achievement of the policy targets	Incentivizing
10. Low-interest loans/third-party financing	Regulation; Proximity and communication with customers	Installers and Final Consumers	National/Regional	Attraction of wrong audience Supporting the wrong industry development (e.g., foreign vs local)	Incentivizing
11. Prize and Awards	Regulation, planning and economic resources	Installers and Final Consumers	National, Regional, Local	Expensiveness	Incentivizing

4.3.5 Relation between Technical Measures and Policy Instruments

The relation between technical measures and policy instruments normally relies in the policy instruments fostering the implementation of the technical measures. The possible combinations are systematized in Table 31. The detailed technical measures have been enlisted with a

corresponding policy instrument. This identification allows for the analysis of which instruments are more often used to promote the implementation of certain measures.

Table 31. Combination of technical measures and policy instruments identified in the literature review.

	Policy Instruments										
	1. MEPS and other standards	2. Technology phase-out	3. Rating system	4. Labelling	5. Certification	6. Information, Education and awareness	7. Grants and subsidies	8. Tax credits/tax incentives	9. Fines and tax increase.	10. Low-interest loans/Third-party financing	11. Prizes and awards
Technical	1. Individual/collect-ive optimization of the WHS	X		X							
	2. Replacement of WH technologies for more efficient or less-carbon intensive ones						X	X			
	3. Installation of solar thermal technologies (to complement WHS)	X	X			X	X			X	
	4. Insulation of boilers		X								
	5. Heating pipes insulation										
	6. Installation of (or replacement for) efficient water appliances		X	X	X						
	7. Regular maintenance of Water Heating Systems										
	8. Installation of Smart systems	X		X							
	9. Reduction in the use of hot water						X				

The review resulted in the identification of a wide set of technical measures, that go from the installation of devices that improve the system's performance to the replacement of the whole existing system by a new one (more efficient, with a technology shift). The great majority of the technical measures found within the policies and programs reviewed refers to the replacement of the WHS technology or to the installation of devices or equipment that improves the system's performance.

When analyzing the identified measures, it was noted substantial differences and a wide spectrum of possibilities. When assessing the scope of the measures by their applicability in a single vs. multi-apartment, it was found that most measures are not constrained by the type of dwelling, being applicable to both, single and multi-apartment buildings. The installation of solar

thermal and photovoltaic systems could be an exception, depending on the roof area available, together with the change from an individual to a collective WHS (Individual/collective optimization of the system). Moreover, when characterizing the measures according to the need for technical or specialized intervention, most of the identified measures require technical expertise to be implemented. There are still a few measures that can be directly implemented by the final user, as the reduction in the use of hot water.

By identifying the policy instruments used to support the implementation of the reviewed WHS policies, it was possible to observe that the instruments mostly used are either economic instruments, education and awareness campaigns or labelling and standards. For instance, regulatory instruments are not commonly adopted in the implementation of policies associated with DHW.

When characterizing the policy instruments under the selected variables, it was found that the competences required for the implementation of each instrument are considerably different. Even so, the competences required for the implementation of instruments under the incentivizing category are relatively similar. This coincidence can be explained by the similarity in their main activities, even if different instruments may require different specific actions for their implementation.

The two most common levels of implementation found are national and regional; not many instruments have been found to explicitly apply a local or international geographical scope.

Regarding the possible challenges or barriers faced by policy makers throughout the instruments' implementation, market-related problems are the most common, whereas the state of the market may be determinant for the instrument choice, e.g., the existing market (or institutional) barriers that are currently hampering the distribution and commercialization of certain technologies.

The large and diverse set of stakeholders that interact with the WHS-related markets may imply a difficulty in choosing the most effective policy instrument(s), as the impact on different stakeholders will vary substantially. Nevertheless, the selection of some instruments may lead to positive externalities, as the economic effect on certain technologies (price decrease), as a consequence of the market development and spread of those technologies (after the use of incentivizing instruments); or the innovation boost derived from the technological research encouragement behind the economic support of certain technologies.

Another important finding of this review refers to the features that need to be taken into account when choosing the technical measures to be promoted and the respective policy instruments. By classifying the instruments and relating them with the technical measures, it was possible to identify how the informative instruments are widely used, both directly and indirectly. Providing information, educating the consumer and other stakeholders and raising the awareness of different actors may be used to demonstrate the benefits and relevance of energy efficiency, help and assist a consumer with the installation of a more efficient device, and even incentivize regular inspections and maintenance work. Informative instruments could also lead to measures that require behavioral changes from final users, as using less hot water.

Moreover, it was also noted that economic instruments are often used to promote the implementation of measures that require engaging consumers, to commit to the policy objectives (partially or totally). Economic instruments are considered to be effective for consumer engagement, probably due to the positive response of consumers to financial rewards, and their willingness to change their energy use in exchange for a monetary compensation (Pothitou et al., 2014). Even so, there are situations where the financial reward may not be enough. For instance, for gauging the attention and commitment of the targeted group, economic stimulus could be insufficient (as when a lack of interest from targeted audience can be experienced). These cases may be overcome by the combination of several policy instruments. For instance, when experiencing a low participation level to initiatives that are based on economic instruments, education and awareness initiatives may be used to foster participation and adhesion to the economic incentives. Therefore, the combination of the instruments should be seen as a possibility, which may have advantages depending on the policy objectives and characteristics of the target group as well as on the available resources.

4.4 Intended analysis of the effectiveness of the DHW measures and policy instruments

After having identified the effectiveness concerns and their indicators, together with the identification of the technical measures and policy instruments for DHW, an enquiry was prepared as a data collection tool. The purpose of the enquiry was the recovery of the data required for the further application of the EP evaluation methodologies. In particular, it was sought to explore, from empirical data, the relationships between the geographical context, policy instruments and the results achieved in what regards energy efficiency and renewable energy in DWH.

WHS policies were identified worldwide via the IEA and Solarthermalworld (STW) databases, available in Appendix D (presented in table D1 and D2 respectively). The survey was distributed among the policy makers or responsible authorities designated in the policy documents. The survey and contact form intended to be applied is presented in Appendix D. The survey is divided in three parts (Country/region context, Policy input and Policy output). It also includes a policy instruments types and subtypes classification, for an easier and standardized use.

Unfortunately, this process was not very fruitful and only a couple of answers were received from the total of 64 policies retrieved (33 policies from the IEA and 31 from the STW database). There could be different explanations for this to happen. It was identified the lack of clarification on the contacts responsible for some policies. In some cases, the identification of the main responsible person within the institution was not possible. For some other cases, the contact details available may not longer be available if the policy is not longer valid (or even if it is still valid), making impossible the contact. Finally, the success in retrieving the info may have been affected by the initial phase of the SARS COV 2 (COVID-19) pandemic in the spring of 2020. The lists of the responsible authorities contacted is available in table D1 and D2.

4.5 Conclusions of the Chapter

This chapter led to the identification and classification of nine types of WHS technical measures. These were characterized in terms of scope, level of transformation, level of energy savings and the requirements for training for their implementation. By classifying the measures, it was also possible to understand and systematize the differences among them. After this, decision makers can evaluate their alternatives, taking into consideration the different features.

Moreover, eleven types of policy instruments were also identified and characterized according to the required competences for implementation, the most common levels in which they are implemented, and the challenges that may hamper their implementation. The characterization of policy instruments according to their main features has been performed, enabling policy makers to compare them against the available resources and context characteristics, and to select the most suitable instruments.

Lastly, an identification and assessment of the most common combinations between technical measures and policy instruments was also included in this work. Results show that there has been a preference of using economic instruments to support DHW technologies. Notable relevance and applicability of the “education and awareness campaigns” instruments were also identified. Complementarity among instruments has been observed, leading to the policy instruments combination with other policy instruments, providing a wider set of alternatives.

Considering the policy characterization performed in this work, some of the context specificities that should be assessed in order to choose the most adequate measure/instruments include:

1. Policy objective (e.g., reduce GHG emissions, energy savings, reduced costs, etc.);
2. Main type of dwellings covered by the policy;
3. Availability of skilled/trained technical staff;
4. Regulatory competences of the entity responsible for the policy implementation;
5. Budget/resources availability;
6. Policy target group (e.g., end-user, technology provider, technology developer, etc.)

It was the goal of the chapter to gather data to perform the analysis of the effectiveness of the different policy instruments for DHW. However, it was not possible to perform such due to the difficulties in collecting data, which occurred concomitantly with the outset of the Covid-19 pandemic, when most people were ongoing significant adaptation processes at their professional and personal lives. This very likely hindered their availability to cooperate in the data gathering, together with the lack of available data itself. An alternative procedure, at a broader scale, will be sought in chapter 5.

Chapter 5. Analysis of policies through machine learning

5.1 Introduction

The main motivation of this chapter is to contribute to elaborate predictions on the effectiveness and efficacy of Renewable Energy (RE) policies using Machine Learning (ML) Techniques. This case is useful for the analysis of policy effectiveness and efficacy through the RE target achievement. Critical situations highlight the motivation of this analysis, like the non-achievement of the 2020 RE targets by the countries (e.g. France) (Eurostat, 2022).

In particular, the tool under development aims at predicting whether or not a RE target will likely be achieved (efficacy) and to what degree (effectiveness), depending on the geographical context, characterizing concerns and policy characteristics (measures and instruments). To do so, the effectiveness concerns organized in Chapter 3 and the policy options in Chapter 4 have been used for the elaboration of the Decision Trees.

The main contribution of this proposal is the provision of a solution that may support policy makers in designing policies with higher propensity to achieve the desired goal (as when designing the policies, decision-makers can test/predict whether the target will be achieved or not or in what degree).

Scientific research incorporation into the country policy design, contributes to locate scientific progress as an essential key for development (Bush, 1945), with this in mind, in the conclusions of this chapter, a summary for policy makers is presented. The summary aims to leveraging the key highlights of the chapter, serving as a reference point for evidence-based energy policy making.

5.2 Literature Review of Machine Learning

Machine Learning includes different techniques, such as Support Vector Machine (SVM), Artificial Neural Networks (ANN), Random Forest (RF) or Decision Trees (DT) (Nitze, Schulthess, & Asche, 2012). Regarding the application of these techniques across the energy field, there are two main ideas to be highlighted.

First, ML has been mainly used to analyze patterns of energy features like energy consumption and prices, using the results to design alternatives and solutions that better respond to specified conditions (like the weather or the integration of RE) (Royal Society, 2017).

Second, there is also the agreement that ML techniques are generating new opportunities for innovative research in energy, especially connected with topics like economics and finance (Ghoddusi, 2019). They include different applications like risk management, trading strategies, energy prices, demand forecasting and analyzing macro/energy trends, among others.

Decision Tree (DT) is a popular ML method that has been successfully used in many different energy systems (Mosavi, 2019), mainly due to its interpretability. DT has an easy reasoning and reading process, through what is known as induction rules behind the model. The induction rules prevent the existence of a total black box, which characterize other types of techniques where the internal logic is not that easy to be understood (Rokach & Maimon, 2015).

Examples of Machine Learning applications in the energy field have been organized in Table 32.

Table 32. Examples of Machine Learning applications in the energy field

Year	Authors	Application	Document focus
2018	Marugán et al.	Wind energy systems	NN applied in forecasting and predictions; design optimization; fault detection and diagnosis; and optimal control in wind energy systems
2018	Zaidi et al.	Energy-water nexus	Description of different ML methodologies applied in the Energy-water nexus
2018	Zeng et al.	Optimization of reactors	Development of a support vector regression for the creation of autonomous control for small reactors
2018	Zendehboudi et al.	Oil and gas processes	Review on hybrid models with focus on applications in chemical, petroleum, and energy systems
2017	Anifowose et al.	Oil and gas field exploration	Modeling based in ensemble learning paradigm for oil reservoir and other applications
2017	Voyant et al.	Solar radiation forecasting	Development of hybrid models to use an ensemble forecast approach on solar radiation
2016	Heinermann and Kramer	Wind power forecasting	Proposal of a prediction framework based on heterogeneous machine learning ensembles
2016	Fulford et al.	Shale gas well diagnosis	Model application for shale gas well
2015	Gupta et al.	Failure prediction	Development of a support vector machine model for a blackout prediction
2017	Kamali et al.	Prediction of the risk of a blackout in electric energy systems	Smart grid early warning system DT support (in several scenarios)
2016	Moutis et al.	Energy storage planning and energy controlling	Application of a DT to improve storage planning
2016	Ottesen	Total cost minimization in energy systems for the prosumers' buildings	DT for the minimization of total costs
2016	Costa et al.	Security dispatch method for coupled natural gas and electric power networks	DT for preventing contingencies that may cause interruption in the power networks
2018	Aguado et al.	Railway electric energy systems optimal operation	DT applied for multiple railway electric energy systems and operation modes

Through the documents enlisted above, it is noted the growing use of ML techniques for the short-term predictions in the energy industry. The literature presented above mainly use neural networks, support vector regression techniques or decision trees, although there are other methodologies being developed and applied.

Problem statement at the strategical, tactical and operational levels can be observed across the DT literature, for which different target users of the models have been observed, including energy aggregators, planners in utilities or energy planners.

It is noted that some of the benefits of the application of Decision Trees may be obvious like their easiness to be interpreted or the creation of prediction rules, nevertheless the diversity of the challenges associated with their application (and of other ML techniques) in the policy-making field vary. They include the possible lack of knowledge around the applicability of ML to solve prediction problems by a high share of public policymakers (Steuer, 2018), and the lack of data availability. This last may probably be the main challenge.

In addition, the poor communication between the study stakeholders like machine learning experts, public policymakers, and other actors can raise a communication barrier (Rudin & Wagstaff, 2014). The interaction of stakeholders has its relevance for some ML techniques in which for each input/output connection weighting is involved and some participatory approaches may be sought (Magesh et al., 2013).

5.3 Methods: Machine Learning application

Building a DT is mainly divided into two stages: tree building, and testing (Rokach & Maimon, 2015). In the building stage, the training data is partitioned using testing conditions. The first node (at the top of the tree) acts as the root, specifying the testing condition for the following branches, known as internal nodes. Each internal node can split into two or more sub-spaces (Rokach & Maimon, 2015). The terminal nodes (located in an end node) assign the classifications and are also known as leaf nodes (Baesens, 2014).

In the testing stage, the performance of the model is tested (Zhang, Zhao, & Yeom, 2020). There are different methods that can be used for testing purposes (further explained in the Validation section of this chapter). An iterative process of identifying the best performing tree is common in this stage, aiming to increase the performance of the decision tree.

Algorithm

For DT, different types of algorithms are available, some of the most frequent ones include CART, C4.5, CHAID, and QUEST YAN YAN (Song & Lu, 2015). They all share the task to predict the value of a dependent variable from a set of independent variables (Royal Society, 2017). The criteria to decide the splits depends on the algorithm (Rokach & Maimon, 2015). Each algorithm leads to a different way of building up the tree under tree main elements (Baesens, 2014):

- Splitting decision: selection of the independent variable that has the strongest interaction with the dependent variable in every step of the tree.
- Stopping decision: the splitting process is repeated for all input variables until the defined tree levels are achieved.
- Assignment decision: the class assigned to each terminal node.

For this study, the CHAID (Chi-squared Automatic Interaction Detection) algorithm was selected. This algorithm selects the variables for partitioning using Chi-square test. It has been selected as it is possible to apply it to both categorical and continuous variables (Rokach & Maimon, 2015).

The software used for the analysis was Statistical Package for the Social Sciences (IBM SPSS Statistics 26). It has an easy to be used interface, aiming to facilitate the replication of the analysis here presented (and other analysis) by non-technical users.

Data

The final dataset used to construct the DT was self-elaborated. The dataset is composed by a sample of 292 observations. Each one reflects a set of RE policies (policy mix) assessed in a specific year and country, including their respective dependent variable and independent variables. The variables composing the dataset have different origins. A variables directory is presented in Appendix E (Tables E.1 to E.9).

All the observations used for this analysis refer to the years 2004 to 2018. A total of 89 policy programs was initially enlisted. These policies were extracted from the MURE-ODYSEE database (ADEME,2020). When considering each policy program by its year and country of implementation, 889 policy programs resulted. However, after integrating them as policy mixes per year per country, the final data set consisted in 292 observations. This conglomeration of the policy programs (done by grouping sets of policies by year and place of implementation) was required to be able to assess the RE target share achievement (dependent variable). An individual assessment per policy programs was not possible to be carried out, since a result (dependent variable) that can be directly assessed by policy was not identified in the literature.

An example of the RE policy programs integrated to conform the policy mixes used for the database is provided in Table 33.

Table 33. Example of the integration of Policy mixes

Policy Mix No.	Year of evaluation	Individual Policy	Policy Instruments*	Policy subtypes
1	2004	Promotion of Electricity from Renewable Sources	Information/ Education	Information campaigns
2	2005	Promotion of Electricity from Renewable Sources	Information/ Education	Information campaigns
		Mobility management consulting and funding program	Financial	Grants / Subsidies for investments

*The policy instruments and the subtypes can be reviewed in Appendix E (Table E.9)

On the specific experience of the formulation of the database, it is noticed the difficulty to conform it using the survey that was originally designed (Appendix D) for the purpose of data gathering. RE polices are extended worldwide and, in some cases, contact details can be found, but similarly as the WHS policies and as described in Chapter 4, the contact with their policy makers or responsible authorities was very difficult. This was perhaps because the contacts

occurred at the time of the onset of the COVID-19 pandemic, when most people's personal and professional lives were having a shock.

To overcome the data unavailability, existing online policy databases were searched. The MURE-ODYSEE database was identified. It gathers policy programs under different energy topics, being RE policies included. The policies included in this database regard the European Union and Schengen space countries.

Other general data availability challenges were identified. They are now described:

- Fragmented data: in the policymaking field, the availability of data can regard the disposal of information from different sources and in diverse formats (Buchanan & Miller, 2017).
- Unreachable data: even if national or international efforts are being taken to organize data required for policy evaluation or other analysis, the reachability of the info may be stressed by the open access to the data or its availability in only the mother tongue languages.
- Disparities in data: the different purposes behind the data organization and sources, can result in disparity of information and their formats from source to source (Royal Society, 2017).
- Basic or non-existence information registration: in some cases, it can be noted the non-existence of records on policy data or other cross-cutting topics that regard the policy evaluation process (Kim et al., 2020).

To cope with these general challenges, some general recommendations include the governmental promotion to share data within stakeholders; have a data openness approach around policies (Buchanan & Miller, 2017); create the infrastructure required to accumulate and generate reliable data (Kim et al., 2020). In addition, ML techniques are expected to be promoted by the recognition that efforts are required from the governments to assess systematically the policy outcomes (Development, 2012).

The variables

- ***Dependent Variable***

Effectiveness has been selected as the core of the assessment of policy performance and it is defined as "the degree to which something is successful in producing a desired result" (Cambridge Dictionary, 2020). The impact of the performance of Renewable Energy (RE) policies is reflected in the Renewable Energy share from the total energy consumption.

In line with the paragraphs above, the desired dependent variable of our model is the degree of Renewable Energy share achieved by country by year (Eurostat, 2020) (variable 1 of Table 33).

About the RE targets, the EU defined a target of 20% from the total energy consumption by 2020. In addition, member countries established binding national targets for raising their share, under the Renewable Energy Directive (EC, 2005). The targets vary by country, reflecting the countries' different starting points for RE production and their resources to increase it. Contrasting examples include from 10% in Malta to 49% in Sweden (EC, 2020).

A second, alternative, dependent variable has been considered. The focus on effectiveness has changed to efficacy in this variable, explained by the binarization of the possible dependent

variables. Therefore, the focus has changed from the degree of achievement in producing a desired result (effectiveness) to the achievement or not of producing a desired result (efficacy).

The procedure followed for the calculation of this binary variable was:

- Step 1: The self-defined “RE Target until 2020” of every country (EC, 2020) and the variation to their starting value “Initial RE share values in 2004” were used to calculate their difference: “Intended growth”. Afterwards, the “Intended growth” was divided by the number of years in the period of analysis (16 years, from 2004 to 2020), producing a value that can be used as a threshold and under the name of “Average Intended growth by year” (being the reference threshold). Examples of the calculations are introduced in table 34.

Table 34. Estimation of the average intended growth by year.

Country	Initial RE share values in 2004	RE Target until 2020	Intended growth	Average Intended growth by year (threshold)*
EU	8.5	20	11.5	0.71875
Belgium	1.9	13	11.1	0.69375

*Average Intended growth by year (threshold) = (RE Target until 2020- Initial RE share values in 2004)/ number of years in the period of analysis

- Step 2: The “Average Intended growth by year” (calculated threshold in Table 34) is compared against the RE share achieved each year: “Achieved Difference in RE share”. To do so, the “Achieved Difference in RE share” is calculated by subtracting the “Achieved RE share” value of the consecutive year from the year of evaluation (Consecutive year value - Year of evaluation value). An example of this estimation is presented in Table 35.

Table 35. Estimation of the intended growth by year.

Year of evaluation	Achieved RE share	Achieved Difference in RE share
2005	8.5	0.600*
2006	9.1	

*Achieved Difference in RE share of 2005 = (RE share by year 2006) – (RE share by year 2005).

- Step 3: For the dependent variable binarization (under the name of “Efficacy by country”), if the “Achieved Difference in RE share” (step 2) is equal or lower than the “Average Intended growth by year” (threshold table 34), the value of 0 (non-efficacious) is assigned. If the “Achieved Difference in RE share” is higher than the “Average Intended growth by year”, the variable takes the value of 1 (efficacious). An example of this estimation is presented in Table 36 and a representation by country for the year 2010 can be seen in Figure 6.

Table 36. Example of the estimation of the category of effective by country or not.

Year of evaluation	RE share by year	Achieved Difference in RE share	Average Intended growth by year	Efficacy by country
2005	8.5	0.600	0.71875	0 Non-efficacious
2006	9.107	0.578	0.71875	0 Non-efficacious
2007	9.685	0.931	0.71875	1 Efficacious
2008	10.616	0.752	0.71875	1 Efficacious
2009	11.368	1.254	0.71875	1 Efficacious

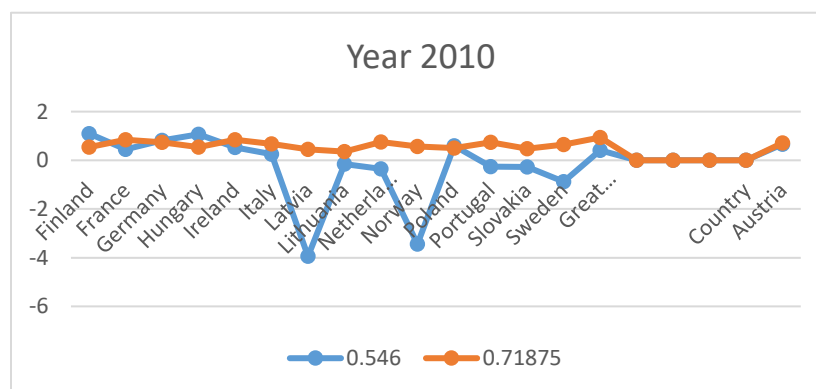


Figure 6. Comparison of the Achieved growth and Intended Growth** for the year 2010*

• Independent Variables

As part of the data organization, it is required to define the attributes that will be tested in the model for prediction purposes (Zhang et al., 2020). As explained in Chapter 3, it was sought to identify attributes that characterize energy policy effectiveness from different angles. Through the incorporation of the effectiveness concerns, a multidisciplinary assessment has been applied, including variables that cover different dimensions. The aim of doing so was to enrich the proposed data-driven analysis and have an integral analysis.

The independent variables have been organized into three groups. A complete description of each variable is presented in Appendix E (Tables E1. to E.9), together with the possible values that each variable can take, their units, etc. The available variables will now be presented by category.

1. **Country Characteristics:** include the variables that regard sociodemographic and other contextual conditions of the country. All the independent variables of this group report the data from one year before the evaluation year (year-1 format), in order to enable the model to be used in the future for prediction purposes. The variables under this group are introduced in Table 37.

Table 37. Country Contextual Characteristics variables

Table 37. Country Contextual Characteristics variables.

	Country Location	Population
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1. Country Characteristics	EU member	Human Development Index (HDI)
	Member of the Eurozone	Harmonised Index of Consumer Prices (HICP)
	Population	Total people at risk of poverty or social exclusion by age and sex
	Long-term interest rate	Gini coefficient
	Cooling degree days	Average household size
	Heating degree days	Air pollutants by source sector
	Final energy consumption	Pollution, grime or other environmental problems
	Total energy supply by product	Exposure to air pollution
	Renewables and biofuels	Environmental protection expenditure
	Oil and petroleum products	Total general government expenditure
	Non-renewable waste	Number of national civil servants in central public administration
	Nuclear heat	FiT-Small Hydro
	Electricity	FiT-Biomass
	Solid fossil fuels	FiT-Waste
	Final energy supply	FiT-Waste
	Expenditure on research and development	FiT-Geothermal
	GDP per capita	FiT-Marine

2. **Policy Characteristics:** include the variables self-calculated (by using other variables of the database). These variables provide a radiography of the policy mix at the moment of analysis. This group includes for example the amount of policies in the sample and the number of years of operation. This group also includes the amount, types and subtype of instruments included in the sample. The different types and subtypes of policies that a policy mix can include are detailed in the Appendix E (Table E.9). The variables under this group are introduced in Table 38.

Table 38. Policy Characteristics variables.

2. Policy Characteristics	Other related policies
	Average duration of the programs
	Average years of activity
	Median years of activity
	Number of RE programs
	Policy Type
	Policy subtype

3. **Policy Effectiveness Concerns:** these variables are focused on assessing the effectiveness concerns identified. The literature on energy policy effectiveness is extensive (Ortiz & Leal, 2020). These variables have been identified following the concerns and indicators proposed on the systematic review on energy policy effectiveness concerns, presented in Chapter 3. The identified individual concerns were organized into the eight core condensed concerns proposed in the report.

Nevertheless, when searching the data for the database organization, more detailed concerns and their metrics were identified, considering to be part of the model. In Appendix E (Tables E.1 to E.9), the variables have been differentiated if they were presented under the Effectiveness concerns review done in Chapter 3 or not. All the variables in this category have a year-1 format. An important observation is that from the eight condensed concerns reported in Chapter 3, after recovering the data, it was possible to find variables included in seven condensed concerns; no data for the employment subcategory was able to be used.

The variables under this group are introduced in Table 39.

Table 39. Policy Effectiveness Concerns variables.

Category	Subcategory	Variable
Economic	1. Affordability	Electricity price for households
		Electricity prices for non-household consumers
		Gas Price for households
		Gas prices for non-household consumers
	2. Economic Competitiveness	Market share of the biggest competitor
		Energy productivity
		Energy intensity of the economy
		Energy intensity of the population
Environmental	3. Accessibility	Energy balance
		Energy import dependency
	4.Impact on climate-change	Total Greenhouse gas emissions
		Greenhouse gas emissions intensity of energy consumption
	5. Impact on the environment	Increase in renewable electricity capacity
		Energy efficiency
Social	6.Health	Population unable to keep home adequately warm by poverty status
Institutional	7. Governance effectiveness and efficacy	Expenditure on energy and fuels expenditure
		Environmental tax revenues (energy tax)

5.4 Results

The performance of the two models, with the two dependent variables analyzed, are now presented, including their dependent variable prediction, tree diagram, the Decision Tree results in a table format, findings and classification rules.

The results for the continuous dependent variable “RE share” are presented first as the variable used for analyzing energy policy effectiveness and therefore the degree of RE share achievement. Secondly, the categorical dependent variable “Efficacious by country” results are presented.

5.4.1 Effectiveness Analysis

For the continuous variable used for the Energy Policy effectiveness model, the predicting performance has been estimated using the Coefficient of Determination or R-squared. It is estimated via the proportion of the variation in the dependent variable that is predictable from the independent variables (Wright, 1921). It has been calculated using the formula:

$$R^2 = 1 - \frac{SS_{res}}{SS_{tot}} = 1 - \frac{\sum_i (Y_i - \hat{Y}_i)^2}{\sum_i (Y_i - \bar{y})^2}$$

SS_{res} = Residual sum of squared errors; Y actual values - $\hat{Y}$ predicted values

SS_{tot} = Total sum of squared errors; Y actual values - the mean value

Y_i = actual y values

$\hat{Y}_i$ = predicted y values

$\bar{y}$ = baseline model the mean

The validation procedure adopted was the 10 cross-fold validation. This means that the whole data was randomly partitioned into 10 parts, and then 9 parts were used for training the model, and the rest 1 part used for testing. This process iterated 10 times.

The R-squared compares the predicted values and the observed ones. As seen in the calculation done below, with an R-squared value of 0.917 and as seen in Figure 7, the EP effectiveness model has a high performance.

$$R^2 = 1 - \frac{5096.5}{61529} = 1 - 0.082 = 0.917$$

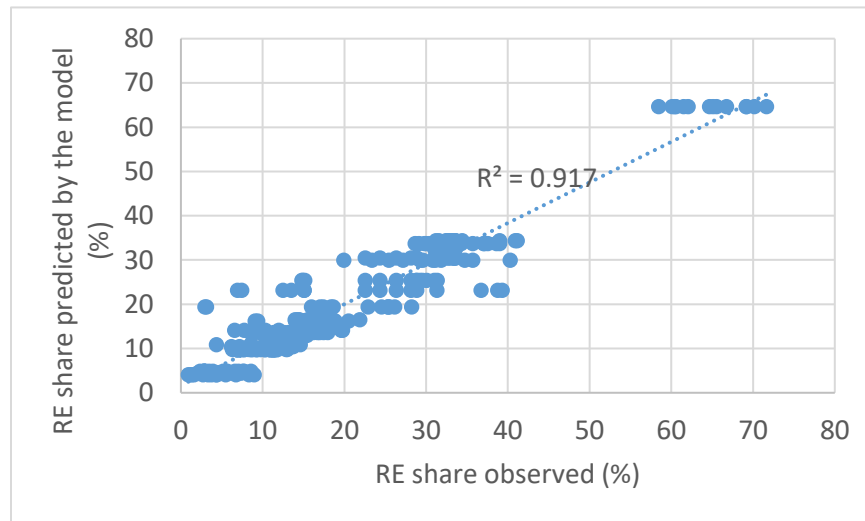


Figure 7. EP effectiveness model: predicted vs observed

Tree Diagram

The tree diagram is the graphic representation of the model. The technique for determining the optimal pathway in a decision tree is known as the “rollback method” (Lucertini, 2012). To apply this method, the tree is analyzed from the bottom to the top (or right to the left if it is the case) by considering the later decisions first. The decision tree resulting is presented in Figure 8.

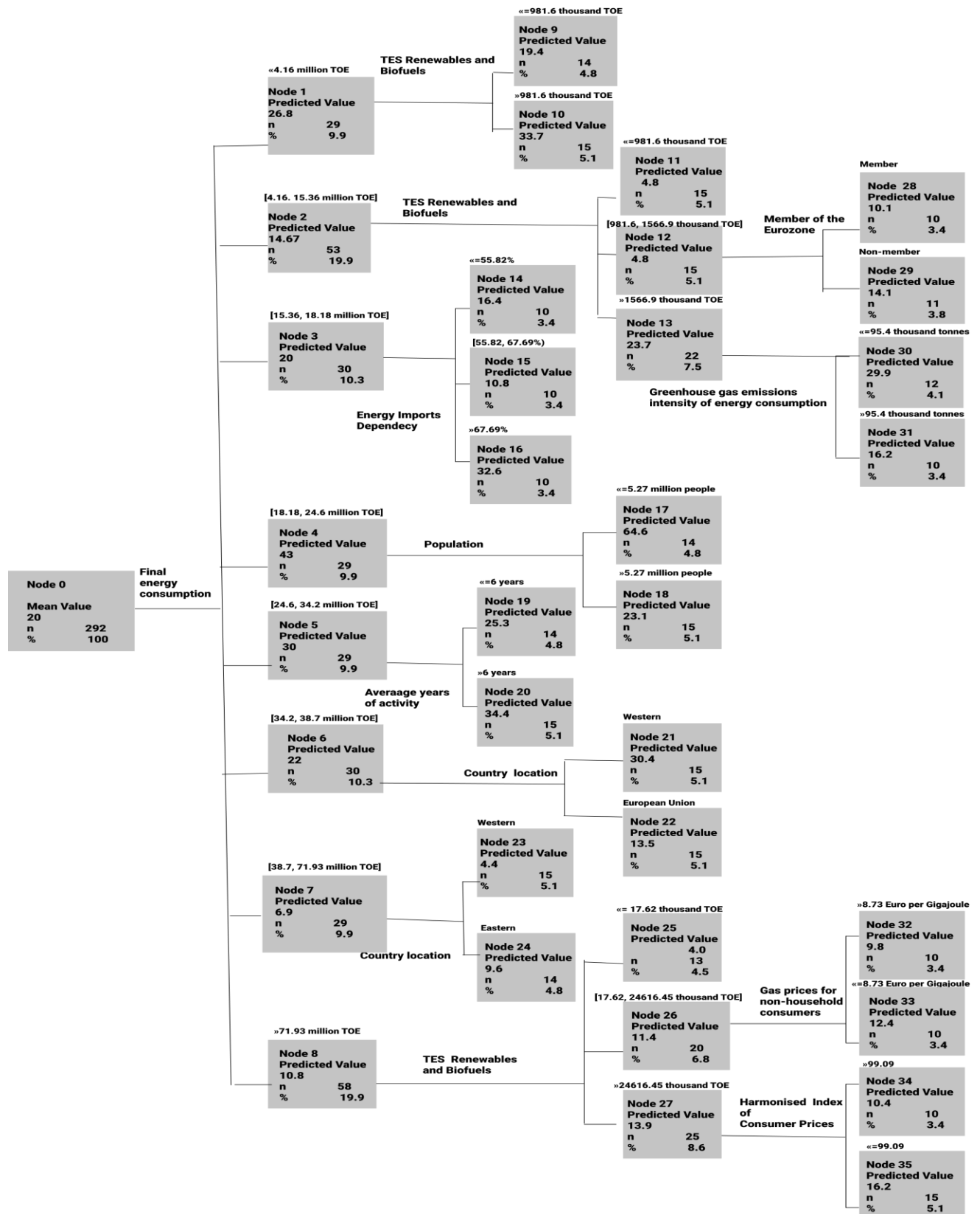


Figure 8. Decision Tree for energy policy effectiveness analysis

From the decision tree (vertically aligned), we can affirm that:

- *Final energy consumption* is the best discriminator of *Energy policy effectiveness*.
- The subsequent branch on the lower side of the DT has selected the *Total energy supply by renewables and biofuels* as the second best discriminator. The policy mixes included in the three consecutive nodes present higher mean values, as the value of the *Total energy supply by renewables and biofuels* increases (with a 17625.4 thousand TOE the mean value of RE share is 4%, with TOE between 17,625.4 and 24616.4 the mean value of the RE share is 11.4%, with TOE higher than 24616.4 the mean value of the RE share is 13.9%). Two child nodes are derived from this branch (child nodes), for which the *Gas prices for non-household consumers* and the *Harmonised Index of Consumer Prices* respectively are the best next discriminators.
- For the next five branches above, a second best predictor has been identified: *Final energy consumption*. If the *Final energy consumption* is in between 38.7 and 71.9 million TOE, and the Country is located in the Western area of Europe, the predicted mean value for the RE Target to be achieved is 4.4%, while if located in the Eastern the mean value is 9.6%.
- Similarly as the previous observation, if the *Final energy consumption* is in between 34.2 and 38.7 million TOEs, and the Country is located in the Western part of Europe, the predicted mean value for the RE Target to be achieved is 30.4%, compared to the mean value of the European Union is 13.5%.
- If the *Final energy consumption* is in between 24.6 and 34.2 million TOE, and the *average years of activity* of the policy mix is higher than 6 years, the mean value predicted to be achieved is 34.4%, compared to a 25.3% if lower than 6 years.
- If the *Final energy consumption* is in between 24.6 and 18.1 million TOE, and the *population* is higher than 5.2 millions of people, the RE target mean value predicted to be achieved is 23.1%, compared to a 64.6% if lower than 5.2 millions of people.
- If the *Final energy consumption* is in between 18.1 and 15.3 million TOE, and the *energy import dependency* is lower than 55.8%, in between 55.8% and 67.6%, or higher than 67.6%, the mean values of the predicted RE target are respectively 16.4%, 10.8%, and 32.6%.
- Whenever the *Final energy consumption* is in between 15.3 and 4.1 million TOE, the next best predictor is *Total Energy Supply with Renewables and Biofuels*. At this level, an increase in RE share mean value is observed as the variable increases (from 981.6 to 1566.9 thousand TOE). A third level can be observed, in which if the country is a member of the Eurozone, the predicted RE target is 10.1% compared to 14.1% if not. If the *GHG emissions intensity of energy consumption* is lower than 95.4%, the predicted RE target value is 29.9%, falling to 16.2% if higher than 95.4%.
- Finally, the second predictor on the upper branch of the tree is *Total Energy Supply with Renewables and Biofuels*. If its value is lower than 981.6 thousand TOE, the predicted RE Target to be achieved is 19.4%, compared to 33.7% if the predictor is higher than 981.6.

The DT data has been organized in a table (table 40) presenting the details for each node. It includes the amount of observations (N) included in each node and the percentage of observations that represents. The table also presents the predicted value of each node, being the policy mix prediction values. The table also includes the parent node, as the immediate ascendant node and the Primary Independent Variable, as the most influential attribute to determine the tree partition. The terminal nodes of the model have been highlighted in Table 40.

Table 40. Decision Tree results in a table format

Node	Non-Efficient		Efficient		Total		Predicted Category	Parent Node	Primary Independent Variable
	Number of policies	Percentage of policies	Number of policies	Percentage of policies	Number of policies	Percentage of policies			
0	150	<u>51.40%</u>	142	48.60%	292	100.00%	Non-efficient		Variable used to split the node
1	140	<u>56.00%</u>	110	44.00%	250	85.60%	Non-efficient	0	Fiscal
2	10	23.80%	32	<u>76.20%</u>	42	14.40%	Efficient	0	Fiscal
3	20	<u>69.00%</u>	9	31.00%	29	9.90%	Non-efficient	1	Gas price for households
4	23	<u>32.40%</u>	48	<u>67.60%</u>	71	24.30%	Efficient	1	Gas price for households
5	97	<u>64.70%</u>	53	35.30%	150	51.40%	Non-efficient	1	Gas price for households
6	2	<u>11.80%</u>	15	<u>88.20%</u>	17	5.80%	Efficient	2	Total energy supply by product
7	7	<u>58.30%</u>	5	41.70%	12	4.10%	Non-efficient	2	Total energy supply by product
8	1	7.70%	12	<u>92.30%</u>	13	4.50%	Efficient	2	Total energy supply by product
9	15	<u>88.20%</u>	2	11.80%	17	5.80%	Non-efficient	3	FiT-Small Hydro
10	5	41.70%	7	<u>58.30%</u>	12	4.10%	Efficient	3	FiT-Small Hydro
11	26	<u>92.90%</u>	2	7.10%	28	9.60%	Non-efficient	5	Total people at risk of poverty
12	41	<u>68.30%</u>	19	31.70%	60	20.50%	Non-efficient	5	Total people at risk of poverty
13	30	48.40%	32	<u>51.60%</u>	62	21.20%	Efficient	5	Total people at risk of poverty
14	17	37.00%	29	<u>63.00%</u>	46	15.80%	Efficient	13	Harmonised index of consumer prices
15	13	<u>81.30%</u>	3	18.80%	16	5.50%	Non-efficient	13	Harmonised index of consumer prices
16	8	<u>24.20%</u>	25	<u>75.80%</u>	33	11.30%	Efficient	14	Total general government expenditure

No de	Non-Efficacious		Efficacious		Total		Predicted Category	Parent Node	Primary Independent Variable
17	9	69.20%	4	30.80%	13	4.50%	Non- efficacious	14	Total general government expenditure

Findings

- When the Population addressed by a policy mix is higher, the predicted RE share value is reduced in almost the half (from 64.6% to 23.1%) (as seen in NODE 17 & 18). The model predicts more effective policy mixes in the context of smaller population (within the range of 18.1 and 24.6 million TOE of final energy consumption).
- Considerable distinction in the predicted RE share values can be seen if the policy mixes have more than 6 years of average duration, compared to lower than 6 years, being reduced in almost 10% of RE share (from 34.4 to 23.6%). The model predicts a more efficient policy mix if the average duration surpasses 6 years (within the range of 24.6 and 34.2 million TOE of final energy consumption).
- As the amount of the Total Energy Supply by Renewables and Biofuels addressed by a policy mix is increased, the policy mixes addressed will be in the trend of increasing their RE share values (as seen in NODE 9 to 13 and 25 to 27).
- The threshold determined by the model at 95.4 for the GHG emissions intensity of energy consumption, denotes a decrease in RE share value if it is surpassed (within the range of 4.169 and 15.364 million TOE of final energy consumption and higher than 1566.9 of TES Renewables and Biofuels thousand TOE) (as seen in NODE 30 & 31).

These results need to be seen with care, as the decision tree model detects associations, which do not always imply causation.

Classification Rules

The classification rules (also known as induction rules) reveal the paths followed by the tree for making predictions, leading to the identification of routes with different degrees of RE target achievement. Via the classification rules, the replication of the tree is possible using modelling softwares (e.g. Microsoft Excel or Python).

The identification and application of rules can simplify the definition of policy profiles, making it easier to determine the possible course of action of certain choices.

The classification rules generated by the model are now presented in Table 41.

Table 41. Classification Rules

Node	Rules
Node 9	IF (Finalenergyconsumption <= 4.169) AND (Renewablesandbiofuels <= 981.668) THEN RE share =19.40%.
Node 10	IF (Finalenergyconsumption <= 4.169) AND (Renewablesandbiofuels >= 981.668) THEN RE share = 33.72%.

Node	Rules
Node 11	IF (Finalenergyconsumption => 4.169 AND <= 15.364) AND (Renewablesandbiofuels <= 981.668) THEN RE share = 4.84%.
Node 28	IF (Finalenergyconsumption => 4.169 AND <= 15.364) AND (Renewablesandbiofuels => 981.668 AND <=1566.912) AND (MemberoftheEurozone = 1) THEN RE share=10.11%.
Node 29	IF (Finalenergyconsumption => 4.169 AND <= 15.364) AND (Renewablesandbiofuels => 981.668 AND <= 1566.912) AND (MemberoftheEurozone ~= 1) THEN RE share = 14.12%.
Node 30	IF(Finalenergyconsumption => 4.169 AND <= 15.364) AND (Renewablesandbiofuels => 1566.912) AND(Greenhousegasemissionsintensityofenergyconsumption <= 95.4) THEN RE share = 29.95%.
Node 31	IF (Finalenergyconsumption => 4.169 AND <= 15.364) AND (Renewablesandbiofuels => 1566.912) AND (Greenhousegasemissionsintensityofenergyconsumption => 95.4) THEN RE share = 16.23%.
Node 14	IF (Finalenergyconsumption => 15.364 AND <= 18.188) AND (Energyimportdependency <= 55.823) THEN RE share = 16.49%.
Node 15	IF (Finalenergyconsumption => 15.364 AND <= 18.188) AND (Energyimportdependency => 55.823 AND <= 67.691) THEN RE share = 10.88%.
Node 16	IF (Finalenergyconsumption => 15.364 AND <= 18.188) AND (Energyimportdependency => 67.691) THEN RE share = 32.63%.
Node 17	IF (Finalenergyconsumption => 18.188 AND <= 24.680) AND (Population <= 5.276) THEN RE share = 64.67%.
Node 18	IF (Finalenergyconsumption => 18.188 AND <= 24.680) AND (Population => 5.276) THEN RE share = 23.13%.
Node 19	IF (Finalenergyconsumption => 24.68 AND <= 34.24) AND (Averageyearsofactivity <= 6) THEN RE share = 25.37%.
Node 20	IF (Finalenergyconsumption => 24.68 AND <= 34.24) AND (Averageyearsofactivity => 6) THEN RE share = 34.40%.
Node 21	IF (Finalenergyconsumption => 34.240 AND <= 38.742) AND (CountryLocation ~= "European Union") THEN RE share = 30.44%.
Node 22	IF (Finalenergyconsumption => 34.24083 AND <= 38.742) AND (CountryLocation = "European Union") THEN RE share = 13.59%.
Node 23	IF (Finalenergyconsumption => 38.742 AND <= 71.933) AND (CountryLocation ~= "Eastern") THEN RE share = 4.46%.
Node 24	IF (Finalenergyconsumption => 38.742 AND <= 71.933) AND (CountryLocation = "Eastern") THEN RE share = 9.68%.
Node 25	IF (Finalenergyconsumption => 71.933) AND (Renewablesandbiofuels <= 17625.451) THEN RE share = 4.08%.
Node 32	IF (Finalenergyconsumption => 71.933) AND (Renewablesandbiofuels => 17625.451 AND <= 24616.453) AND (Gaspricesfornonhouseholdconsumers <= 8.734) THEN RE share =9.82%.
Node 33	IF (Finalenergyconsumption => 71.933) AND (Renewablesandbiofuels => 17625.451 AND <= 24616.453) AND (Gaspricesfornonhouseholdconsumers => 8.734). THEN RE share = 12.98%.

Node	Rules
Node 34	IF (Finalenergyconsumption => 71.933) AND (Renewablesandbiofuels => 24616.453) AND (HarmonisedIndexofConsumerPrices <= 99.09) THEN RE share = 10.43%.
Node 35	IF (Finalenergyconsumption => 71.933) AND (Renewablesandbiofuels => 24616.453) AND (HarmonisedIndexofConsumerPrices OR => 99.09) THEN RE share = 16.21%.

Command Orders (IBM, 2021): AND= And, IF= If, OR= Other than, THEN= Compute

5.4.2 Efficacy analysis

For categorical dependent variables, the performance of the model results by the calculation of the accuracy of the model (overall right prediction of the positive and negative classes) (Rottmann, 2019). It is calculated using the following formula:

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN}$$

TP (True Positive): amount of right predictions for the positive class in the model.

TN (True Negative): amount a right predictions for the negative class in the model.

FP (False Positive): amount of wrong predictions for the positive class in the model.

FN (False Negative): amount a wrong predictions for the negative class in the model.

$$Accuracy = \frac{107 + 111}{107 + 111 + 35 + 39} = .746$$

The accuracy rate of 74.6% is expressed in what is known as confusion matrix (Table 42). It reflects the overall percentage of correct classifications.

Table 42. Confusion Matrix

Classification			
Observed	Non- efficacious	Predicted	Percent
		Efficacious	Correct
Non-Efficacious	111	39	74.0%
Efficacious	35	107	75.4%
Overall Percentage	50.0%	50.0%	74.6%

With the results displayed in the Confusion Matrix, the Sensitivity (True positive rate) and Specificity (True negative rate) measures can be calculated. Sensitivity, also known as True Positive Rate, measures how well a test can identify true efficacious. Specificity, also known as True Negative Rate, measures how well a test can identify true non-efficacious (Rottmann, 2019).

For the efficiency analysis, Sensitivity refers to the rate of observations predicted as efficacious, and Specificity as non-efficacious. They are calculated using the following formulas:

$$\text{Sensitivity} = TP / (TP + FN)$$

$$\text{Specificity} = TN / (TN + FP)$$

TP (True Positive): amount of right predictions for the positive class in the model.

FN (False Negative): amount of wrong predictions for the negative class in the model.

TN (True Negative): amount of right predictions for the negative class in the model.

FP (False Positive): amount of wrong predictions for the positive class in the model.

Applied to this study, the higher probability of a positive prediction on efficacious (RE target achievement), the lower the non-efficacious one (RE target non-achievement). The Sensitivity and Specificity of the RE efficacy model are calculated below:

$$\text{Sensitivity} = 107 / (107 + 35) \text{ observations} = 0.754$$

$$\text{Specificity} = 111 / (111 + 39) \text{ observations} = 0.740$$

The results for the Energy Policy efficiency analysis are now presented, including the Decision Tree Diagram (Figure 9), the DT result in a table (Table 43), findings and Classification rules (Table 44).

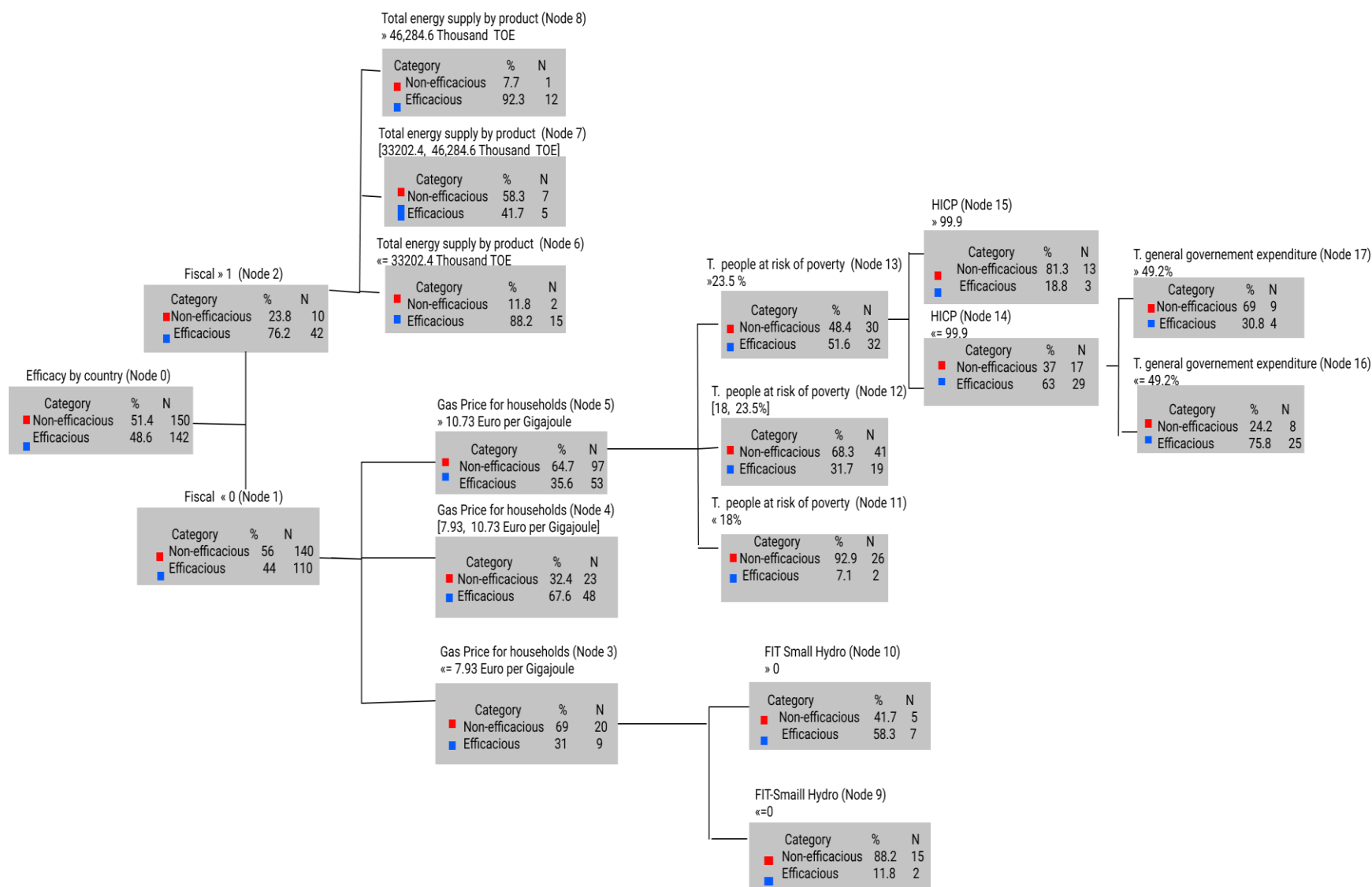


Figure 9. Energy Policy efficacy Decision Tree

From the Decision Tree we can affirm that:

- *Fiscal* is the best discriminator of *Energy policy efficacy*.
- The subsequent branch on the upper side of the DT have selected the *Total energy supply by product* as the second best discriminator (with a P. Value of 0.023). The policy mixes included in the three consecutive nodes, independently of the total energy supply by product, have an average of high probability to achieve their national RE targets (therefore classified as efficacious). Since there are no child nodes below this branch, the nodes are considered terminal nodes.
- On the left branch, the second best predictor is the *Gas price for households*; only one out of the tree branches of it is a terminal node, in which if the *Gas price for households* is in between 7.93 and 10.73 Gigajoules/Euros, there is a probability of 67.7% for the RE Target to be achieved (classified as efficacious and therefore a 32.3% for non-efficacious).
- If the *Gas price for households* is lower than 7.93 Gigajoules and there is a Feed In Tariff for Small Hydro (FIT), there is the probability of 58.3% for the RE Target to be achieved. If this FIT is not present in the analyzed policy mix, the probability for being classified as efficacious falls to 11.8 %.
- The third predictor on the left branch of the tree is *People at risk of poverty*. If its value is lower than 18% or between 18-23%, the probability is very low with 7 and 31% respectively for the policy mixes to be efficacious. In this same level of the tree, if the *people at risk of poverty* is higher than 23%, and the Harmonised Index of Consumer Prices (*HICP*) (fourth predictor) is higher than 99,9 the policy mix is predicted to be efficacious with a 18.8% of probability, but if lower is than 99,9 the policy mix is predicted to be efficacious with a 63% of probability.
- Whenever the *HICP* is lower than 99.9, the next (and fifth) best predictor is the *Total general government expenditure*, whenever is lower than 49.2% of GDP the probability to fall in the category of efficacious is 75.8% and whenever higher than 49.2%, the probability is 30.8%.

Table 43 presents the results of the Decision Tree in a table format. The terminal nodes have been highlighted in bold and italic letters. The highest percentage of policies by category in each node has been underlined.

Table 43. Decision Tree results in a table format

Node	Non- efficacious		Efficacious		Total		Predicted Category	Parent Node	Primary Independ ent Variable
	Number of policies	Percentage of policies	Number of policies	Percentage of policies	Number of policies	Percentage of policies			Variable used to split the node
0	150	<u>51.40%</u>	142	48.60%	292	100.00%	Non- efficacious		
1	140	<u>56.00%</u>	110	44.00%	250	85.60%	Non- efficacious	0	Fiscal (Tax C./Tax I.)
2	10	23.80%	32	<u>76.20%</u>	42	14.40%	Efficacious	0	Fiscal (Tax C./Tax I.)
3	20	<u>69.00%</u>	9	31.00%	29	9.90%	Non- efficacious	1	Gas Price for househol ds
4	23	<u>32.40%</u>	48	<u>67.60%</u>	71	<u>24.30%</u>	<i>Efficacious</i>	1	<i>Gas Price for househol ds</i>
5	97	<u>64.70%</u>	53	35.30%	150	51.40%	Non- efficacious	1	Gas Price for househol ds
6	2	<u>11.80%</u>	15	<u>88.20%</u>	17	5.80%	<i>Efficacious</i>	2	<i>Total energy supply by product</i>
7	7	<u>58.30%</u>	5	41.70%	12	4.10%	<i>Non- efficacious</i>	2	<i>Total energy supply by product</i>
8	1	7.70%	12	<u>92.30%</u>	13	4.50%	<i>Efficacious</i>	2	<i>Total energy supply by product</i>
9	15	<u>88.20%</u>	2	11.80%	17	5.80%	<i>Non- efficacious</i>	3	<i>FiT- Small Hydro</i>
10	5	41.70%	7	<u>58.30%</u>	12	4.10%	<i>Efficacious</i>	3	<i>FiT- Small Hydro</i>
11	26	<u>92.90%</u>	2	7.10%	28	9.60%	<i>Non- efficacious</i>	5	<i>Total People at risk of poverty</i>
12	41	<u>68.30%</u>	19	31.70%	60	20.50%	<i>Non- efficacious</i>	5	<i>Total People at risk of poverty</i>

Node	Non- efficacious		Efficacious		Total		Predicted Category	Parent Node	Primary Independ ent Variable
13	30	48.40%	32	<u>51.60%</u>	62	21.20%	Efficacious	5	Total People at risk of poverty
14	17	37.00%	29	<u>63.00%</u>	46	15.80%	Efficacious	13	Harmoni sed Index of Consume r Prices
15	13	<u>81.30%</u>	3	18.80%	16	5.50%	Non- efficacious	13	<i>Harmoni sed Index of Consume r Prices</i>
16	8	24.20%	25	<u>75.80%</u>	33	11.30%	Efficacious	14	Total general governm ent expendit ure
17	9	<u>69.20%</u>	4	30.80%	13	4.50%	Non- efficacious	14	Total general governm ent expendit ure

Findings

The findings of this study suggest some policy implications useful for locations with similar circumstances. Policymakers must be selective when designing energy policy mixes, as small variations in predictors can bring very different outcomes. This predictive model aims to be an inspiration to prevent the non-achievement of policy targets or pursue their achievement, leading to the identification of the following findings:

- First, when a policy mix addresses FIT for Small Hydro, a considerable difference in the probability of target achievement (therefore being efficacious or not) is made (from 11.8 to 58.3%) (as seen in NODE 9 & 10).
- When a policy mix is addressing a Fiscal policy type, and if there is a High gas price for households (after 10.73 Gigajoule/euro), the higher the risk of poverty, the more efficacious a policy mix becomes (as seen in NODE 11 & 12).
- When the Total general government expenditure addressed by a policy mix is higher than 49.2 (Percentage of GDP), the probability for policies to fall in the category of efficacious is reduced in almost the half (from 75.8 to 30.8%) (as seen in NODE 16 & 17).
- If there is a Fiscal policy type addressed by the policy mix, no matter the amount of Total energy supply, all the profiles will be in the trend of RE target achievement (efficacious) (70% average) (as seen in NODE 6, 7 & 8).

- The threshold determined by the model at 99.9 for the HICP value, denotes an increase in the probability for the policy mixes to achieve their RE target, if the threshold is surpassed (as seen in NODE 4).

Classification Rules

The classification rules generated by the model are presented in Table 44.

Table 44. Classification Rules

Node	Rules
Node 9	IF (FiscalTaxC.TaxI ~= 1) AND (Gaspricehousehold <= 7.931) AND (FiTsmallHydro <= 0) THEN Non- efficacious (Prob = 0.882)
Node 10	IF (FiscalTaxC.TaxI ~= 1) AND (Gaspricehousehold <= 7.931) AND (FiTsmallHydro => 0) THEN Efficacious (Prob = 0.583)
Node 4	IF (FiscalTaxC.TaxI ~= 1) AND (Gaspricehousehold => 7.931) AND (Gaspricehousehold <= 10.731) THEN Efficacious (Prob = 0.676)
Node 11	IF (FiscalTaxC.TaxI ~= 1) AND (Gaspricehousehold => 10.731) AND (Peopleatriskofpovertyorsocialexclusionbyageandsex <= 18) THEN Non-Efficacious (Prob = 0.928).
Node 12	IF (FiscalTaxC.TaxI ~= 1) AND (Gaspricehousehold => 10.731) AND (Peopleatriskofpovertyorsocialexclusionbyageandsex => 18 AND <= 23.5) THEN Non- efficacious (Prob = 0.683).
Node 16	IF (FiscalTaxC.TaxI ~= 1) AND (Gaspricehousehold => 10.731) AND OR (Peopleatriskofpovertyorsocialexclusionbyageandsex => 23.5) AND (HICP <= 99.91) AND (Totalgeneralgovernmentexpenditure <= 49.2) THEN Efficacious (Prob = 0.757).
Node 17	IF (FiscalTaxC.TaxI ~= 1) AND (Gaspricehousehold => 10.731) AND (Peopleatriskofpovertyorsocialexclusionbyageandsex => 23.5) AND (HICP <= 99.91) AND (Totalgeneralgovernmentexpenditure => 49.2) THEN Non- efficacious (Prob = 0.692).
Node 15	IF (FiscalTaxC.TaxI ~= 1) AND (Gaspricehousehold => 10.731) AND (Peopleatriskofpovertyorsocialexclusionbyageandsex => 23.5) AND (HICP => 99.91) THEN Non- efficacious (Prob = 0.812).
Node 6	IF (FiscalTaxC.TaxI = 1) AND (Totalenergysupplybyproduct <= 33202.406) THEN Efficacious (Prob = 0.882).
Node 7	IF (FiscalTaxC.TaxI = 1) AND (Totalenergysupplybyproduct => 33202.406) AND (Totalenergysupplybyproduct <= 46284.6) THEN Non-Efficacious (Prob = 0.583).
Node 8	IF (FiscalTaxC.TaxI = 1) AND (Totalenergysupplybyproduct => 46284.6) THEN Efficacious (Prob = 0.923).

5.5 Analysis with other dependent variables

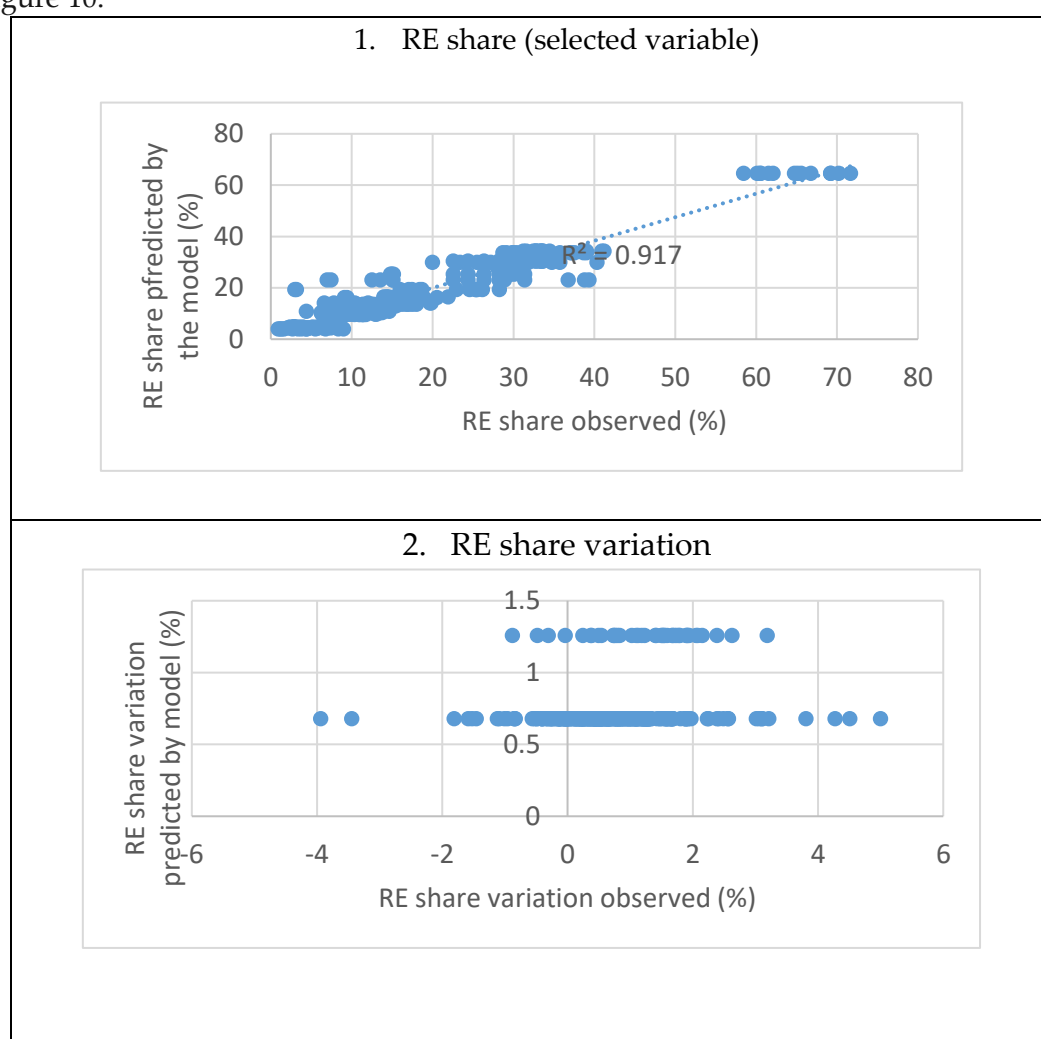
As part of the robustness validation of the models, other possible dependent variables were tested. The additional variables are variations of the initial one “RE share” (Eurostat, 2020). Their descriptions are included in Table 45 for the continuous variables and Table 46 for the categorical variables that were tested. For the EP effectiveness model, two additional continuous dependent variables were tested, comparing their R-squared values. This process is documented in Table 45. RE share, as the selected variable (highlighted variable), has the highest R-squared compared to the additional tested variables.

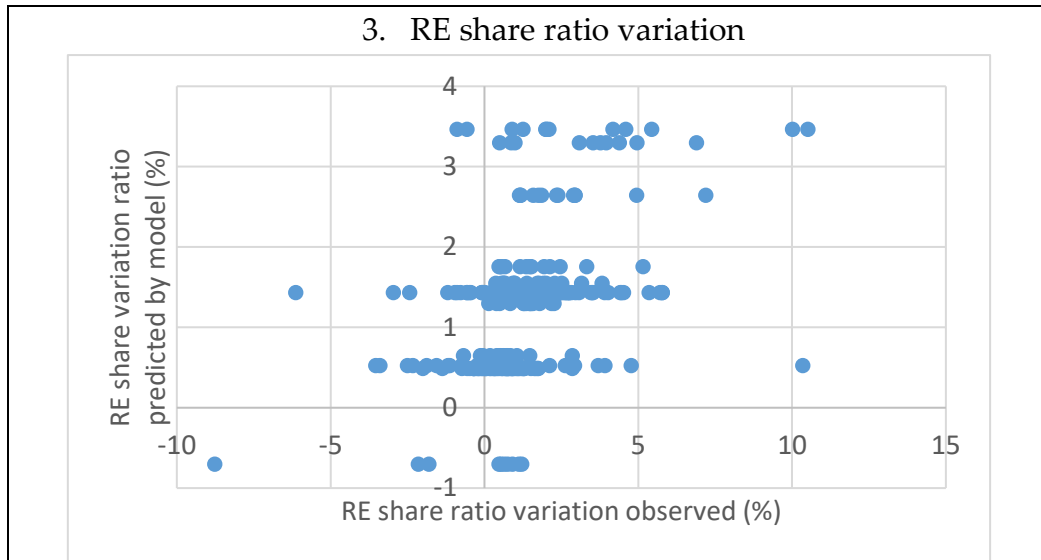
Table 45. Continuous Dependent Variables

Possible Dependent Variable	Dependent Variable Description	Type of Variable (categorical/continuous) & (binary/non-binary)	R-squared
1. RE share*	Observed share of Renewable Energy of the total electricity consumption achieved in the year of measurement.	Continuous	.917
2. RE share variation (self-calculated)	Observed difference in RE share between consecutive years.	Continuous	.039
3. RE share ratio variation (self-calculated)	Variation of the ratio between the observed increase in RE share and the country expected growth in a year.	Continuous	.198

Source: *(Eurostat, 2020)

The results of the predicted and observed values by the models are presented graphically in Figure 10.





.Figure 10. Comparison of possible dependent variables.

For the categorical variables tested for the EP efficacy model, the Sensitivity and Specificity measures were compared. The accuracy was also estimated and compared. The comparisons are reported in Table 46.

Variables 1, 2 and 4 have similar accuracy values (with around .7). Nevertheless, when comparing their sensitivity and specificity values, differences can be seen on having a non-balanced value among sensitivity and specificity. Variable number 1 “Efficacy by country” (highlighted in the table) has more equilibrated values among its sensitivity and specificity values, meaning that the model will perform similarly in predicting both the efficacious policies, and the non-efficacious ones. It also has the highest accuracy rate, and the higher its value the better the model is (Buchanan & Miller, 2017).

Table 46. Categorical Dependent Variables

Possible Dependent Variable	Description	Type of Variable (categorical/continuous) & (binary/non-binary)	Accuracy	Sensitivity	Specificity	True Positives	True Negatives
1. Efficacy by country (self-calculated)	Comparison of the observed RE share increase and the country expected growth in a year (threshold)	Categorical; binary	.746	0.754	0.740	107	111
2. RE share Increase vs Decrease (self-calculated)	Increase or decrease of the RE share compared to the RE share value of the consecutive year by country.	Categorical; binary	.718	0.674	0.802	130	81
3. RE share Efficacy over .6% (self-calculated)	Comparison of the observed RE share increase and the EU expected growth of .6% per year.**	Categorical; binary	.554	0.786	0.516	33	130
4. RE share Efficacy (over 1) (self-calculated)	Comparison of the observed RE share increase and the self-defined value of 1 (from the RE share mean value of 0.7 plus 1/3 of one standard deviation value).*	Categorical; binary	.732	0.659	0.765	60	156

*Efficacious class is assigned if the RE share growth is higher than 1, otherwise non-efficacious.

** Efficacious class is assigned if the RE share growth is higher than .6, otherwise non-efficacious.

The comparison of the accuracy values of the categorical variables tested are presented in figure 11. The comparison of the sensitivity and specificity values of each variable can be seen in figure 12.

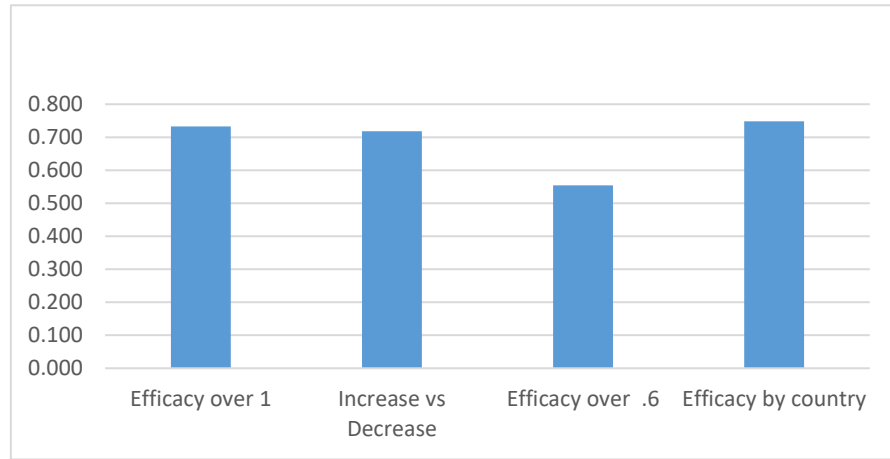


Figure 11. Comparison of the accuracy values of the categorical variables

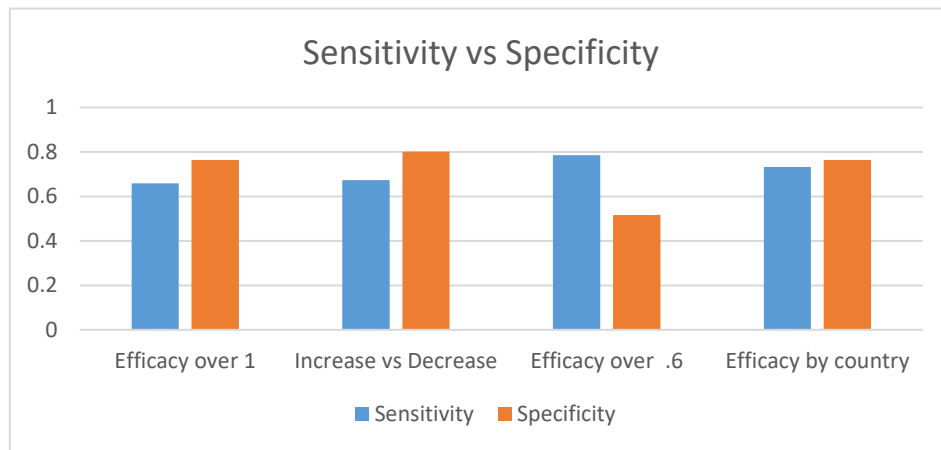


Figure 12. Comparison of the sensitivity and specificity values of the categorical variables.

5.6 Conclusions of the Chapter

The objective has been to develop a support tool that provides information towards assisting targeted interventions and tailoring of policies. With the use of advanced analytics, it was aimed to find out whether there is a relationship between the different independent variables retrieved through the framework presented in Chapter 3 and RE share and its target achievement.

By using Decision Trees for predicting the degree of RE share and for classifying the policy mixes into efficacious and non-efficacious, the methodology here presented covered topics at the intersection of machine learning, energy, and policymaking. The methodology here reported aimed at bringing different fields closer together to advance in policy-making data-driven support techniques. Contributing to the intersection of public policy and computational sciences may help to grow the field of computational social sciences and may enable the future policies to answer to real needs and increase their potential for better outcomes in the long term.

To the best of our knowledge, this study is one of the few studies in policymaking to incorporate ML methods to analyze energy policies.

The results of the Decision Tree models have produced the stratification of the policy mixes according to their potential to promote RE share target (effectiveness model) and its achievement or not (efficacy model). Each of the nodes of the trees have different profiles of predictors and therefore different RE share degree (for the EP effectiveness analysis) and different achievement probability of achieving the efficacious or non-efficacious category (for the EP efficiency analysis).

Classification rules have been generated to estimate outcomes, highlighting the easy application of DT as prediction tools. Through the tree paths that are created, the prediction of future trends can be done.

The main outcome of this predictive model relies on an estimate of the RE share and/or its target achievement before policies are implemented (in their design stage). The understanding of the results with the variables selected contributes to anticipating the likely degrees of policy effectiveness and efficacy under different circumstances. Decision-makers can analyze the characteristics of the analyzed policies, together with the country's characteristics and better support their choices.

The proposed predictive models bring the possibility to improve the identification of which policies work or not under certain situations. Machine learning methodologies represent an alternative for time, money, and other resources to be saved from policymakers, as otherwise directed towards policies with a higher probability of being non-effective or non-efficacious

Another contribution is that by the use of Machine Learning techniques, the importance of data availability is remarked. Data-driven processes for decision-making are expected to be improved, together with the promotion of policy data organization. At the same time, the literature gap on the need for multidisciplinary methodologies that can systematically include evidence into policymaking (Debnath et al, 2019) can be reduced.

A summary for Policy Makers on the application of ML techniques for energy policy analysis has been organized and is now presented:

Machine Learning use. Machine Learning methods have been applied within energy for the estimation of short and long-term factors. Their usability is promoted by their capability to alleviate uncertainty of controllable and non-controllable circumstances and provide estimations that lead to cope with a better use of resources.

Decision Trees. They are used to predict a dependent variable based on independent variables. They are characterized by their easiness to be interpreted. Better performing policies can be identified, leading to choices with higher propensity for “success”.

Supported information for Policy Making. A support tool based on the examination of ex-post policy information is available to be used in an ex-ante form, as to adjust or design policies and their interaction (through policy mixes). By doing so, it is possible to provide information that could guide targeted interventions.

Predictive analytics to improve RE target achievement. Predictive analytics provide an alternative of anticipating RE share target achievement and its degree of achievement

through the results of the effectiveness (degree of achievement) and efficacy (achievement or not) analysis.

Data Availability Challenges. Different challenges have been identified, as key aspects to be considered for the fulfillment of the data requirements; actions must be taken by policy developers, institutions and academics towards data registration and openness.

Conformation of a Database. Data combined with Machine Learning has a great potential to tackle complex problems. The database conformed for the analysis includes variables effectiveness assessment concerns, country and policy characteristics. The database can serve for further application of studies.

Findings. Through this paper, it was aimed to find out whether there is a relationship between the different independent variables selected and the RE share and its target achievement. The findings aim to lead to further exploration of certain variables.

Machine Learning opportunities. A call for collaboration among experts of different fields of knowledge is done for the continuation on energy policy analysis based on machine learning methods. The call is extended to energy policy makers and other stakeholders to raise problems on the topic. Computational sciences at the service of qualitative-based sciences ought to be supported.

Chapter 6: Energy Policy Effectiveness Index

6.1 Introduction

The Machine Learning analysis of chapter 5 was a powerful tool to find statistically significant associations between the contextual and policy characteristics of countries and certain output variables. It did not make use of all the performance evaluation data that was structured and gathered in chapter 3 and 4. To have a complementary assessment, it was decided to develop a composite index to evaluate the performance of policies. Nevertheless, it also did not include all the performance evaluation data gathered.

Some advantages of using indexes include allowing comparisons to be made over time or at any given time; they are based on relatively simple calculations (Karach, 2017). Some of their disadvantages include provision of a big picture that may lead to simplistic conclusion and their construction involves judgements (Karach, 2017). Despite sharing some characteristics, indexes are easier to understand and therefore to communicate their results than other methods like Multi Criteria Decision Analysis (EC, 2020).

The elaboration of an index is proposed in this Chapter. It has been named Energy Policy Effectiveness Index (EPEI), as it aims to assess the effectiveness of the energy policies.

The steps to elaborate an index are reviewed in detail through this Chapter. The selection of the preferred procedures for every step is presented. Stakeholders' identification and participation is highlighted across the Chapter.

6.2 Literature Review of Index elaboration

6.2.1 Policy effectiveness indexes found in the literature

In order to inspire the development a new energy policy effectiveness index, a review was made on existing policy effectiveness indexes, not necessarily focused specifically on energy. After searching for “Policy effectiveness index” in the search engine Google (Google, 2019), three representative examples were selected – from those in which the policies or governments were assessed under a multidisciplinary way, and an effectiveness-related approach. They are presented in Table 47.

Table 47. Policy effectiveness indexes found in the literature

Index	Reference	Region	Comments	Concerns covered
Government effectiveness index	(World Bank Group, 2019)	Global (the index assesses 193 countries)	It assesses the country governments through their governance framework, including five dimensions: public services, civil service, policy formulation, policy implementation and credibility of the government's commitment.	Voice and Accountability; Political Stability and Absence of Violence; Government Effectiveness; Regulatory Quality; Rule of Law; Control of Corruption.
Policy Effectiveness Index	Jindal School of Government	India	This index includes indicators from different dimensions that assess general policies; it includes a social dimension	Human well-being; Socially meaningful life; Security of life and rule

Index	Reference	Region	Comments	Concerns covered
	and Policy (JSGP, 2019)		assessment through well-being, including livelihood opportunities; a socially. meaningful life; security of life and rule of law; and amenities for a sustained improvement in living standards.	of law; and Amenities for a sustained improvement in living standards.
Sample Policy Framework	International Institute for Sustainable Development (IISD, 2014)	General (focused on mining policies)	This index was created as a tool for decision-makers to rate and compare policies and programs.	Legal and policy framework; Financial benefit optimization; Socioeconomic benefit optimization; Environmental management; Post-mining transition; Artisanal and small-scale mining

None of the presented indexes covers all the analyzed dimensions proposed in the EPEI. General policy indexes do not focus on assessing individual policy effectiveness, instead their focus is on the analysis of the dynamics of policymaking, meaning the whole interactions of the policy process.

Other energy or climate indexes have also been identified and are presented in Table 48.

Table 48. Energy/climate indexes found in the literature.

Index	Reference	Region	Comments	Concerns covered
Energy Architecture Performance Index (EAPI)	World Economic Forum (WEF, 2017)	Global (127 countries)	The EAPI is a composite index that focuses on tracking specific indicators to measure the energy system performance across countries. It uses 18 indicators across.	Economic growth and development; Environmental sustainability; and Energy access and security.
Index of Sustainable Energy (ISE)	European Bank for Reconstruction and Development (EBRD, 2008)	Europe	The ISE assesses three dimensions: institutions, market incentives and outcomes. They are assessed under three main areas of energy sustainability.	Energy efficiency; Renewable energy and Climate change.
World Energy Trilemma Index 2019	World Energy Council (WEC, 2019)	Global (128 countries)	Prepared since 2010, this index assesses energy systems performance, based on three core dimensions.	Energy security; Energy equity; and environmental sustainability.
Renewable Energy Sustainability Index	(Cirstea et al., 2018)	15 European countries	Multidisciplinary tool, designed as a national monitoring mechanism that points out the strengths and weaknesses of a state in terms of renewable energy.	Economic, environmental, social, and institutional.

Index	Reference	Region	Comments	Concerns covered
Climate Change Performance Index	(German Watch, 2019)	58 countries	It evaluates the climate protection performance. Based on indicators of emissions trends and emissions levels. It has been built upon national and international climate policy assessments by more than 200 experts.	Greenhouse Gas Emissions; Renewable Energies; Energy Use and Climate Policy.
Climate Laws, Institutions and Measures	European Bank for Reconstruction and Development (EBRD, 2008)	International	The CLIM Index has 12 constituent variables grouped into four key policy areas.	International cooperation; Domestic climate framework; Sectoral fiscal or regulatory measures or targets and Cross-sectoral fiscal or regulatory measures.

While some of the indexes that relate directly with energy cover the energy systems as a whole, some others assess some specific dimensions (e.g. the Renewable energy country attractiveness index or the Investment composite index for renewable energy industry). Climate change policy indexes seem to be close to the EPEI. However, they categorize energy as a component of the results, not being the core assessed element. Therefore, none of the indexes reported is similar to the new EPEI proposal.

Other relevant metrics that are available in the literature are the batteries of Indicators, whereas information is merely presented through different individual metrics without a weighting and aggregation process. Indexes represent a step further. An example of energy-related indicators battery is the Energy Indicators for Sustainable Development: Guidelines and Methodologies (IAEA et al., 2005). Some of the indicators included are: ambient concentrations of air pollutants in urban areas, energy use per capita, and accident fatalities per energy produced by fuel chain.

6.3 Indexes development method

6.3.1 Selection of the indicators

Defining the phenomenon to be assessed and its theoretical base will allow a deeper understanding of the evaluated issue and a better setting for the selection of its indicators.

The quality of an index relies, among other factors, on the data used to build it, requiring to have relevance, accuracy, credibility (Gaetano, 2016). There is not a rule on the number of indicators required, which must be adjusted to the index characteristics and objectives. If there is a large number of indicators to be selected, the identification of the most significant ones can be done by eliminating the redundant and not significant ones (USAID, 2014).

Index validation techniques are commonly applied before an index elaboration. Three main validation methods were identified and are presented in Table 49.

Table 49. Indicator's validation methods

SMART (Drucker,1954)	SPICED (Roche, 1999)	CREAM (Schiavo-Campo, 1999)
• Specific: measures as closely as possible the result it is intended to measure; uses disaggregated data. • Measurable: quantitative (as much as possible); no ambiguity on what is being measured. • Achievable/Attainable: it is technically possible to obtain data at a reasonable cost. • Reliable; general agreement over the interpretation of the results. • Time-bound: data can be collected frequently enough to inform the progress and influence the decisions.	• Subjective: using informants for their insights. • Participatory: involving a project's ultimate beneficiaries, local staff and other stakeholders. • Interpreted and communicable: explaining locally defined indicators to other stakeholders. • Crosschecked and compared: comparing different indicators and progress, and using different informants, methods, and researchers. • Empowering: allowing groups and individuals to reflect critically on their changing situation. • Diverse and disaggregated: seeking out different indicators from a range of groups, especially men and women, to assess their differences over time.	• Clear: precise and unambiguous. • Relevant: appropriate to the subject at hand. • Economic: available at reasonable cost. • Adequate: able to provide sufficient basis to assess the performance. • Monitorable: amenable to independent validation.

6.3.2 Normalization

After the indicators have been selected and the data has been collected, the data can be normalized. Around 10 different techniques are available for normalization, the most used ones include (JRC, 2005):

- Methods for cyclical Indicators, useful for their applicability for surveys.
- Rescaling, based on the calculation of minimum and maximum for each indicator across countries (min-max procedure).
- Standardization (or z-scores). It is the one most commonly used, and it converts all indicators to a common scale with an average of zero and standard deviation of one.
- Distance to a reference country value, a technique based on locating indicators above or below the mean.

It is relevant to note that, in some cases, there is no need to carry out the data normalization, as the data is already expressed within the same standard.

6.3.3 Weighting

Similarly to the normalization step, for the weighting, different approaches are available. One of the most popular methods is Equal weighting. Other available methods include Principal Component Analysis, Factor Analysis, Data Envelopment Analysis and Public/Expert opinion weighting methods. The Public/Expert opinion methods include Budget allocation process, Analytic hierarchy process and Conjoint analysis (JRC, 2005).

The budget allocation process allows the incorporation of opinions and preferences from decision-makers or any other selected participants (JRC, 2005). It is based on the allocation of 100 points or a 100% across the indicators. Budget allocation opposes equal weighting.

To strengthen the development of the index, and not give random values to the concerns assessed through an index, a pre step for weighting includes the policy choice self-review.

The analysis of the drivers behind a policy choice has been presented in Chapter 1. Each driver leads to different costs and benefits and consequences in the society. The drivers behind the policy choice are not to be confused with the effectiveness characterization concerns, even if some of them share both conditions. A choice framework focuses on understanding what are the driving forces behind the decision-maker preferences and that is to be translated in the assignment of weights.

To strengthen the weight assignation of the index, and reduce the probabilities on giving random values to the concerns assessed through an index, a policy choice framework is proposed. It is presented in Appendix F.

The framework is an invitation to the decision-makers to analyze their orientations and preferences. It is to be used as an inspiration for the weight assignation. Through the proposed framework, a scaling (high, medium, low) of priority about the drivers can be done. The cornerstone of the weighting process relies on the drivers' prioritization.

6.3.4 Experts selection

It becomes crucial for the index results, the right selection of experts. No theoretical guidelines have been found regarding how to select the participants for a weighting process.

General energy policy stakeholders have been identified in Chapter 1. Not all the identified stakeholders can be included as experts, as there are groups that if included could bias the study, tending to only consider (supporting) their perspectives and interests. Selection criteria were defined for this task, namely:

- Experience in the field of knowledge
- Relevant recognized expertise in the relevant area
- Integrative knowledge (consideration of their area, but an understanding of at least one more area)
- To have a well-represented and integral group, experts from the different areas are sought

- Experts in institutional governance and management: to provide information regarding valid legislation and governance principles.
- Experts with leadership experience in research (Academia): to consider the latest academic and technological information and projects being developed.
- Experts with knowledge of the country-specific energy system: to analyze the situation considering the national capabilities and limitations.
- Experts with relevant international experience in the field of knowledge: as to be able to compare the situation internationally.
- Experts from direct crosscutting issues: to provide a complete picture of the relevant topics closely related to the studied phenomena (policy).

After matching the criteria with the stakeholders identified for energy policy, specific suggested expert participants are now presented in Table 50.

Table 50. Experts' group, general and energy-related agents.

Experts group	General agents	Energy-related agents examples
○ Experts in institutional governance and management	Energy authorities	Local, Regional or National authorities (Energy ministry or representation at different levels)
○ Experts with leadership experience in research (Academia)	Academia (University and research centers experts)	Academia professionals from electric, mechanical, chemistry and general engineering, urban planning or architecture
○ Experts with relevant international experience in the field of knowledge	International agencies and organizations	International Energy Agency (IEA)
○ Experts with knowledge of the country-specific energy system	National commissions	Energy efficiency commission, renewable energies commissions
○ Experts from direct cross-cutting issues	Cross-cutting topics authorities	Sustainability/Climate change/Environment authorities

A non-core group of experts is also recommended to be invited (table 51), as they could bring interesting and relevant perspectives from crosscutting areas. They are part of the stakeholders identified in Chapter 1.

Table 51. Non-core general and energy-related agents

General Agents	Energy-Related agents
Labor markets representatives	Energy industrial firms or associations
National and Local authorities from non-direct cross-sectorial energy areas	Health, agriculture, transportation authorities
Private-sector experts or consultancy groups	Private consultant organization

The arguments presented in this section suggest the selection of a group between five to eight agents to conform a representative group. No more than one expert coming from the same entity is suggested, unless their area of expertise regards to more than one knowledge area. Finding the right balance among the participants is recommended to the EPEI users.

6.3.5 Aggregation

Additive and non-additive methods are available for aggregation. Additive methods range from the aggregation of the weighted indicators to ranking summation in each indicator, known as linear methods (Alves et al., 2011). Under the linear methods, the summation of normalized and weighted indicators is the most popular one (JRC, 2005). Non-additive methods include multiplicative (or geometric) and nonlinear aggregations (Mazziotta & Pareto, 2013).

For the additive method, the value of the indicators is multiplied by its assigned weight and it is summed up to a final value. An important consideration is the sign of every indicator. If negative it means that the indicator's impact is negative for the effectiveness of a policy; therefore, its value must be subtracted when aggregated.

This process of aggregation will generate a final value for each observation. These values are then ready to be ranked based on a measure of importance (normally higher number of points).

6.3.6 Visualization of Results

The index must be clear for the decision-maker, the targeted stakeholders, and its users in general. The results of the index application can lead the user to highlight key trends in the assessed phenomena. An index can give the possibility of correlation with other published indicators or metrics, aiming to give the possibility to identify linkages through regressions (Gaetano, 2016).

6.3.7 General Index elaboration steps

The different alternatives for every step are summarized in Table 52.

Table 52. General Index elaboration steps.

Step	Description
1. Selecting indicators (variables)	Selecting the set of indicators used to form the Index, involves defining what elements are required to assess the phenomenon. They can be selected by an expert commission or following certain criteria.
2. Normalization	This step serves to bring indicators into the same units. To do so, different techniques are available including: ranking, standardization, re-scaling, distance to reference country, categorical scales, cyclical indicators, balance of opinions.
3. Weighting	Weighting techniques provide different significance to the selected indicators. Some of the possible approaches include statistical techniques (e.g. factor analysis, data envelopment analysis, unobserved components models), or participatory techniques with stakeholders involvement (e.g. budget allocation or analytic hierarchy processes).
4. Aggregation	The aggregation approaches could be done by summing up the indicators (e.g. linear aggregation), multiplication (geometric aggregation) or nonlinear techniques (e.g. multi-criteria analysis).
5. Presentation	Presenting the information is crucial for the message of the index to be communicated. Making the selection of the most suitable forms is important.

6.4 EPEI calculation and results for the RE policies database

6.4.1 Selection of the Indicators

The steps presented in the above sections are now followed for the calculation of the Energy Policy Effectiveness Index.

The theoretical definition for the EPEI has been done through Chapter 1 and 3. In the first chapter, the general information about the energy policies has been included. Chapter 3 has focused in describing the concept of effectiveness and its evaluation concerns.

The database elaborated for the application of the Decision Tree in Chapter 5 served as a base for the application of the EPEI. The indicators that somewhat represent the policy performance / concerns were selected among the available data, resulting in the indicators shown in table 53, in the following section.

The following sections present the EPEI application for the year 2016 to the RE policy mix of Austria, as a sample scenario.

6.4.2 Normalization

Most of the concern values were expressed unevenly (different units and scales); therefore, a normalization method was required. From the possible normalization techniques, rescaling procedure (also known as min-max procedure) was selected as it implies a simple application process and regardless of the values, the calculations can be easily followed. This was important for making an accessible methodology for the EPEI users. The normalized resulting values are presented in table 53.

The calculation consists of identifying the maximum and the minimum values by concern and applying the following formula to all the values:

$$I = \frac{x - Min}{Max - Min}$$

Max= maximum value of each concern

Min= minimum value of each concern

x= value to be normalized

Table 53. Indicator values: Absolute and Normalized

Concern	Units	Min	Max	Concern Value	Normalized Value
Electricity Price for Households	€/kWh	0.06	0.204	0.125	0.448
Electricity prices for non-household consumers	€/kWh	0.0407	0.14	0.073	0.323
Gas Price for households	€/GJ	3.669	21.045	14.75	0.637
Gas prices for non-household consumers	€/GJ	2.752	14.025	8.34	0.495
Energy Balance	Mtoe	-0.182	123.856	16.917	0.137
Energy import dependency	%	-702.614	97.512	60.371	0.953
Market share of the biggest competitor	%	15.3	96.5	55.5	0.495
Energy Productivity	€/kgoe	1.67	18.58	9.24	0.447
Energy Intensity of the economy	€/kgoe	1.154	13.027	12.313	0.939
Energy Intensity of the population	kgoe/inhabitants	0.036	7.293	0.801	0.105
Total Greenhouse gas emissions	kt	6636.22	1007867.8	74070.77	0.067
Greenhouse gas emissions intensity of energy consumption	Numeric Value (index)	68.5	124.9	83.1	0.258
Increase in Renewable Electricity capacity	MW	-168.482	11316.333	633.443	0.069
Energy Efficiency	Mtoe	4.27	332.75	50.166	0.139
Population unable to keep home adequately warm	%	0.3	69.5	2.6	0.033
Total general government expenditure	% of GDP	25.6	65.1	51.1	0.645
Expenditure on energy and fuels	% of GDP	-0.5	1.8	0	0.217
Environmental tax revenues (energy tax) of GDP	% of GDP	0.97	3.05	1.52	0.264

6.4.3 Weighting

After the normalization of the concerns, the resulting values were weighted under three different scenarios, aiming to present different options and compare them against the objectives behind the formulation of the EPEI.

- **Weight scenario A: Free Assigned weights**

A simulation of weight distribution among the variables has been done. Normally, it would have been the result from the experts' commission participation. Unfortunately, this task was not carried out as the outbreak resulting from the SARS COV 2 (COVID-19) influenced the activities in all fields and the conformation of an experts' commission was

not possible to be carried out. As a result, the weight distribution was assigned by the author of this thesis. The policy choice framework (Appendix F) was used to support this process. It is noted that the scaling of the policy drivers must be clearly differentiated from the weight assignment, as some concerns and drivers fall in both cases, but they are completely different in terms of their function.

Free assigned weights allows providing greater weight to components that are considered to be more significant in the context of each particular index (OECDb, 2003).

- **Weight scenario B. Equal weighting**

Each of the 17 concerns accounts for 5.9 points, summing up the total of 100 points. This scenario does not directly translate particular significance to the concerns, as they all have the same values.

- **Weight scenario C. Distribution of equal weight among the condensed concerns.**

The 100 points have been assigned equally across the seven condensed concerns, by doing so 100 points have been divided by seven. The 14.3 points resulting have been distributed among the extracted concerns (included in each condensed concern). This approach generated uneven values in their weight distribution (from 3.575 to 14.3 points), as the number of extracted concerns under each condensed concern varies from 1 to 4.

Weight scenario C leads to the equal representation of the condensed concerns in the index aggregation, even if every extracted concern has a very different weight.

A comparison of the same concerns under the three different approaches is presented in Table 54.

Table 54. Weight of each concern under each scenario

Condensed concerns	Concern	Scenario A	Scenario B	Scenario C
Affordability	Electricity Price for Households	6.5	5.9	3.57
	Electricity prices for non-household consumers	6.5	5.9	3.57
Affordability	Gas Price for households	6.5	5.9	3.57
	Gas prices for non-household consumers	6.5	5.9	3.57
Accessibility	Energy Balance	5.5	5.9	7.15
	Energy import dependency	5.5	5.9	7.15
Economic				
Competitiveness	Market share of the biggest competitor	6	5.9	3.57
	Energy Productivity	6	5.9	3.57
Economic				
Competitiveness	Energy Intensity of the economy	5	5.9	3.57
	Energy Intensity of the population	5	5.9	3.57
Economic				
Impact on climate change	Total Greenhouse gas emissions	6.5	5.9	7.15
	Greenhouse gas emissions intensity of energy consumption	6.5	5.9	7.15
Impact on the environment	Increase in Renewable Electricity capacity	6	5.9	7.15

Condensed concerns	Concern	Scenario A	Scenario B	Scenario C
Impact on the environment	Energy Efficiency	6	5.9	7.15
Health impact	Population unable to keep home adequately warm by poverty status	5	5.9	14.3
Governance effectiveness and efficacy	Expenditure on energy and fuels	5.5	5.9	7.15
Governance effectiveness and efficacy	Environmental tax revenues (energy tax) of GDP	5.5	5.9	7.15
Total		100	100.3	100.1

6.4.4 Aggregation

The relevance behind the aggregation step relies on the generation of the value to be compared, as the value obtained after normalization and weighting may not reveal the values to be evaluated (just an overall result of performance), while an aggregated value is ready to be compared among other values. For the EPEI, the aggregation leads to a final value per policy mix in a specific year, for which the higher the number, the higher the policy effectiveness.

It is important to consider the sign of the concern for its aggregation. From the concerns assessed in the EPEI, several concerns have been identified with a negative sign (presented in Table 55).

Table 55. Concerns with negative sign for aggregation.

Concern	Explanation
Electricity price for households & Non-households	The higher the price, the less affordable the electricity.
Gas Price for households	The higher the price, the less affordable the electricity.
Energy imports dependency	The higher the value, the more dependent a country is.
Market share of the largest utility	The higher the percentage, the less participation openness in the energy system.
Greenhouse gas emissions intensity	The higher it is the more GHG produced per unit of energy.
Total Greenhouse gas emissions	The higher the value, the smaller the contribution to environmental sustainability.
Population unable to keep home adequately warm	The more people in this condition, the higher the risk of health's impacts

For the EPEI, a linear aggregation was followed. The aggregation leads to a final value per policy mix in a specific year, for which the higher the number, the higher the policy

effectiveness. The results of applying each weight scenario and aggregating them linearly is presented in Table 56.

Table 56. Aggregated values

Concern	Sign	Scenario A	Scenario B	Scenario C
Electricity Price for Households	Negative	2.913	2.644	1.602
Electricity prices for non-household consumers	Negative	2.102	1.908	1.156
Gas Price for households	Negative	4.145	3.763	2.280
Gas prices for non-household consumers	Negative	3.222	2.925	1.772
Energy Balance		0.758	0.813	0.986
Energy import dependency	Negative	5.245	5.626	6.818
Market share of the biggest competitor	Negative	2.970	2.921	1.770
Energy Productivity		2.686	2.641	1.600
Energy Intensity of the economy		4.699	5.545	3.360
Energy Intensity of the population		0.527	0.622	0.377
Total Greenhouse gas emissions	Negative	0.438	0.397	0.482
Greenhouse gas emissions intensity of energy consumption	Negative	1.683	1.527	1.851
Increase in Renewable Electricity capacity		0.419	0.412	0.499
Energy Efficiency Aggregated values		0.838	0.824	0.999
Population unable to keep home adequately warm	Negative	0.166	0.196	0.475
Expenditure on energy and fuels		1.196	1.283	1.554
Environmental tax revenues (energy tax) of GDP		1.454	1.560	1.891
Total		-10.3	-8.2	-6.94

6.4.5 Presentation of Results of the application of the EPEI

To present possible formats of index results', the EPEI calculations have been applied to the RE policies database (previously presented in Chapter 5), in which 292 observations of policy mixes are included, each assessed in a specific time and country. The examples shown in this subsection present the results under the Weight Scenario C (Distribution of equal weight among the condensed concerns). Different alternatives on the presentation of the results are possible; including the simple listing/ranking, and the contrast of each resulting value against a threshold (frequently used values for comparison include the median or the mean or the best performing value, either of the whole index dataset or from a specific year or country).

In Table 57, the index resulting values are shown and ranked. They are compared against the mean value of the complete dataset from year 2005 to 2019 (-8.85) and the mean value of Austria, as the example country of evaluation (-7.59). It can be noted in the column "Comparison against the mean value (-8.85)", that the majority of the values were above the mean values of the complete dataset. In figure 13, a trend can be seen, in which the EPEI values went down from 2005 to about 2012; rising up again. This means that the EPEI values of the valley had a worse performance compared to their predecessor and successor years.

Table 57. Index by an individual country (Austria) for the period 2005 to 2019

Index Value	Year	Rank	Comparison against the mean value (-8.85)	Comparison against the country mean value (-7.59)
-6.152	2005	1	Above	Above
-6.298	2006	2	Above	Above
-6.362	2017	3	Above	Above
-6.538	2019	4	Above	Above
-6.589	2018	5	Above	Above
-6.940	2016	6	Above	Above
-7.065	2008	7	Above	Above
-7.556	2007	8	Above	Above
-7.769	2009	9	Above	Below
-8.012	2015	10	Above	Below
-8.598	2014	11	Above	Below
-8.780	2011	12	Above	Below
-8.868	2012	13	Below	Below
-9.087	2010	14	Below	Below
-9.326	2013	15	Below	Below

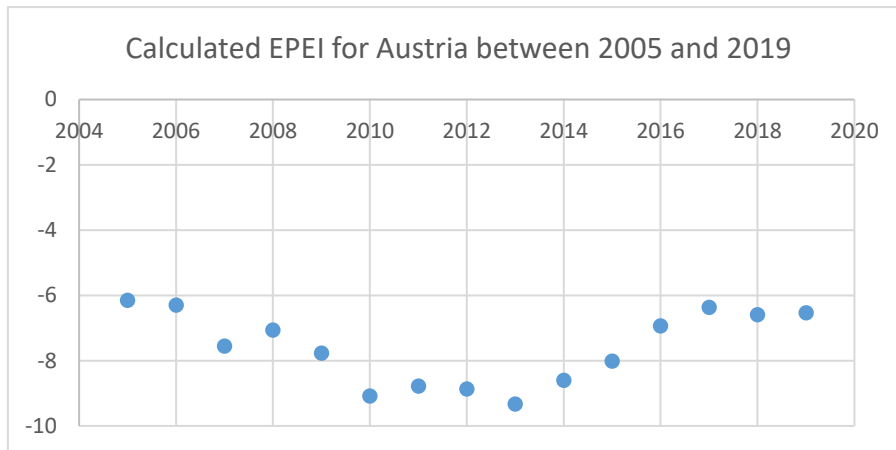


Figure 13. Calculated EPEI for Austria between 2005 and 2019

A histogram with all the 292 results of the EPEI application is presented in Figure 14. In the histogram, the frequency of occurrence of values (vertical axis) can be seen through the bars that are grouped under different ranges of values (horizontal axis).

The range of values included in the EPEI results goes from -22.52 to 3.58. The majority of the evaluated observations are located in the sixth block (64 observations), followed by the fifth one (59 observations).

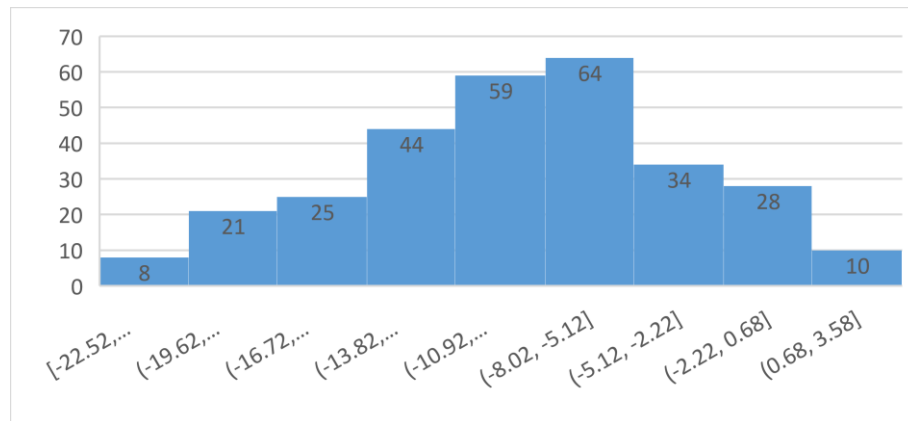


Figure 14. Histogram with the results of the EPEI for the years 2005- 2019

When comparing the EPEI values of the different countries included in this analysis (shown in Table 58 and Figure 15), it can be noted some similar trends among them. It is noted that the higher the EPEI value is, the better performing the policy mix is.

First, Germany, Portugal, Iceland, Italy and Bulgaria have increased their values in the period between 2009 and 2014, to lower them again afterwards. For a similar period, but in the opposite direction Norway has performed. Great Britain and Sweden share the trend of having decreased around the year 2007, increased softly in the years 2010 and 2011 respectively to fall again in a valley until the years 2016 and 2017. Another group of countries, including France, Finland, Poland and the Netherlands seem to have a flat performance, without any remarkable variations. The EU values are considered flat, having no representative waves. Finally, Slovakia, Estonia, Latvia and Denmark have several waves in their performance line, but overall with a positive trend. The trends here reported are not self-explicatory; nevertheless, they raise the interest around the index values and the policy mixes in the reported years. It is important to bear in mind, that it is likely that a policy takes several years to produce effects.

Table 58. EPEI results for the years 2005- 2019

Year	Austria	Bulgaria	Czech Rep.	Denmark	Estonia	EU	Finland	France	Germany	Hungary	Iceland
2005	-6.152			-4.689	-10.472	-10.166	-8.424		2.760	-11.252	-15.907
2006	-6.298			-5.688	-8.917	-10.821	-7.026		1.961	-9.977	-16.319
2007	-7.556	-19.228		-10.452	-9.195	-12.273	-8.760	-2.086	0.593	-9.865	-16.192
2008	-7.065	-19.336		-8.588	-11.349	-13.191	-8.472	-1.453	-1.504	-11.356	-17.642
2009	-7.769	-20.193		-8.383	-10.384	-13.670	-8.204	-2.128	-3.265	-13.842	-18.503
2010	-9.087	-22.141		-4.960	-7.778	-12.362	-8.510	-2.054	1.806	-13.360	-15.311
2011	-8.780	-22.523		-5.730	-10.069	-11.759	-9.244	-0.694	2.459	-12.363	-14.109
2012	-8.868	-20.302		-6.271	-11.437	-12.133	-8.052	-0.365	1.922	-12.743	-14.764
2013	-9.326	-20.278		-3.740	-11.878	-12.764	-7.857	-1.154	1.945	-13.591	-17.539
2014	-8.598	-18.772		-4.724	-13.783	-12.963	-7.332	-1.650	-2.844	-12.616	-18.552
2015	-8.012	-18.159	-7.110	-2.830	-12.328	-12.316	-6.435	-1.174	-1.798	-10.597	-17.662
2016	-6.940	-14.635	-6.675	-2.099	-10.437	-11.380	-4.672	0.506	-0.546	-8.714	-17.742
2017	-6.362	-14.804	-6.450	-1.676	-8.186	-10.018	-4.090	1.203	-0.637	-8.434	-15.118
2018	-6.589	-13.651	-5.489	-1.631	-10.208	-9.218	-4.009	2.089	1.128	-7.152	-13.819
2019	-6.538	-9.461	-6.340	-2.643	-9.697	-9.416	-6.111	2.061	0.345	-8.052	-15.050

Year	Italy	Latvia	Lithuania	Luxemburg	Netherlands	Norway	Poland	Portugal	Slovakia	Sweden	Great Britain
2005	-6.029	-13.133			-9.756	-1.425		-17.910		-4.005	-2.572
2006	-5.627	-11.883			-9.617	-1.245	-11.628	-18.755		-4.129	-3.334
2007	-6.824	-12.710	-15.084		-10.096	-2.363	-8.357	-19.579	-12.734	-7.666	-6.361
2008	-7.746	-14.480	-15.053		-11.164	-3.538	-8.930	-19.595	-13.935	-7.776	-7.360
2009	-8.795	-15.619	-17.130	-12.051	-11.295	-2.144	-8.838	-19.979	-16.225	-8.509	-7.362
2010	-5.899	-12.765	-15.861	-13.337	-11.534	-2.139	-7.453	-18.052	-15.904	-6.971	-6.602
2011	-4.830	-11.939	-19.867	-12.755	-9.941	-4.072	-7.519	-16.912	-13.849	-8.575	-5.225
2012	-1.346	-14.302		-14.187	-10.157	-5.618	-7.463	-16.890	-12.695	-9.179	-6.635
2013	-4.978	-12.575		-15.132	-10.313	-3.544	-7.930	-18.774	-13.060	-8.425	-9.651
2014	-6.029	-11.041			-10.198	-3.732	-7.452	-19.099	-11.683	-8.900	-8.713
2015	-5.425	-6.663			-10.119	-3.566	-6.912	-19.897	-11.325	-7.206	-9.166
2016	-4.545	-6.549			-9.503	-2.431	-5.730	-18.140	-10.155	-6.992	-6.579
2017	-2.537	-5.156			-7.050	-2.429	-3.235	-15.746	-9.359	-6.403	-3.455
2018	-1.737	-1.996			-6.870	-1.768	-3.217	-14.265	-6.470	-7.316	-1.941
2019	-2.866	-4.712			-6.169		-3.130	-13.607	-7.708	-7.609	-2.856

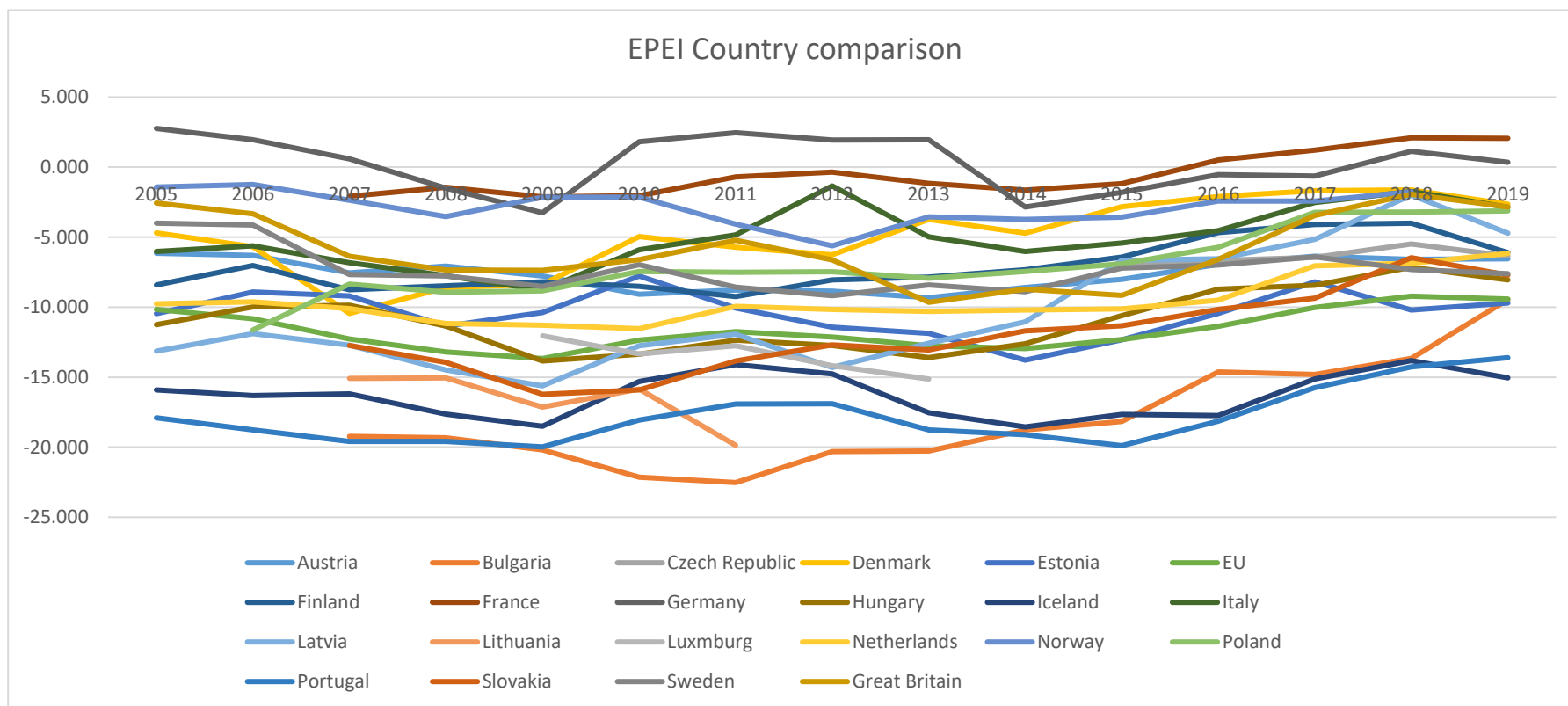


Figure 15. EPEI Country comparison for the years 2005- 2019

6.5 Conclusions of the Chapter

The steps for the elaboration of an Index were explained. This has led to the selection and application of the best procedures for the elaboration of a complementary support tool, under the name of Energy Policy Evaluation Index (EPEI). For the robustness of the EPEI calculation, three weighting scenarios were presented and applied. With the aim to promote a conscious weight assignation, a policy driver's framework was developed.

Austria as the selected example country for presenting the EPEI elaboration steps, shown an over the average performance when being compared against the its own yearly and complete dataset mean values.

A comparison of the EPEI values for the EU countries assessed was included, with this in mind, different trends among the performance of the countries (and their policy mixes) through the analyzed period were noted.

Some degree of subjectivity is perceived in the index preparation. The weights definition can have a crucial impact on the value of the index and the resulting values and ranking. Index represents a direct way to integrate stakeholders' participation. Through the index elaboration, the incorporation of some type of variables may not be possible to be included (as the country contextual variables).

Chapter 7. Conclusions

7.1 Chapter summary

To understand the different layers around the energy policy decision-making, framing questions were presented in Chapter 1. Relevant concepts, like the energy plans, were covered through the questions presented, with the aim of establishing the theoretical background of the proposed decision-making support tool. Four core principles to consider in the elaboration of the support tool were defined: Impact, Cost-effectiveness, Equity/Distributional Fairness, and Participatory approach.

Methodologies available in the literature for energy policy evaluation were identified and classified in Chapter 2. Both qualitative and quantitative methods were organized, for which the data-driven ones have been of special interest, as to select a main methodology (Machine Learning techniques) and a complementary one (Index) for the development of a decision-making support tool.

Defining Effectiveness and differentiating it from other policy “success” concepts was done in Chapter 3, serving also as the base to characterize effectiveness. As a multidisciplinary perspective was sought, characterizing concerns from four dimensions (Economic, Environmental, Social and Institutional) were retrieved. A condensation process was applied, in which the extracted (individual) concerns were translated into bigger groups (under the name of condensed concerns). To do so, the final objective of each extracted concern was identified. Indicators like assessment metrics of the retrieved concerns were presented, including their functionalities and main characteristics. A general identification of sources proposing indicators for the energy field was done. For each condensed concern, at least one assessment metric was identified. Indicators for some extracted concerns were also covered. Concerns without suitable indicators were reported.

In Chapter 4, Domestic Hot Water support policies were selected for characterization (for their potential of GHG emissions abatement around the world). The characterization was done from the policy options perspective, including the most frequent types of technical measures and policy instruments. The combinations of technical measures and policy instrument were organized and presented in the chapter. An enquiry for the characterization of the policies and their results was prepared.

In chapter 5, Machine Learning, as the methodology selected to elaborate the proposed decision-making support tool, was applied. A Decision Tree model was elaborated to characterize, and therefore predict, RE policy mixes effectiveness, as the degree of Renewable Energy share, through an effectiveness analysis. A second DT was applied to classify RE policy mixes into efficacious and non-efficacious, through an efficacy analysis. Multidisciplinary independent variables were used as predictors, considering the effectiveness concerns (identified in Chapter 3), together with the policy options (inspired in Chapter 4), and other country and policy characteristics. The resulting Decision Tree on effectiveness analysis produced the stratification of the analyzed policy mixes, predicting different degrees of RE target achievement. Through the Decision Tree that analyzes

efficacy, the tested policy mixes were assigned into different class labels (efficacious and non-efficacious) with different probabilities. Each class has a different profile of predictors. The results of the trees were shown in graphic and non-graphic representations. In addition, the classification rules that serve as the structuration of the policy mixes profiles were produced, generating a set of rules for further replication of the models.

An Energy Policy Evaluation Index (EPEI) was proposed in Chapter 6. For the elaboration of the EPEI, some variables of the database used for the Decision Trees were not able to be used (country characteristics, policy characteristics and policy options). Different modalities on the index preparation steps were presented in the chapter. Details on the stakeholders' selection behind a participatory weighting were highlighted. Different alternatives on how to organize and show the results of the Index were presented.

7.2 Contributions

The key research question underlying this thesis was: *How to develop a data-driven support tool for energy policy analysis, which includes an integral perspective (economic, environmental, social and institutional)?* The question has found answers through the two methodological approaches applied in the thesis. Both, a Machine Learning technique, through Decision Trees and an Index were implemented to integrally assess Renewable Energy policies, seeking to pave the way towards supporting more informed decision-making and therefore their improvement in their target achievement.

The identification of extracted concerns has covered the four intended dimensions (economic, environmental, social and institutional). As they result in too much detail, their conglomeration was done. By doing so, the opportunity to deep on the essence of the concerns and ensuring their consideration in the analysis are given. The resulting eight condensed concerns and the consideration of their ends objective ensured a multidisciplinary approach to our study. The conglomeration process can be replicated to any other energy policy study that follows the approach of using the ends objective as guideline to incorporate the condensed concerns.

Regarding the policy options, the technical measures were characterized in terms of the level of transformation, impact and scope, among others. The policy instruments were characterized in terms of target groups, competences required for implementation, major challenges and nature of the instruments. A matrix showing the applicability of policy instruments per technical measure was derived. These results enable policymakers to better choose articulated measures and policy instruments.

The pillar of the energy policy analysis methodologies presented in this thesis is data analysis, and for the application of the selected methodologies, it was crucial the elaboration of the database. A database that gathers more than 50 variables (based on the findings of the effectiveness concerns and policy options) has been elaborated. The database itself seems to be a valuable contribution for further analysis.

The analysis of the data availability challenges on energy policy evaluation and the recommendations on how to cope with them are a novelty that aims to contribute to better understand the data behind a data-driven methodology.

Learning from the experience of other countries or a selected country itself (in past situations) can represent a resource-efficient technique. It was achieved through the Decision Tree (DT) results in which the most “effective” and “efficacious” policy mixes were identified under certain profiles and can serve to guide decisions.

The resulting final nodes of the Decision Tree models separated policy mixes by different profiles according to their degree to promote RE share values (effectiveness model) and its achievement or not (efficacy model). Through the tree paths that were created, some likely prediction of impact of policies can be done.

The DT models opened the possibility to improve the identification of which policy options work or not under certain situations. Nevertheless, the results must be read with care, because association does not always imply causation and because the data set for analysis can have limitations in size and quality. The findings aim to be inspirational in the achievement of policy targets. The DT models can be supportive in the policy-making data-driven support techniques advance, bringing closer together different fields (as policymaking and machine learning).

Regarding the application of the Index methodology, with the aim of having a thoughtful application of the EPEI (Energy Policy Effectiveness Index), the drivers behind the policy choice were exhaustively studied, from which a chart to analyze them has been created, as a policy choice framework. The policy choice framework is a useful tool for policy makers to analyze their preferences and support the weighting process, regardless of who is the decision-maker. The analysis contributes to support the analysis of the available options and the preferences around them.

The criteria used in the composite index included some of the effectiveness concerns (from Chapter 3). An application of the index to the case of Austria showed the country’s policy mixes performing over the dataset mean values. A comparison of among the different analyzed countries through the period was presented. The index results aims to enrich the consideration of the policy mixes as a whole, and to support taking decisions that are more conscious on the combination of them.

Possible results’ presentation formats of the EPEI application and the Decision Trees were shown. Decision Trees (DT) techniques have a fast applicability and ease of calculation (through a software, but the results require more effort to be interpreted, as they are less summarized than the results of an Index.

One relevant advantage of DT is their capability to identify likely better policy options, given that the *ex-post* analysis of past data can guide *ex-ante* decisions. The EPEI does not allow the incorporation of the policy options in the assessment, therefore *ex-ante* information on better or worse policy options is not generated.

7.3 Limitations

The “substep” behind the condensation of the extracted concerns, even if it is a contribution, it also represents a limitation of this study. Almost every concern can be included in a condensed one (via the reasoning of which ends objective is connecting them). However, the condensation can generalize too much the concerns, and therefore their identified metrics and indicators. To cope with the risk that the indicators of the condensed concerns do not fully provide the complete assessment that is sought, the desired level of detail can be translated to the amount and type of variables incorporated in the analysis, selecting the ones that reflect the desired dimensions and their degree of detail.

Recognizing that the RE share is also influenced by the energy efficiency and other factors; and that different energy policies are available to promote energy efficacy, effectiveness and efficiency (each policy subject involves different types of policy instruments and technical measures), the policy analysis done, was applied only to a certain type of policies: Renewable Energy Policies.

In addition, all the 22 sample countries used in the analysis are located in the same continent (Europe). This was produced mainly due to the data availability. Even through Europe, not all the countries were evaluated, since not enough information for the assessed years was found.

One of the presented weighting scenarios for the index formulation: budget allocation, provides the possibility to involve expert’s opinion in the index elaboration. It is recommended for containing the multiplicity of stakeholders’ viewpoints and aiming to reflect their policy knowledge, opinions and needs. Nevertheless, this was not possible to be carried out as planned, because of the SARS-CoV-2 (COVID) outbreak. Probably, without an event of such magnitude, gathering the recommended stakeholders may be possible.

7.4 Further research

Future work in this topic could include analyzing in detail the cost structure of the technical measures and policy instruments (average costs and who pays for each), and identifying/recommending regional differences regarding the choice to be adopted, based on local specificities found.

It is of interest, the application of the developed tools to other policy types, that include evidence-based decision-making in different energy policy types, as could be electric vehicles support policies or climate change mitigation policies.

The application of other Machine Learning techniques is of high interests, particularly Neural Networks; nevertheless to do so the database has to be enlarged to have the capability of the application of such technique. Therefore, organizing data under the retrieved concerns is suggested for longer periods or more countries, as a way to enlarge the database.

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Appendix A. Identification of Documents by Search Terms

Table A1. Energy Policy Evaluation documents adopted (Sciencedirect).

#	Name of Document	Authors
1	Proposing an evaluation framework for energy policy making incorporating equity: Applications in Australia	(Chapman et al., 2016a)
2	An analytical framework for energy policy evaluation	(Chen, 2011)
3	Energy efficiency policy evaluation by moving from techno-economic	(Bukarica & Tomšić, 2017)
4	Why is South Korea's renewable energy policy failing? A qualitative evaluation	(Yoon & Sim, 2015)
5	A multiple perspective modeling and simulation approach for renewable energy policy evaluation	(Alyamani, Damgacioglu, Celik, Asfour, & Feiock, 2016)
6	Consumers' evaluation of national new energy vehicle policy in China: An analysis based on a four paradigm model perceptions of importance and satisfaction	(W. Li, Long, & Chen, 2016)
7	Renewable energy policy evaluation using real option model—The case of Taiwan	(Lee & Shih, 2010)
8	Analysis of energy end-use efficiency policy in Spain	(Collado & Díaz, 2017)
9	Development and assessment of renewable energy policy scenarios by 2030 for Bulgaria	(Nikolaev & Konidari, 2017)

Table A2. Energy Policy Evaluation documents adopted (Google).

#	Number of Document	Number of Document
10	Residential solar PV policy: An analysis of impacts, successes, and failures in the Australian case	(Chapman et al., 2016b)
11	Conceptual and empirical advances in analysing policy mixes for energy	(Rogge, Kern, & Howlett, 2017)
12	IRENA: Evaluating Renewable Energy Policy: A Review of Criteria and Indicators for Assessment	(IRENA, Nicholls, Mawhood, Gross, & Castillo-Castillo, 2014)
13	Strengthening the Energy Policy Making Process and Sustainability Outcomes in the OECD through Policy Design	(Chapman et al, 2016c)
14	Moving Toward Energy Efficiency: A Results-Driven Analysis of Utility Based Energy Efficiency Policies	(Theel & Westgaard, 2017)
15	Evaluation of Energy Policy Instruments for the Adoption of Renewable Energy: Case of Wind Energy in the Pacific Northwest U.S.	(Abotah, 2015)
16	Climate and energy policy solutions for China	(Qiang et al., 2016)
17	Evaluating Consistency in Environmental Policy Mixes through Policy, Stakeholder, and Contextual Interactions	(Lieu et al., 2018)
18	A Framework for Energy Policy Evaluation and Improvement Incorporating Quantified Social Equity	(A.J. Chapman, 2016)

19	Evaluation of Hawaii's Renewable Energy Policy and Procurement	(Energy and Environmental Economics, 2014)
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Table A3. Energy Policy Assessment documents adopted (Sciencedirect).

#	Name of Document	Authors
20	Public perceptions of energy policies: Predicting support, opposition, and non-substantive responses	(Edwards, 2018)
21	Ex-post assessment of China's industrial energy efficiency policies during the 11th Five-Year Plan	(Yu, Wang, Li, Qi, & Tamura, 2015)
22	Energy security and renewable energy policy analysis of Pakistan	(Aized, Shahid, Bhatti, Saleem, & Anandarajah, 2018)
23	Energy policy assessment at strategic, tactical, and operational levels: Case studies of EU 20-20-20 and U.S. Executive Order 13514	(Arababadi, Moslehi, El Asmar, Haavaldsen, & Parrish, 2017)
24	Energy democracy: Goals and policy instruments for sociotechnical transitions	(Matthew J. Burke & Stephens, 2017)
25	Efficient, equitable and sustainable energy policy in a small open economy Concepts and assessments	(Chang & Fang, 2017)
26	Comprehensive effectiveness assessment of renewable energy generation policy: A partial equilibrium analysis in China	(Liu et al., 2018)
27	Assessment of energy policies to promote photovoltaic generation in the European Union	(García-Álvarez, García, & Soares, 2018)
28	A review of energy and power planning and policies of Pakistan	(Mirjat et al., 2017)
29	An Alternative Assessment of Global Climate Policies	(Atalla, Bigerna, Bollino, & Polinori, 2018)

Table A4. Energy Policy Effectiveness documents adopted (Sciencedirect).

#	Name of Document	Authors
30	Effectiveness of policy incentives on electric vehicle acceptance in China: A discrete choice analysis	(Wang, Tang, & Pan, 2017)
31	Analysis of the effectiveness of national renewable energy policies: A case of photovoltaic policies	(Hafeznia, Aslani, Anwar, & Yousefjamali, 2017)
32	The effectiveness of China's wind power policy: An empirical analysis	(X. Zhao, Li, Zhang, Yang, & Liu, 2016)
33	The policy effectiveness of economic instruments for the photovoltaic and wind power development in the European Union	(S. J. Li, Chang, & Chang, 2017)
34	The effectiveness of federal renewable policies in India	(Shrimali, Srinivasan, Goel, & Nelson, 2017)

Table A5. Energy Policy Effectiveness documents adopted (Google scholar).

#	Name of Document	Authors
35	Effectiveness of policy measures in transforming the energy system	(Lund, 2007)
36	U.S. state policies for renewable energy: Context and effectiveness	(Delmas & Montes-sancho, 2011)
37	Which renewable energy policy is a venture capitalist's best friend? Empirical evidence from a survey of international clean tech investors	(B & Rolf, 2009)
38	The effectiveness of different policy regimes for promoting wind power: Experiences from the states	(Menz & Vachon, 2006)
39	The effectiveness of European energy policy on the Italian system: Regional evidences from a hierarchical cluster analysis approach	(Arbolino, Boffardi, & Ioppolo, 2019)
40	Analysing the effectiveness of renewable energy supporting policies in the European Union	(Harmelink, Voogt, & Crème, 2006)
41	The effectiveness of policy instruments in promoting bioenergy	(Thornley & Cooper, 2008)
42	A quantile approach to assess the effectiveness of the subsidy policy for energy-efficient home appliances: Evidence from Rizhao, China	(Yao, Liu, & Yan, 2014)
43	Assessing the strength and effectiveness of renewable electricity feed-in tariffs in European Union countries	(Jenner, Groba, & Indvik, 2013)
44	Feed-in tariff vs. renewable portfolio standard: An empirical test of their relative effectiveness in promoting wind capacity development	(Dong, 2012)
45	Wind electricity in Denmark: A survey of policies, their effectiveness and factors motivating their introduction	(Agnolucci, 2007)
46	Effectiveness through risk reduction: a comparison of the renewable obligation in England and Wales and the feed-in system in Germany	(Mitchell, Bauknecht, & Connor, 2006)
47	Double dividend effectiveness of energy tax policies and the elasticity of substitution: A CGE appraisal	(Sancho, 2010)
48	Assessing the effectiveness of city-level electric vehicle policies in China	(Qiu, Zhou, & Sun, 2019)
49	Renewable energy policy effectiveness. A panel data analysis across Europe and Latin America	(Menanteau & El-methni, 2020)

Table A6. Energy Policy Effectiveness documents adopted (JSTOR).

#	Name of Document	Authors
50	Policy Effectiveness in Energy Conservation and Emission Reduction	(Yuan et al, 2011)
51	An ex-ante evaluation of the EU Energy Efficiency Directive— Article 7	(Rosenow, Leguijt, Pato, & Eyre, 2016)
52	Effectiveness, Implementation, and Policy Diffusion: Or “Can We Make That Work for Us?	(Nicholson-crotty & Carley, 2016)

Table A7. Energy Policy Evaluation documents adopted (Google Scholar).

#	Name of Document	Authors
53	Multicriteria evaluation and public participation: the case of UK energy policy	(Stagl, 2006)
54	A real option model for renewable energy policy evaluation with application to solar PV power generation in China	(Zhang, Zhou, & Zhou, 2014)
55	Economic and Technological Models for Evaluation of Energy Policy	(Hoffman et al., 1977)
56	State renewable energy electricity policies: An empirical evaluation of effectiveness	(Carley, 2009)
57	Theory-based policy evaluation of 20 energy efficiency instruments	(Harmelink, Nilsson, & Harmsen, 2008)
58	Policy instruments fostering wind energy projects multi-perspective evaluation approach	(Enzensberger, Wietschel, & Rentz, 2002)
59	Outcome indicators for the evaluation of energy policy instruments and technical change	(Neij & Kerstin, 2006)
60	Hybrid agent-based simulation for policy evaluation of solar power generation systems	(Zhao, Mazhari, Celik, & Son, 2011)
61	The evaluation of renewable energy policies across EU countries and US states: An econometric approach	(Kilinc-ata, 2016)
62	An evaluation of government incentives for new energy vehicles in China focusing on vehicle purchasing restrictions	(Ma, Fan, & Feng, 2020)
63	Performance evaluation of renewable energy support policies, applied on Flanders' tradable certificates system	(Verbruggen, 2009)
64	Eco-labeling for energy efficiency and sustainability: a meta-evaluation of US programs	(Banerjee & Solomon, 2003)
65	Evaluation and optimization of feed-in tariffs	(Kim & Lee, 2012)

Table A8. Energy Policy Evaluation documents adopted (JSTOR).

#	Name of Document	Authors
66	Taxing sulphur dioxide emissions: A policy evaluation from public health perspective in China	(Ling-yun & Jia-jia, 2016)

Appendix B. Energy Policy Indicators Documents

The indicators' documents with general energy policy goals from which the indicator identification analysis was initially done is presented in Table B1. The additional energy policy indicators' documents are registered in Table B2.

Table B1. List of documents for the Energy Policy Indicators analysis.

Name	Issued by	Source
Energy Indicators	Sustainable Energy Authority of Ireland	(Statistics, 2012)
Energy Indicators for Sustainable Development: Country Studies	International Atomic Energy Agency & United Nations Department of Economic and Social Affairs	(IAEA et al., 2007)
Indicators for Energy Sustainable Development Guidelines and Methodologies	International Atomic Energy Agency & World Bank and Sustainable Energy for All	(IAEA et al., 2007)
Eurostat Energy indicators	Eurostat	(Eurostat, 2017)
Energy Indicators	Organization of the Petroleum Exporting Countries	(OPEC, 2017)
Energy indicators for electricity production	Centre for Environmental Design of Renewable Energy	(CEDREN, 2012)
Renewable energy indicators 2013	The Global Carbon Capture and Storage Institute	(Global CCS Institute, 2013)
Energy Efficiency Indicators	World Energy Council	(World Energy Council, 2016)
Energy Efficiency Indicators: Fundamentals on Statistics	International Energy Agency	(International Energy Agency, 2014)
India Energy Indicators Index	Ycharts, cloud-based investment decision-making platform.	(Ycharts, 2018)
New Zealand Energy Indicators	Ministry of Business, Innovation and Employment	(Business & Employment, 2016)
EEA energy and environment indicators	European Environmental Agency	(European Environmental Agency, 2005)
UK Energy Sector Indicators 2015	Department of Energy and Climate change	(DECC, 2015)
Canada Energy Statistics	Statistics Canada	(Government of Canada, 2016)
Odysee Project Database(Indicators)	Enerdata	(Enerdata, 2016)
Indicators and potentials in buildings, communities, and energy systems	Consultancy Group	(Forsström et al., 2011)
MENA-Energy Indicators (2017)	World Bank Group	(World Bank Group, 2017)
Sweden Energy Indicators	Sweden Energy Agency	(Swedish Energy Agency, 2016)
Regulatory Indicators for Sustainable Energy	Energy Sector Management Assistance Program, World Bank	(World Bank Group, 2018)
Nordic Countries Energy Indicators	Nordic Energy Research	(Nordic Energy Research, 2017)

Evaluating Renewable Energy Policy: Indicators	International Renewable Energy Agency	(IRENA et al. 2014)
Energy efficiency and conservation indicators in Yemen	Ali M. Al-Ashwal	(Al-Ashwal, 2016)
Measuring Economic Policy Uncertainty	Baker et al.	(Scott R. Baker, Nicholas Bloom, 2016)

Table B2. Additional Energy Policy Indicators Documents list.

Name	Issued by	Source
Government at a Glance—2017 edition	Organisation for Economic Co-operation and Development	(OECD, 2017)
Indicators of Effective Policy Development & Implementation	Schoolwide Integrated Framework for Transformation	(Stonemeier, Trader, Kaloi, & Williams, 2016)
Indicators for policy management	Interagency (leaded by the United Nations Development Programme)	(UNDP, 2005)
Climate policy confidence indicator	Grantham Research Institute on Climate Change and indicators	(Mcdowall, Zenghelis, & Drummond, 2016)
Measuring Willingness to Pay for Electricity	Asian Development Bank	(Choynowski, 2002)
World Energy Trilemma Index 2018	World Energy Council	(World Energy Council, &Wyman 2018)
World Bank Data	The World Bank	(The World Bank, 2019)
Harmonized Competitiveness Indicators (HCIs)	European Central Bank	(European Central Bank, 2019)
Global Competitiveness Index	World Economic Forum	(World Economic Forum, 2018)
Environmental Sustainability Indicator	Government of Canada	(Government of Canada, 2019)
Electricity Access Data	World Bank	(The World Bank, 2019)
Environmental Performance Index (EPI)	Yale, Center for Environmental Law and Policy and other int. organizations	(Yale, 2019)
Energy Equity Indicators	California Energy Commission	(California Energy Commission, 2019)
Greenhouse gas inventories	European Commission	(Maria, Dg, & Eea, 2018)
Mitigation Goal Standard	World Resource Institute	(Levin, Owen-, Dickinson, & Barth, 2014)
Policy and Action Standard	World Resource Institute	(Rich et al., 2015)
Climate Action Tracker	New Climate Institute, Ecofys and Climate Analytic	(Climate Action Tracker, 2019)
Baseline Emission Inventory	Covenant of Mayors	(Covenant of Mayors, 2010)
Environmental Protection Indicators for California (EPIC)	California Environmental Protection Agency, the Resources Agency, the Department of Health Services	(California Environmental Protection Agency (Cal/EPA), the Resources Agency, 2004)
Renewables 2018 global status report	REN21 (a multi-stakeholder network)	(Hales, 2018)

Cost-Effectiveness and Productivity KPIs	KPI Drafting Group	(KPI Drafting Group, 2001)
New and Renewable Technologies for Sustainable Development Book	Naim Hamdia Afgan and Maria Cristina Ramos de Carvalho	(Afgan & Carvalho, 2002)
New Energy Externalities Developments for Sustainability	Paul Scherrer Institut	(Stefan Hirschberg, Christian Bauer, Peter Burgherr, Roberto Dones, Andrew Simons, 2008)
Sustainability and Financial Performance of Companies in the Energy Sector in Romania	Dragos Paun	(Paun, 2017)
Consumers' willingness to pay for renewable energy: A meta-regression analysis	Chunbo Ma et al.	(C. Ma, Rogers, Kragt, & Zhang, 2016) [
Assessing the performance of renewable energy support policies with quantitative indicators	DIA-CORE Project	(Held et al., 2014)
Energy Intensity Indicator	U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy	(Office of Energy Efficiency & Renewable Energy, 2019)
Worldwide Governance Indicators	Kaufmann et al.	(Kaufmann et al., 2010)

Appendix C. Identified technical measures enlisted with the policy instrument used to implement the policies

Table C1. Technical measure with policy instrument.

Detailed Technical Measure	Technical Measure Type	Detailed Policy Instrument	Policy Instruments Type	Policy or Document
Device change (from fuel to gas)	Installation/Replacement of heating technologies with more efficient ones	Fiscal/financial incentives	Tax credits/tax incentives	Energy Star Loan Program (SaskEnergy/SaskPower)
				British Columbia Energy Star Water Heater Program + Furnace and Boiler Replacement Program
				Warm Up New Zealand: Heat Smart
Device change (from oil boiler; Gas or propane furnace/boiler to more efficient ones)				Insulation Programmes 2009-2018
Installation of renewable-based systems (SWH, photovoltaics, heat pumps, small windmills)		Rebate		Slovakian incentive programme Green Homes
Installation of solar water heaters, pellet boilers and heat pumps				“Enovatilskuddet” (Enova grants)
Installation of SWH systems, heat pumps, pellets tanks, woodchips equipment		Tax relief		Market Rebate Programme for Renewable Energy
Installation of solar water heaters and heat pumps		Tax credits		Solar water heaters
Installation of Solar water heating systems and other renewable technologies				Eco Fund, Slovenian Environmental Public Fund

Detailed Technical Measure	Technical Measure Type	Detailed Policy Instrument	Policy Instruments Type	Policy or Document
Addition Solar thermal systems, biomass boilers and heat pumps		Grant or reimbursable credit		Nova Zelena Usporam (New Green Savings / New Greenlight to Savings)
Solar thermal systems addition	Addition/installation of solar thermal technologies (to complement WHS)	Economic Subsidy		Demoprojekte Solarhaus (Demo Projects Solar House)
				Industrial and Institutional solar thermal collector systems for water heating needs
				Western Balkan Sustainable Energy Financing Facility II (WEBSEFF II)
				Montesol
				Energy Saving programme for residents of the Lviv region for the year 2013-2016
				Prosol II
		Interest-free loans		Capital subsidy scheme for installation of solar thermal systems
				The National Financing Mechanism for Solar Water Heaters
			Low-interest loans / third-party financing	Mechanism of Renewable Heating Systems and Energy Efficient Measures "Conto termico 2.0"
				Solar Plan
		Low-interest loans		Programme for partial subsidising of purchased and installed solar water heaters for households
		Informative campaigns	Information, education and awareness campaigns	Residential Energy Efficiency Credit Line 3 (REECL 3)

		Rating systems	Rating systems	Energy Efficient Homes Package and Solar Hot Water Rebate
Installation of solar WHS (for new construction buildings)		Other Standards		Andalusia: Sustainable Construction Incentive Programme
Electric hot water cylinder wraps installation Insulation	Insulation of boilers	Rating System	Rating System	Northwest Territories Energy Efficiency Incentive Program

Appendix D. Intended Survey (and contact) for Policy Stakeholders



Water Heating Policy Enquiry

Country and region:

Policy program name:

Policy program summary description:

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Context and motivation for this enquiry

This enquiry intends to systematize and extract knowledge from the experience of dozens of policy programs on renewable energy based Domestic Hot Water (DHW) that have taken place around the world, in order to assist the design of future policy programs.

Water heating is one of the major uses of energy, typically ranking from third to first largest energy use in households. It comprises approximately 25% of household energy use in Australia (Government of Australia, 2019), 20% in Canada (Kegel et al., 2017) and 14% in the European Union (European Commission, 2016). Furthermore, water heating demand is growing, in both developed and developing countries.

Most of today's DHW is supplied with fossil fuels or electricity-based technologies. Electric storage systems are the mostly often used, corresponding to around 55% of the DHW systems across the world (IEA, 2012). Yet, there are also technologically proven and often cost-effective renewable energy technologies available such as solar thermal, biomass boilers and PV-driven heat pumps, either air-water or water-water.

In a time of climatic crisis and urgency to act, it is of utmost importance to be able to identify the technological solutions that are best suited for a given context considering the environmental, economic and social dimensions. Moreover, it is crucial to be able to design policy programs that can successfully deploy those technologies, within new buildings as well as in existing buildings.

The success of a policy program depends on many factors, like the climate, technology maturity, and crucially the type, combination and intensity of the policy mechanisms chosen. While some important theoretical considerations can be made, it has not been possible to develop a solid model for policy design based exclusively on this. It is thus important to learn from previous policy programs in order to better inform future policy decisions. That is the goal of this survey.

Enquiry structure

Part 1. Country Context: retrieves the general data of the country or region where the policy program is/was active. Part 2. Policy Input: aims to describe the policy program, including information about its design and designing parties. Part 3. Policy Output: deals with the results of the policy program.

Instructions for filling:

The first column of the format (marked in gray) corresponds to the description of the information required. The second column provides an example. The third column is to be filled with the information concerning the policy program that is being described.

The information provided should preferably be expressed in the suggested units; however, it is possible to use different units depending on data availability (if different units are used, please provide them).

Part 1: Country / region context

Data Requested	Example	Participating Country
1. Country and region	-----	
2. Rate of housing ownership	66%	
3. Average home occupancy	2.6 occupants per home	
4. Most used energy carriers for water heating in households	Electricity 65%; gas 22%; solar 13%	
5. Natural gas price for domestic users	60 usd/btu gas	
LPG price for domestic users	58 usd/btu gas	
Electricity price for domestic users	0.25 usd cent/kWh	
6. Key Energy-Environment Goals in National policy	20% of final energy consumption from renewables by 2020	
7. Average education level of the program participants	College	
8. Average age of the program participants	All ages included	
9. Share of the population with access to hot water before the program	95%	

Part 2: Policy Input

Data Requested	Example	Participating Country
10. Geographical scope	National	
11. Stated program objectives	To increase the solar WH and to reduce the GHG emissions	
12. Start/end date	2009/2010	
13. Technical measures supported	Replacing fuel or electricity based WHS by PV Solar Thermal WHS	
14. Policy Instrument category *	Economic Instruments	
15. Policy Instrument *	Tax Rebate (\$400 in SWH over \$1,000)	
16. Entity or Institution responsible for the policy design	Department of Climate Change and Energy Efficiency	
17. Entity or Institution responsible for the policy implementation	Department of Climate Change and Energy Efficiency	
18. Other involved entities or stakeholders	Environmental Agency	
19. Degree of participation from stakeholders in the policy design stage **	Medium	
20. Description of the participatory process in the design of the program	Citizen survey applied to know the preferences around the policy	
21. Beneficiary differentiation (Y/N) ***	Yes	
22. Description of beneficiary differentiation	Different subsidy amount by income group	
24. Policy Evaluation (Y/N)	Yes	
25. Evaluation timeframe	Ex-post	
26. Policy Evaluation parameters	Cost-efficiency, % of targeted households reached	
27. Entity responsible for the evaluation process	Department of Climate Change and Energy Efficiency	
28. Difference in average price between the WHS technology promoted by the program and other available technologies in the country/region	\$1,000 to \$2,000 for Solar WHS compared to \$800 to \$1,500 for other available technologies	

29.	Expected reduction in GHG emissions	12(MMTCO ₂)	
30.	Expected distribution of program participants by income group (%)	25% of the low income population; 55% of medium income population; 20% high income population	
31.	Possible Health incidents associated with the program	None	
32.	Need for specialized training for the program implementation (Y/N)	Yes	
33.	Total duration of training provided	12 hours	
34.	Number of people that received the training	10 people from the agency (provided by 1 specialist)	
35.	Size of the entity responsible for the program (number of employees)	200 people	
36.	Size of the team responsible for the program implementation	10 people	
37.	Entity annual budget	\$400 million usd yearly	
38.	Policy program overall budget	\$20 million usd in 4 years	
39.	Expected share of households with WHS, by type of technology	30% Solar; 40% Electric; 20% gas instantaneous; 10% gas tankless	
40.	Expected number of dwellings reached by the program	8000 dwellings	
41.	Expected savings in energy expenses attributable to the program	17-25 usd per household per month	
42.	Expected number of new jobs attributable to the program	20 new jobs in the WHS subsector	
43.	Expected fuel savings (by type of fuel)	800 l bbl; 0.5 lp gas btu	

*See table in annex 1

**Degree of participation by different stakeholders in the policy design process (Low, Medium, High; e.g. Low for no participation, Medium for citizen consultation and High for Referendum).

*** Policy differentiation by different beneficiaries (e.g. higher financial support for lower income groups).

Part 3: Policy Output

Data Requested	Example	Country or region
1. Sales increase of promoted WHS technology(ies)	5% in solar thermal thermosyphoon; yy% solar thermal forced convection	
2. Initial structure of households WHS, by technology type (before the program)	10% Solar; 60% Electric Joule; 20% gas instantaneous.; 10% gas tankless	
3. Final structure of households WHS, by technology type (after the program)	30% Solar; 40% Electric; 20% gas instantaneous; 10% gas tankless	
4. Actual number of dwellings reached by the program	5000 dwellings	
5. Actual savings in energy expenses attributable to the program	17-25 usd per household per month	
6. Actual number of new jobs attributable to the program	50 new jobs in the WHS subsector	
7. Actual fuel savings (by type of fuel)	700 oil bbl; 0.48 lp gas btu	
8. Share of the population with access to hot water after program	95%	
9. Actual reduction in GHG emissions (due to the program)	10(MMTCO ₂)	
10. Actual distribution of program participants by income group (%)	20% of low income population; 60% of medium; 20% of high	
11. Number of innovative (new) products, processes or services created during the program	1 new patent	

Survey Annex 1. Policy Instrument Types

Policy instruments are tools used to implement policies. A wide variety of alternatives exists, from which seven main categories of policy instruments have been outlined by the International Energy Agency (IEA, 2019) through its Energy Efficiency policy and programs data base. For each category, different instruments are available, as shown in table 1.

Table 1. Policy Instruments types and subtypes.

Categories	Policy Instrument
Economic Instruments	1. Direct investment
	2. Fiscal/financial incentives (e.g. rebate)
	3. Market-based instruments
Information and Education	1. Advice/Aid in Implementation
	2. Information provision
	3. Performance Label

	4. Professional training and qualification
Policy Support	1. Institutional creation 2. Strategic planning
Regulatory Instruments	1. Auditing 2. Codes and standards 3. Monitoring 4. Obligation schemes 5. Mandatory requirements 6. Demonstration project
Research, Development and Deployment (RD&D)	1. Demonstration project 2. Research programme
Voluntary Approaches	1. Negotiated Agreements (Public-private sector) 2. Public Voluntary Schemes 3. Unilateral Commitments (Private sector)
Behavioral Measures	1. Behavioral Measures

Source: Energy Efficiency policy and programs data base, available at <https://www.iea.org/policiesandmeasures/energyefficiency/>

1. Contact email for survey participants

Dear X

I hope this email finds you well. My name is Dania Ortiz, and I am doing my Ph.D. on Sustainable Energy Systems (under the MIT Portugal program). The objective of this email is to kindly ask for your collaboration to fill the attached survey. This study aims to develop a tool to assist Domestic Hot Water (DHW) policy design.

Particularly, it is of interest to retrieve information regarding the (XXXX NAME OF THE POLICY/PROGRAM). The summary results will be public and disseminated among the participants.

Please fill and send to up201608014@fe.up.pt | Questions and clarification requests welcome on the same e-mail.

Thanks for your collaboration,
Dania Ortiz

References:

- Government of Australia. (2019). *Water Heating | Energy Rating*. <http://energyrating.gov.au/products/water-heaters>
- IEA. (2019). *Solar Heat Worldwide 2019*. Retrieved July 7, 2020, from <https://www.iea-shc.org/Data/Sites/1/publications/Solar-Heat-Worldwide-2019.pdf>
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- Kegel, M., Tamasauskas, J., Sunye, R., & Giguere, D. (2017). Heat Pump Water Heaters in the Canadian Residential Market. *Natural Resources Canada, Varennes*, 5–15.
- European Commission. (2016). *“Common understanding of the heating energy labelling concept, FAQs: Frequently Asked Questions.”*

Table D.1 List of Contacts from Solar Thermal World (STW, 2019)

Policy/Program	Country/Region	Contact	Email
CSI – Thermal Program in California: performance-based Incentives decreasing over the Years	California	California Public Utilities Commission	tdp@cpuc.ca.gov
Otthon Melege (Warm Homes) programme	Hungary	National Development and Strategic Institute	futes2017@nfsi.hu
Andalusia: Sustainable Construction Incentive programme	Andalusia	Agencia Andaluza de la Energía	atencionalciudadano.aae@juntadeandalucia.es
State subsidies for solar thermal energy in Macedonia	Macedonia	Macedonian Ministry of Economy	info@economy.gov.mk
Residential Energy Efficiency Credit Line (REECL) 3 in Bulgaria	Bulgaria	REECL Project Office	info@reecl.org
Slovakian incentive programme Green Homes	Slovakia	Slovak Innovation and Energy Agency	www.siea.sk
Residential Support programme in Norway	Norway	Enova SF	svarer@enova.no
Low-interest Loans for Energy Service Providers	Spain	IDAE	solcasa@idaes.es
Germany: MAP – national subsidy scheme for Renewable heating technologies	Germany	BAFA	Contact fomulary
India: National Subsidy Scheme Phase II	India	Ministry of New and Renewable Energy	veena.sinha@nic.in
Demo Projects Solar House (Demoprojekte Solarhaus)	Austria	Austrian Climate and Energy Fund	umwelt@kommunalkredit.at
The domestic Renewable Heat Incentive	United Kingdom	Energy Saving Advice Service	energy-advice@est.org.uk
India: Rebate programme for 400,000 m ² in public, social and industrial sector	India	Ministry of New and Renewable Energies	Veena.sinha@nic.in chalapathi.rao@nic.in
Non-domestic Renewable Heat Incentive (RHI) in Great Britain	United Kingdom	Department of Energy and Climate Change	rhi.enquiry@ofgem.gov.uk
Czech Republic: Residential Rebate programme Nova Zelena Usporám	Czech Republic	Ministry of the Environment	info@sfzp.cz

Policy/Program	Country/Region	Contact	Email
Western Balkans Sustainable Energy Financing Facility II (WEBSEFF II)	Balkan countries	Daniela Diedrich-Ristic Associate Manager Energy Efficiency & Climate Change Team	diedricd@ebrd.com
Lebanon: Subsidy and Interest-free Loan for Residential Solar Water Heaters	Lebanon	Lebanese Center for Energy Conservation Rani Al Achkar	rani.alachkar@lcecp.org.lb
Italy: Conto Termico financed through Levy on Natural Gas Tariffs	Italy	Gestore dei Servizi Energetici	rinnovabili@gse.it
MONTESOL – Solar Water Heating Project for Montenegro's Domestic Sector	Montenegro	Energy Efficiency Sector	info@ee-me.org
Uruguay's Solar Plan Grants Solar Water Heaters	Uruguay	National Energy Administration Martín Scarone	energiasrenovables@dne.miem.gub.uy
Residential Energy Saving programme in Lviv Region Extended	Lviv, Ukraine	Department of Economics of the Lviv regional administration:	no email has been identified
Subsidy Programme in Malta	Malta	Regulator for Energy and Water Services	enquiry@rews.org.mt
Tax Credits for Construction Companies	Chile	National Energy Commission Ruben Bustos Muñoz	rmunoz@cne.cl
ECO Fund Offers Grants and Low-interest Loans	Slovenia	Eco Fund, Slovenian Environmental Public Fund	ekosklad@ekosklad.si
Carbon Trust 0% Interest Loans in Great Britain	United Kingdom	Carbon Trust	Online enquiry
Tax Credits for Home Owners in France	France	ENERPLAN	info@enerplan.asso.fr
Prosol: Successful grant and credit programme in Tunisia	Tunisia	Abdelkader Baccouche Agence nationale pour la maîtrise de l'énergie	abdelkader.baccouche@anme.nat.tn
Solar Association	USA	n.a.	info@seia.org.
British Columbia Energy Star Water Heater Program + Furnace and Boiler Replacement Program (Fortis)	Canada	n.a.	rebates@fortisbc.com

Policy/Program	Country/Region	Contact	Email
Operational Programme Environment (2014-2020): Sustainable Use of Energy Sources	Czech Republic	n.a.	dotazy@sfzp.cz
Warm Up New Zealand: Healthy Homes	New Zealand	ECCA	info@eeca.govt.nz

Table D.2 List of Contacts from the International Energy Agency (IEA, 2019)

Policy	Country:	Contact	Email
Standards and Labelling Scheme (Mandatory and Voluntary)	India	Help-Desk	helpdesk@beenet.in
Federal Promotion of Extraordinary Efficiency in Buildings	Austria	Bundesministerium für Nachhaltigkeit und Tourismus	service@bmnt.gv.at
Energy Efficiency and Demand Side Management (EEDSM) Programme	South Africa	ESMAP	esmap@worldbank.org; cfassist@worldbank.org
Roadmap for Building Energy Codes and Standards for Mexico	Mexico	IEA country representation	anna.lepure@iea.com
Program for Promotion of Solar Heaters of Water in Mexico	Mexico	IEA country representation	anna.lepure@iea.com
New Zealand Energy Efficiency and Conservation Strategy	New Zealand	Ministry of Business, Innovation & Employment	media@mbie.govt.nz; info@mbie.govt.nz.
Energy Saving Scheme : Solar Heaters Support	New Zealand	EECA	info@eeca.govt.nz
Energy Star	New Zealand	EECA	info@eeca.govt.nz
National Energy Conservation and Efficiency Policy (Draft)	Jamaica	Ministry of Science, Energy & Technology	info@mset.gov.jm
Law 697 on the promotion of the efficient and rational use of energy and alternative energies	Colombia	Ministerio de Minas y Energía	Institucional: menergia@minenergia.gov.co

Policy	Country:	Contact	Email
Energy Efficiency for Public Services (Gestiona Energia)	Chile	Gestiona Energía	Enquiry site or tl +56 2 2 365 6800
Energy Korea Show	Korea	Korean Energy Agency	kea@energy.or.kr
High Efficiency Appliance Certification Programme	Korea	Korean Energy Agency	kea@energy.or.kr
Energy Star Loan Program (SaskEnergy/SaskPower)	Canada	SaskEnergy Network	n.a.
British Columbia Energy Star Water Heater Program + Furnace and Boiler Replacement Program (Fortis)	Canada	ForTIS	rebates@fortisbc.com
Northwest Territories Energy Efficiency Incentive Program	Canada	Artic Energy Alliance	Enquiry contact link
ecoENERGY Efficiency for Housing and Buildings	Canada	Natural Resources Canada	nrcan.media.nrcan@canada.ca
Warm Up New Zealand: Heat Smart	New Zealand	EECA	info@eeca.govt.nz
Insulation Programmes 2009-2018	New Zealand	EECA	info@eeca.govt.nz
Energy Efficient Homes Package and Solar Hot Water Rebate	Australia	Department of Environment and Energy	Fraudliaison@environment.gov.au
Regulation on Indoor Heating and Air-conditioning Systems (RITE)	Spain	Instituto para la Diversificación y Ahorro de la Energía (IDAE)	ciudadano@ida.es; comunicacion@ida.es
National Framework for Energy Efficiency (NFEE) Stage Two	Australia	Clean Energy Regulator	enquiries@cleanenergyregulator.gov.au
Blue Angel	Germany	Blue Angel	Enquiry contact link
ENERGY STAR for New Homes	Canada	Natural Resources Canada	nrcan.media.nrcan@canada.ca
Minimum Energy Performance Standards (MEPS)	New Zealand	EECA	info@eeca.govt.nz

Policy	Country:	Contact	Email
Sustainable Energy Irelands Boilers Initiative	Ireland	Sustainable Energy Authority of Ireland	tel 353-1-8082100
Tax Credits for Energy Saving Facilities	Korea	Korean Energy Agency	kea@energy.or.kr
Energy Star	United States	Energy Star	Enquiry contact link
Top Runner Programme	Japan	Agency for Natural resources and Energy	n.a.
Energywise Solar Water Heating Grants	New Zealand	EECA	info@eeca.govt.nz
Innovation Fund for Solar Water Heating	New Zealand	EECA	info@eeca.govt.nz
Home Energy Ratings Scheme	New Zealand	New Zealand Green Building Council	info@nzgbc.org.nz
Home Star Ratings	New Zealand	New Zealand Green Building Council	info@nzgbc.org.nz

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Appendix E Variables Directory

Context Variables

Context Variables

Table A.1 Country Characteristics (1)

Variable Name	Description	Example	Binary, polynomial or numeric	Units	Min	Max	Mean	Std. Deviation	Source
Country Location(2)	Geographical Country location in which the program has been implemented	Western	Polynomial	no units	n.a.	n.a.	n.a.	n.a.	(Unstats, 2020)
EU member	The country was a member of the EU at the moment of evaluation or not	1 (or 0)	Binary	no units	0	1	0.95	0.23	(European Commission,2020)
Member of the Eurozone	The country had the Euro as currency at the moment or not	1 (or 0)	Binary	no units	0	1	0.47	0.5	(European Commission,2020)
Population	Number of persons having their usual residence in a country	10 million	Numeric	million people	0.49	82.91	20.61	24.95	(Eurostat,2020)
Cooling degree days	Weather-based technical indexes designed to describe the energy requirements of buildings in terms of cooling	4.94	Numeric	Numeric Value	0	320.38	54.48	71.73	(Eurostat,2020)

Variable Name	Description	Example	Binary, polynomial or numeric	Units	Min	Max	Mean	Std. Deviation	Source
Heating degree days	Weather-based technical indexes designed to describe the energy requirements of buildings in terms of heating	36	Numeric	Numeric Value	1054.83	6179.75	3329.1	1081.02	(Eurostat,2020)
Final energy consumption	Total final energy consumption	38381 Million tonnes of oil equivalent (TOE)	Numeric	Million tonnes of oil equivalent (TOE)	2.77	225.35	49.99	58.49	(Eurostat,2020)
Total energy supply by product	For the total of all energy products it is the total energy delivered/consumed in a country	33218.11	Numeric	Thousand TOE	3948.82	335474.27	73683	88544.81	(Eurostat,2020)
Supply by Renewables and biofuels	Supply by renewables and biofuels	9789.91	Numeric	Thousand TOE	125.54	43693.14	9627.3	9781.01	(Eurostat,2020)
Supply by Oil and petroleum products	Supply by the Oil and petroleum products	11698.52	Numeric	Thousand TOE	61.1	110941.29	23479	28753.99	(Eurostat,2020)
Supply by Non-renewable waste	Supply by the non-renewable waste	634.23	Numeric	Thousand TOE	0	4514.02	629.28	941.77	(Eurostat,2020)

Variable Name	Description	Example	Binary, polynomial or numeric	Units	Min	Max	Mean	Std. Deviation	Source
Supply by Nuclear Heat	Supply by the Nuclear Heat	0	Numeric	Thousand TOE	0	115209	9470.7	23010.26	(Eurostat,2020)
Supply by Electricity	Supply by Electricity products	534.19	Numeric	Thousand TOE	-5777.3	3987.79	-17.6	1564.75	(Eurostat,2020)
Supply by Solid Fossil Fuels	Supply by Solid Fossil Fuels	3205.97	Numeric	Thousand TOE	8.66	81561.13	12034	20038.21	(Eurostat,2020)
Final energy supply	Total final energy supply	58031(Million TOE)	Numeric	Million TOE	3.95	349.21	73.95	88.02	(Eurostat,2020)
Expenditure on Research and Development	Percentage of government budget allocations for Research & Development	1.90%	Numeric	Percentage	0.35	2.13	1.28	0.44	(Eurostat,2020)
Long-term interest rate	The amount a lender charges a borrower, being a percentage of the principal	4%	Numeric	Percentage	0.09	10.55	3.39	1.92	(Eurostat,2020)
Air pollutants by source sector	Air pollutants emissions for the entire territory	240593	Numeric	Tonnes	32138	1783137	391508	444570.42	(Eurostat,2020)
Pollution or other environmental problems	Environmental problems by degree of urbanization	14.1	Numeric	Percentage	5.2	43.6	18.33	7.5	(Eurostat,2020)

Variable Name	Description	Example	Binary, polynomial or numeric	Units	Min	Max	Mean	Std. Deviation	Source
GDP per capita	Country's GDP per capita	36883.87 (U.S. dollars per capita)	Numeric	U.S. dollars per capita	4477.03	117366.01	36674	22373.49	(World Economic Outlook,2020)
Human Development Index	Average achievement of a long and healthy life, being knowledgeable and have a decent standard of living	0.86	Numeric	Numeric Value (Scale 0 to 1)	0.77	0.95	0.88	0.04	(UNDP,2020)
Harmonised Index of Consumer Prices	Change over time of the prices of consumer goods and services acquired by households	80.6	Numeric	Index	63.06	108.05	93.72	8.38	(Eurostat,2020)
Total People at risk of poverty	Indicator to monitor the EU 2030 target on poverty and social exclusion	0.14	Numeric	Percentage	12.2	61.3	23.31	7.94	(Eurostat,2020)
Gini coefficient of equivalised disposable income	Indicator relating to poverty risk	.43 (Scale 0 to 1)	Numeric	Numeric Value (Scale 0 to 1)	20.9	40.2	29.62	3.91	(Eurostat,2020)
Average household size	Average household inhabitants	2.3 inhabitants	Numeric	Number of inhabitants by house	1.9	2.9	2.36	0.27	(Eurostat,2020)

Variable Name	Description	Example	Binary, polynomial or numeric	Units	Min	Max	Mean	Std. Deviation	Source
Exposure to air pollution by particulate matter	Measures the population weighted annual mean concentration of particulate matter	23.3	Numeric	Numeric Value	4.9	51.4	15.8	7.73	(Eurostat,2020)
Environmental protection expenditure	General government expenditure by environmental protection	0.005	53.7	Euro per inhabitant	-0.3	1.7	0.72	0.29	(Eurostat,2020)
Environmental tax revenues	Proportion of environmental tax revenues in total revenues from all taxes and social contributions	43.3	Numeric	Percentage	173.76	49474	11402	15029.44	(Eurostat,2020)
Remuneration of civil servants	Annual evolution in the remuneration of national civil servants working in central public administrations	102.5	Numeric	Index	73	148.7	103.21	5.91	(Eurostat,2020)
Number of national civil servants	Number of national civil servants in central public administration	42005	Numeric	Numeric Value	825	435660	65250	85104.49	(Eurostat,2020)
FiT-Solar PV	Feed in Tariff for Solar technologies	0.6717	Numeric	US Dollars	0	0.83	0.15	0.22	(OECD,2020)
FiT-Wind	Feed in Tariff for Wind technologies	0.097	Numeric	US Dollars	0	0.68	0.07	0.09	(OECD,2020)

Variable Name	Description	Example	Binary, polynomial or numeric	Units	Min	Max	Mean	Std. Deviation	Source
FiT-Small Hydro	Feed in Tariff for Hydro technologies	0.6717	Numeric	US Dollars	0	0.25	0.06	0.06	(OECD,2020)
FiT-Biomass	Feed in Tariff for Biomass technologies	0.097	Numeric	US Dollars	0	0.21	0.06	0.07	(OECD,2020)
FiT-Waste	Feed in Tariff for Waste technologies	0	Numeric	US Dollars	0	1.13	0.08	0.17	(OECD,2020)
FiT-Geothermal	Feed in Tariff for Geothermal technologies	0.1477	Numeric	US Dollars	0	0.33	0.05	0.08	(OECD,2020)
FiT-Marine	Feed in Tariff for Marine technologies	0.0964	Numeric	US Dollars	0	0.71	0.05	0.1	(OECD,2020)
Total general government expenditure	Total General government expenditure	0.65	Numeric	Percentage of GDP	25.6	65.1	45.62	6.31	(Eurostat,2020)

(1) Country Characteristics: The variables of this group have not been included for the EPEI application.

(2) Country Location possible values: Western, Eastern, Northern, Southern or European Union (as the average values).

Effectiveness Concerns

Table A.2 Affordability Variables

Variable Name	Description	Example	Binary, polynomial or numeric	Units	Min	Max	Mean	Std. Deviation	Source
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Electricity price for households	Yearly average of the price paid for electricity in a country by households users	0.89 €/kWh	Numeric	Euros/ Kilowatt-hour/	0.06	0.2	0.12	0.03	(Eurostat,2020)
Electricity prices for non-households	Yearly average of the price paid for electricity in a country by industrial users	0.81 €/kWh	Numeric	Euros/ Kilowatt-hour/	0.04	0.14	0.08	0.02	(Eurostat,2020)
Gas Price for households	Yearly average of the price paid for gas in a country by household users	10.4 €/GJ	Numeric	Euros/Gigajoules	3.67	21.05	11.8	3.11	(Eurostat,2020)
Gas prices for non-households	Yearly average of the price paid for gas in a country by industrial users	7.3 €/GJ	Numeric	Euros/Gigajoules	2.75	14.03	8.38	1.83	(Eurostat,2020)

Table A.3 Accessibility Variables

Variable Name	Description	Example	Binary, polynomial or numeric	Units	Min	Max	Mean	Std. Deviation	Source
Energy Balance	Difference between the final energy consumption and final energy supply	19650 Million tonnes of oil equivalent (TOE)	Numeric	Million tonnes of oil equivalent (TOE)	-0.18	123.86	23.96	30.53	Own calculated

Energy import dependency	Share of total energy needs of a country met by imports from other countries	50%	Numeric	Percentage	-	702.61	97.51	19.15	139.86	(Eurostat,2020)
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Table A.4 Economic Competitiveness Variables

Variable Name	Description	Example	Binary, polynomial or numeric	Units	Min	Max	Mean	Std. Deviation	Source
Market share of the biggest competitor	Market share of the largest generator in the electricity market	55.30%	Numeric	Percentage	15.3	96.5	49.11	21.36	(Eurostat,2020)
Energy Productivity	Indicator that measures the amount of economic output that is produced per unit of gross available energy	8.05	Numeric	Euro per Kilogram of Oil Equivalent (KGOE)	1.67	18.58	7.13	3.13	(Eurostat,2020)
Energy Intensity of the economy	Primary energy consumption per unit of GDP	12.7	Numeric	Numeric Value	1.15	13.03	3.11	2.49	Own Calculated
Energy Intensity of the population	Primary energy consumption per inhabitant	1.04	Numeric	Numeric Value	0.04	7.29	1.48	1.66	Own Calculated

Table A.5 Impact on the Environment Variables

Variable Name	Description	Example	Binary, polynomial or numeric	Units	Min	Max	Mean	Std. Deviation	Source
Total Greenhouse gas emissions	Total GHG emissions in a country	81987.78	Numeric	Thousand tonnes	6636.22	1007867	181129	236340.85	(Eurostat,2020)
GHG emissions intensity of energy consumption	Ratio between energy-related GHG emissions and gross inland consumption of energy	105.4	Numeric	Numeric Value	68.5	124.9	91.61	8.88	(Eurostat,2020)

Table A.6 Impact on Climate Change Variables

Variable Name	Description	Example	Binary, polynomial or numeric	Units	Min	Max	Mean	Std. Deviation	Source
Renewable Electricity capacity	Maximum net generating capacity of power plants and other installations that use renewable energy sources	303	Numeric	MW	- 168.48	11316.33	941.11	1807.05	(IRENA,2020)
Energy Efficiency	Ratio of the total energy delivered by the sytem and the energy consumed by it	55.6 (Million tonnes of oil equivalent (TOE))	Numeric	Million TOE	4.27	332.75	70.96	85.12	(European Commission,2020)

Table A.7 Equity Variables

Variable Name	Description	Example	Binary, polynomial or numeric	Units	Min	Max	Mean	Std. Deviation	Score
Population unable to keep home adequately warm	Population unable to keep home adequately warm by poverty status	0.03%	Numeric	Percentage	0.3	69.5	10.05	12.27	(Eurostat,2020)

Table A.8 Governance effectiveness and efficacy variables

Variable Name	Description	Example	Binary, polynomial or numeric	Units	Min	Max	Mean	Std. Deviation	Score
Expenditure on energy and fuels expenditure	General government expenditure by fuels and energy	0.53	Numeric	Percentage of GDP	-0.5	1.8	0.23	0.28	(Eurostat,2020)
Environmental tax revenues (energy tax) of GDP	Proportion of environmental tax revenues in Gross Domestic Product (GDP)	0.01	Numeric	Percentage of GDP	0.97	3.05	1.94	0.4	(Eurostat,2020)

Policy Characteristics

Table A.9 Policy Characteristics (1)

Variable Name	Description	Example	Binary, polynomial or numeric	Units	Min	Max	Mean	Std. Deviation	Source
Other related policies	Amount of RE policies included part of the policy mix	2	Numeric	Numeric Value	0	136	25.61	21.25	Own Calculated
Average duration of the programs	Average of the years the programs were designed to be active	15 years	Numeric	no units	4	16	11.38	2.89	Own Calculated
Average years of activity	Average of the years the programs have been active	5	Numeric	no units	1	15	6.28	3.62	Own Calculated
Median years of activity	Median of the years the programs have been active	5.5	Numeric	no units	1	15	6.51	4.06	Own Calculated
Number of RE programs	Total amount of RE programs that are active simultaneously	3 policies active at the analyzed year	Numeric	no units	1	14	3.02	2.73	Own Calculated
Age of oldest program	Age of the oldest policy program considered	1 or 0	Binary	no units	4	141	14.41	13.19	Own Calculated

Variable Name	Description	Example	Binary, polynomial or numeric	Units	Min	Max	Mean	Std. Deviation	Source
Policy Type (2)	General program type class	General Programme	Polynomial	no units	n.a.	n.a.	n.a.	n.a.	(Fraunhofer Institute,2020)
Policy Sub type (3)	Detailed program type class	General programme renewables	Polynomial	no units	n.a.	n.a.	n.a.	n.a.	(Fraunhofer Institute,2020)

- (1) Policy Characteristics: The variables of this group have not been included for the EPEI application
- (2) Legislative/Normative; Legislative/Informative; Financial; Fiscal/Tariffs; Information/Education; Co-operative Measures; Cross-cutting
- (3) Mandatory Standards for Buildings; Regulation for Heating Systems; Other Regulation in the Field of Buildings; Mandatory Standards for Appliances; Mandatory labelling; Mandatory energy efficiency certificates; Mandatory audits; Grants / Subsidies for investments; Grants / Subsidies for audits; Loans/Others; VAT Reduction; Income tax reduction; Linear electricity tariffs; Voluntary labelling; Information campaigns; Detailed energy/electrical bill; Regional and local information centres; Voluntary/Negotiated agreements; Voluntary DSM measures of suppliers; Technology procurement; Eco-tax on electricity/energy; Eco-tax on CO₂ – emissions

Table E.9 Policy instruments and subtypes

Policy Type	Policy subtype
Legislative/Normative	Mandatory Standards for Buildings
	Regulation for Heating Systems
	Other Regulation in the Field of Buildings
	Mandatory Standards for Appliances
Legislative/Informative	Mandatory labelling
	Mandatory energy efficiency certificates
	Mandatory audits
Financial	Grants / Subsidies for investments
	Grants / Subsidies for audits
	Loans/Others
Fiscal/Tariffs	VAT Reduction
	Income tax reduction

	Linear electricity tariffs
Information/Education	Voluntary labelling
	Information campaigns
	Detailed energy/electrical bill
	Regional and local information centres
Co-operative Measures	Voluntary/Negotiated agreements
	Voluntary DSM measures of suppliers
	Technology procurement
Cross-cutting	Eco-tax on electricity/energy
	Eco-tax on CO ₂ - emissions

(Boonekamp & Piccioni, 2014)

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Appendix F. Policy choice framework

A policy choice framework is a support tool for decision-makers that enables to structure the selection process on weight definition. Nonetheless, following a framework may require that policy-makers have expertise and information together with the problem definition to do the choices and justify their decisions (Boswell et al., 2011).

Some advantages of the Policy choice framework include that it can enhance the consideration of the limitations and constraints around a decision. The framework may facilitate the exploration of various drivers, with differences in terms of efficiency, equity, accountability, and robustness involving the trade-offs among them (Heikkila & Cairney, 2017).

On the disadvantages, it is noted that even if the policy choice framework should be able to reflect all the constraints and drivers influencing the decisions, some of them may be difficult to be organized and integrated e.g. some challenging drivers that influence the choice are the national mood around a policy (Zahariadis & Al, 2007). The suggestion of a Policy framework has been done in the form of a checklist including different drivers. They are organized in 10 groups in which the decision-maker can give a priority reference in the scale of their own needs and preferences (High, Medium or Low). With the aim of facilitating the scale given to each alternative, each driver can be discussed in the form of a question: How important is the DRIVER in the context of the policy choice to be done?

Table F.1 Policy choice driver's chart and example of assigned priorities

Group	Drivers	Priority
Micro-Economic	Innovation stimulation Efficiency Cost-Effectiveness Broader costs Budget Large industrial clients and lobbies	Medium
Macro-Economic	Energy security Country context (Domestic nature) International considerations	High
Environmental	GHG emissions mitigation and control Climate Change concern	High
Social	Stakeholders (receive support) Stakeholders (Equity)	Medium
Institutional	Regulatory interactions Policy linking Governmental level of instrument implementation Policy compliance Policy feasibility	Low

Effectiveness	Objective's achievement	High
Policy Makers (PM) style	PM ideology PM values & beliefs	Low
Policy Makers interest	Support from stakeholders Strengthen or weaken the position of an actor PM biases	Low
Instrument and problem characteristics	Instrument nature Instrument evolution (previous policies and future stages) Targeted issue nature	Low
Others	Externalities	Medium