ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΕΙΡΑΙΩΣ
ΤΜΗΜΑ ΒΙΟΜΗΧΑΝΙΚΗΣ ΔΙΟΙΚΗΣΗΣ
& ΤΕΧΝΟΛΟΓΙΑΣ

UNIVERSITY OF PIRAEUS
DEPARTMENT OF INDUSTRIAL MANAGEMENT
& TECHNOLOGY

"Designing effective Policy Instruments for Energy Efficiency: An analysis in the frame of policy planning & evaluation"

By

Spyridaki Niki-Artemis

University of Piraeus, Greece

Members of the supervisory committee:

- Associate Professor, Flamos Alexandros, University of Piraeus (supervisor)
- Professor, Stella Sofinopoulou, University of Piraeus
- Professor, John Psarras, National Technical University of Athens
- Professor, Vaggelis Grigoroudis, Technical University of Crete
- Associate Professor, Haris Doukas, National Technical University of Athens
- Assistant Professor, Athanasios Dagoumas, University of Piraeus
- Assistant Professor, Kyriakos Drivas, University of Piraeus

Acknowledgments

The doctoral dissertation took part in the Department of Industrial Management and Technology of the School of Maritime and Industrial Studies of the University of Piraeus, in the framework of the works of the Techno-economics of Energy Systems Laboratory (TEESlab), from September 2011 to September 2019. The completion of the doctoral research project is the culmination of a personal journey and struggle where the assistance and support of many people has been detrimental and to whom I express my sincere gratitude.

At first, I would like to thank my supervisor, Associate Professor Mr Flamos Alexandros, for his continuous support, encouragement and valuable contribution, not only during my dissertation but also throughout my course at the Laboratory. The confidence he has shown in me over the years, as well as the recognition of my dedication and contribution to the Laboratory, were crucial to the completion of this research work. I would also like to express my sincere gratitude to the members of the seven-member advisory committee for their meticulous and constructive remarks.

Part of my gratitude belongs to Assistant Professor Haris Doukas, member of the examining committee for the careful reading of my work and their valuable suggestions. I would also wish to acknowledge the great support I have had from Professor Emeritus Mr. Yiannis Siskos and the Assistant Professor Ioannis Dendramis, who helped me decisively in my research work, devoting part of their valuable time. Special thanks also go to Dr. Vlasios Oikonomou (Institute for European Energy and Climate Policy Studies), who supported me in different ways and at different stages of my PhD journey.

I would also like to thank all of my colleagues at (TEESlab) with whom I have worked all of these years and learned a lot from and with them. More specifically, I would like to thank Vasilis Stavrakas for his continuous encouragement and his continual constructive collaboration. I would also like to thank Serafeim Michas, a reliable and systematic collaborator, with whom I have also worked closely throughout these years.

I would like to thank all my close friends and family members for believing in and supporting me during these years. Last but certainly not least, I would like to thank my parents for all their love, support and encouragement during this time. I thank them warmly through my heart and dedicate this thesis to them.

Athens, February 2020

Niki-Artemis Spyridaki

Περίληψη

Στη παρούσα Διδακτορική Διατριβή αναπτύσσονται βελτιωμένες μεθοδολογίες αξιολόγησης εργαλείων πολιτικής για την ενεργειακή εξοικονόμηση. Η διατριβή συμβάλλει στη βελτίωση των υπάρχοντών διαδικασιών σχεδιασμού και αξιολόγησης εργαλείων πολιτικής για την ενεργειακή απόδοση, επεκτείνοντας σημαντικά τη σύγχρονη βιβλιογραφία. Η βελτίωση αυτή κρίνεται αναγκαία ενόψει των συνεχώς αυξανόμενων απαιτήσεων για εξοικονόμηση ενέργειας σε εθνικό και διεθνές επίπεδο καθώς και των αυστηρότερων προϋποθέσεων επι-προσθετικότητας των πολιτικών ενεργειακής απόδοσης. Συνεπώς οι υφιστάμενες διαδικασίες σχεδιασμού εργαλείων πολιτικής για την εξοικονόμηση ενέργειας είναι αναγκαίο να βελτιωθούν ώστε να αξιολογούν τα εργαλεία πολιτικής σε διαφορετικά στάδια στον κύκλο εφαρμογής τους και να εξετάζουν πτυχές και κανόνες μέτρησης που είχαν παραμεληθεί στο παρελθόν. Η διατριβή συμβάλει στην κάλυψη του επιστημονικού «κενού» που εντοπίστηκε για την καλύτερη ενσωμάτωση αυστηρότερων προϋποθέσεων επι-προσθετικότητας των εργαλείων πολιτικής (i.e. additionality) καθώς και των κοινωνικών πτυχών που χαρακτηρίζουν τις επενδύσεις για ενεργειακή εξοικονόμηση.

Μέσω μιας εμπεριστατωμένης ανάλυσης όλων των παραμέτρων του προβλήματος και της ανάπτυξης μιας βάσης τεκμηρίωσης, αναπτύχθηκαν πιο ρεαλιστικές και διαφανείς μεθοδολογίες αξιολόγησης. Αυτές βελτιώνουν τις υπάρχουσες πρακτικές αξιολόγησης και αποσκοπούν στην υποστήριξη της διαδικασίας λήψης αποφάσεων των εθνικών φορέων χάραξης πολιτικής για αποτελεσματικότερα εργαλεία πολιτικής για την ενεργειακή απόδοση.

Συγκεκριμένα, η διατριβή προτείνει την ανάπτυξη των κάτωθι μεθοδολογιών:

(i) Ποιοτική αξιολόγηση του σταδίου εφαρμογής των εργαλείων πολιτικής: υποστηρίζει τους υπεύθυνους χάραξης πολιτικής στη διαδικασία εντοπισμού και κατάταξης εργαλείων πολιτικής για την εξοικονόμηση ενέργειας. Η αξιολόγηση και κατάταξη πραγματοποιείται σύμφωνα με ενδιάμεσες επιδόσεις για τη δυνατότητα εφαρμογής των εργαλείων. Η προτεινόμενη προσέγγιση παρέχει προτάσεις ανασχεδιασμού, σύμφωνα με τα εμπόδια που εντοπίστηκαν κατά το στάδιο της εφαρμογής των εργαλείων.

(ii) Εμπειρικό μοντέλο προσδιορισμού της επίδρασης των εργαλείων οικονομικής επιδότησης: ποσοτικοποιεί την επιπρόσθετη επίδραση που μπορεί να αποδοθεί στο επιλεγμένο εργαλείο πολιτικής, αναφορικά με την υιοθέτηση τεχνολογιών ενεργειακής εξοικονόμησης. Η επιλογή του εργαλείου μπορεί να προκύψει από την προηγούμενη αξιολόγηση. Η μοντελοποίηση που προτείνεται λαμβάνει υπόψη την ετερογένεια των οικιακών καταναλωτών καθώς και άλλους εξωγενείς παράγοντες που επηρεάζουν την υιοθέτηση τεχνολογιών εξοικονόμησης και κατ΄επέκταση την επίδραση του εργαλείου πολιτικής.

(iii) Εκ των προτέρων αξιολόγηση των μελλοντικών δυνατοτήτων των οικονομικών επιδοτήσεων για εξοικονόμηση ενέργειας: επικεντρώνεται στο σχεδιασμό ενός χαρτοφυλακίου τεχνολογιών ενεργειακής εξοικονόμησης για την υλοποίηση εναλλακτικών πολιτικών επιδότησης. Για τον σκοπό αυτό αναπτύσσεται ένα καινοτόμο οικονομοτεχνικό πλαίσιο «από κάτω προς τα πάνω» (i.e. bottom-up) που στόχο έχει την μοντελοποίηση των εναλλακτικών πολιτικών. Μέσω του συγκεκριμένου πλαισίου εκτιμώνται οι μακροπρόθεσμες δυνατότητες εξοικονόμησης ενέργειας για τις επιμέρους τεχνολογίες, υπό διαφορετικά σενάρια επιδότησης, καθώς και από

διαφορετικές οπτικές, σε σχέση με τους στόχους που έχουν τεθεί καθώς και τον προϋπολογισμό που απαιτείται.

Στο σύνολό τους, τα προαναφερθέντα ερευνητικά κεφάλαια αποτελούν ανεξάρτητα αλλά διαδοχικά βήματα ενός ολοκληρωμένου μεθοδολογικού πλαισίου αξιολόγησης, το οποίο: αξιολογεί τα εργαλεία πολιτικής σε διαφορετικά στάδια του κύκλου ζωής τους (δηλαδή κατά τη διάρκεια, εκ των υστέρων και εκ των προτέρων) και ενσωματώνει κοινωνικούς και συμπεριφορικούς φραγμούς κατά την εκτίμηση του μελλοντικού δυναμικού τους για εξοικονόμηση ενέργειας.

Επιπλέον, η παρούσα διατριβή συμβάλλει στην ανάπτυξη και αξιοποίηση καινοτόμων μεθόδων και τεχνικών για την υποστήριξη του σχεδιασμού αποτελεσματικότερων πολιτικών ενεργειακής εξοικονόμησης όπως: η πολύ-κριτιριακή ανάλυση, η ανάλυση ευαισθησίας (μέσω cluster analysis), η οικονομετρική μοντελοποίηση βάσει έρευνας (i.e. survey-based), καθώς και η αξιολόγηση «από κάτω προς τα πάνω» για τον προσδιορισμό των μακροπρόθεσμων δυνατοτήτων ενεργειακής εξοικονόμησης.

Η διαθεσιμότητα πραγματικών και εθνικά αντιπροσωπευτικών δεδομένων που συλλέχθηκαν στο πλαίσιο των ευρωπαϊκών έργων “APRAISE-Assessment of Policy Interrelationships and Impacts on Sustainability in Europe” και “ENSPOL - Energy Saving Policies and Energy Efficiency Obligation Schemes”, διαμόρφωσαν το σχεδιασμό του μεθοδολογικού πλαισίου αξιολόγησης και αποτελούν σημαντικό στοιχείο της προτεινόμενης προσέγγισης καθώς και των αποτελεσμάτων της.

Τέλος η εφαρμογή του προτεινόμενου μεθοδολογικού πλαισίου στο μίγμα των εργαλείων εθνικής πολιτικής καθώς και των τεχνολογιών εξοικονόμησης στον Ελληνικό κτιριακό και οικιακό τομέα, επέτρεψε την αξιολόγηση της πληρότητας και της αξιοπιστίας των αποτελεσμάτων. Αυτό επιτεύχθηκε μέσω της ανάπτυξης του μεθοδολογικού πλαισίου σε στενή συνεργασία με τους εθνικούς φορείς χάραξης πολιτικής και τους βασικούς ενδιαφερόμενους στην αγορά.

Λέξεις-κλειδιά: Εθνικός σχεδιασμός πολιτικής για την ενεργειακή εξοικονόμηση, εργαλεία πολιτικής, υποστήριξη λήψης αποφάσεων, πολυκριτηριακή ανάλυση, τεχνο-οικονομική αξιολόγηση από κάτω προς τα κάτω, οικονομετρική μοντελοποίηση βάσει έρευνας, υιοθέτηση τεχνολογίας, μέτρα ενεργειακής απόδοσης, οικονομικές επιδοτήσεις.

PhD Brief Summary

The main objective of this Doctoral thesis is the development of improved assessment methodologies that evaluate energy efficiency policy instruments at different stages in their policy cycle and better account for the social context within which these are implemented. These improvements are deemed necessary in view of the ever-increasing requirements for the realization of energy savings at a national and international level as well as the stricter prerequisites for the additionality of energy efficiency policies. Existing evaluation frameworks and planning processes thus need to be enhanced to account for aspects and rules of measurement that have been neglected in the past. In addition, more realistic and transparent evaluation frameworks should be developed at different stages of the policy instrument cycle, to guide and support their more pragmatic design and implementation towards target achievement. The dissertation aimed at contributing to the scientific "gap" identified for the better integration of the stricter additionality pre-requisites as well as the social and behavioural aspects of energy efficiency-related investments in the policy planning and design processes of energy efficiency policy instruments.

Through a thorough analysis of all the parameters of the problem and the development of an evidence base, more realistic and transparent evaluation methodologies were developed. These improve existing evaluation practices and aim to support the decision-making process of national policy-makers for designing more effective policy instruments for energy efficiency.

Specifically, the thesis proposes the development of the following evaluation methodologies:

(i) Qualitative process evaluation of energy efficiency policy instruments: supports policy decision-makers in the process of assessing and ranking policy instruments. The ranking is conducted through intermediate performance criteria and semi-quantitative assessment scales reflecting the ease of implementation of policy instruments. The proposed approach provides recommendations for policy redesign to address the hurdles identified during the implementation stage of the policy instruments.

(ii) Empirical model for determining the ex-post effect of financial subsidies for energy efficiency: quantifies the additional impact that can be attributed to the chosen policy instrument with regards to the adoption of energy efficiency measures. The selection of the policy instrument may result from the previous evaluation. The proposed modelling considers the heterogeneity of residential consumers as well as other exogenous factors that influence the adoption of energy efficiency technologies and therefore the impact of the policy instrument.

(iii) Ex-ante evaluation of the energy savings potential of financial subsidies: focuses on the design of a portfolio of energy-saving technologies to implement alternative subsidy policies promoting energy efficiency in the household sector. To this end, an innovative bottom-up, techno-economic, assessment framework is being developed to model the alternative subsidy scenarios. The framework assesses the long-term energy savings potential of individual technologies, under different subsidy scenarios, and from three evaluation perspectives (i.e. participant, policy-maker, social). Finally, the results obtained are compared to the targets set for energy efficiency as well as the budget requirements.

Overall, the aforementioned research chapters consist independent yet sequential steps of an integrated methodological evaluation framework, which: evaluates policy instruments at different stages in their policy cycle (i.e. during, ex post and ex ante) and integrates social and behavioural barriers when assessing their future potential for energy savings.

In addition, this thesis contributes to the development and exploitation of innovative methods to support the policy planning and design stage of effective policy instruments for energy efficiency, such as: multi-criteria analysis, cluster analysis, discrete-choice econometric modelling and bottom-up economic-engineering assessment for determining the long-term savings potential.

The availability of real as well as nationally representative data and information, collected in the framework of the European projects “APRAISE-Assessment of Policy Interrelationships and Impacts on Sustainability in Europe” and “ENSPOL - Energy Saving Policies and Energy Efficiency Obligation Schemes” determined the feasibility as well as the design of the proposed methodological assessment framework and consist an important element of the proposed approach as well as of the results obtained.

Finally, the application of the proposed methodological framework in a real situation (i.e. the mix of national policy instruments and technical measures operating and market available targeting the Greek building and household sector), have allowed the evaluation of the results’ completeness and reliability. This was accomplished through the development of the methodological framework in close cooperation with national policy-makers and key market stakeholders.

Keywords: National Energy Efficiency Policy Planning, Policy instruments, Energy Efficiency measures, Decision Support, Multi-Criteria Analysis, Process evaluation, Bottom-up economic-engineering assessment framework, Discrete choice-modelling, technology ownership, Programme potential, Savings to Investment Ratio, Financial subsidies

Table of Contents

List of Tables

Table of Contents

List of Figures

Table of Contents

Abbreviations & Acronyms

Abbreviation	Full Description
PI	Policy Instrument
EE	Energy Efficiency
RES	Renewable Energy Sources
EEMs	Energy Efficiency Measures
GHG	Green House Gas
EED	Energy Efficiency Directive
EEO	Energy Efficiency Obligation
NEEAP	National Energy Efficiency Plan
MCA	Multi-criteria Analysis
CE	Cost-effectiveness
SIR	Savings-to-Investment Ratio
RP	Revealed Preference
EUL	Expected Useful Life

1. Chapter 1: Introduction

This chapter introduces the background and motivation of this thesis as well as the main pillars that this thesis contributes to. In the last part of this chapter we summarize the main challenges and formulate our research questions addressing key issues in the frame of EE policy planning and evaluation processes.

1.1 Background and problem formulation

EU climate change mitigation policy extends over a timeframe of more than 20 years, since 1991 and the launch of the first Community strategy, aiming to limit CO_2 emissions and improving energy efficiency (EE). Climate change mitigation efforts have thus been underway in the European Union (EU) for many years, driven not only by the EU's own priorities but also by the need to fulfil its international commitment under the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol and more recently, the Paris Agreement (Fujiwara et al., 2017). As a direct strategic action, the European Climate Change Programme (ECCP) was introduced leading to a mix of climate change mitigation measures, including emissions trading and EE. This led to the introduction of EU legislation to be transposed and implemented at a Member State (MS) level. The 2020 climate and energy package adopted in 2009, was a turning point where climate and energy policies were integrated in a single package of targets and measures for GHG emission reductions, renewable energy (RE) deployment, and EE improvements. This structure is largely maintained in the Energy Union package towards 2030. It has also been widely acknowledged that the energy sector is responsible for a major proportion of the total GHG emissions, and the EU is focusing on actions to decarbonise it, including the promotion of RE and EE upgrades. Towards this direction, the "Winter Package", published in November 2016 by the European Commission (EC), addresses all areas of the energy system and is anticipated to shape the policy framework for many years post-2020 (Rosenow et al., 2017).

In both the 2030 package and the long-term low emission development strategies, as inspired by the Paris Agreement, EE plays a decisive role within the global strategy to limit the long-term increase of global temperatures to within 2°C above pre-industrial levels. Energy end-use efficiency relevant to fuels, power plant efficiency and electricity savings, can yield more than 70% of the CO2 emission reductions by 2020 within the frame of achieving the 2°C goal (IEA, 2012). In 2014, IEA has underlined the importance of EE towards this goal and proposes that 2/3 of the low carbon investments to be made to EE infrastructure, indicating that EE investments have to increase 8 times compared to 2013 levels (IEA, 2014a). Towards this direction, the EC has suggested that EE should be treated as an independent and competitive energy source (European Commission 2015) and in November 2016 it proposed further strengthening its role beyond 2020 by setting a binding 30 % EE target at EU level by 2030.

Although EE is being recognized as a significant energy source to meet with the ambitious sustainability goals, the latest EU progress towards meeting with its climate change mitigation targets, demonstrates a considerable stagnation of EE improvements and greenhouse gas (GHG) emission reduction trends. Reportedly, although the EU is broadly on track to achieve its 2020 GHG and RES objectives (i.e. 20% greenhouse gas emission reduction, 20% in renewable energy), recent evidence suggest that the 20% energy savings target by 2020 will not be attained (EC, 2018). In 2017, the EU appeared to be very much on track to achieve its 2020 EE targets. In fact in 2014, final end-use energy consumptions levels were lower than any year since the 1980s and even lower than the energy consumption levels required for 2020 (EEA, 2017). However, for the following two years up to 2016, energy consumption has been increasing and has kept the upward trend also for 2017. With the realization that the 2020 energy savings targets might be missed, the need for MS policy makers to carefully plan on how to meet with the 2030 EE targets becomes even more imperative. In fact recent analysis of these trends (Thomas and Rosenow, 2019), (EEA, 2017), suggest that for the primary and final energy targets to be fulfilled, efforts at MS level should focus on better understanding the relationship between EE policy mechanisms and the EE targets, through improved policy monitoring, verification and evaluation requirements and practices (Thomas and Rosenow, 2019). In other words, despite the significant efforts made to develop effective EE policy instruments (PIs), the anticipated energy savings are largely lacking. Reportedly existing EE policies have been falling short of achieving anticipated energy savings, due to lack of understanding of the social context in which energy-relevant behaviors and decisions take place (Bukarica and Tomšić, 2017). This in turn means that in spite of the history in evaluation and measurement research methods, existing evaluation frameworks and planning processes need to be enhanced to account for such aspects and rules of measurement that have been neglected in the past (Schlomann, 2014) .

1.1.1 Challenges in National EE policy planning

At a MS level, decarbonization efforts to achieve the Paris Agreement goals, have been ongoing, however progress toward their achievement is slow and more effort is needed to achieve the 2030 and 2050 EE and GHG reduction commitments. The most important tool to achieve the EE goals is the EU EE Directive (EED) (Directive 2012/27/EU), which came into force in December 2012 (CRES, 2017). The EED establishes a common framework of measures to increase MS efforts to use energy more efficiently. It requires MSs to report on their calculation methodology and sets firm additionality and materiality requirements for the design and operation of their EE obligation scheme and alternative measures (as determined in Article 7 of the EED). More specifically, Article 7 requires MSs to implement EE Obligations (EEOs) and/or alternative policy instruments to achieve savings in final energy use of 1.5% per year. It is anticipated to yield more than half of the required energy savings of the 2020 energy savings reduction target and is thus considered the most important element of the EED in terms of its target contribution (Rosenow et al., 2017).

Under Article 7, eligible (i.e. additional) savings can only be considered the ones exceeding existing performance standards and requirements such as the Eco-design and Labelling directive for products and appliances. For alternative measures, energy savings resultant from the effect of standards and norms in effect that target the energy performance of products or services in buildings or other sectors and which are mandatory under Union law, cannot be considered additional and thus be credited. Under the materiality criteria, savings from eligible measures that are the result of autonomous market or technological developments and rolling out of EU legislation are excluded (Labanca and Bertoldi, 2016). In November 2016 the Commission proposed an update to the EED, which is guided by the EE first principle[1] and introduced a new EE target for 2030 as well as measures to update the Directive to make sure the new target is met. The EE first principle has recently gained traction at the EU level, when on June 2018 an agreement was reached leading to a new, non-binding, EU EE target until 2030 of 32.5%, with an upwards revision clause by 2023. It was also agreed that the annual energy saving obligation under Article 7 of the EED will extend beyond 2020, delivering new energy savings in the next 2021-2030 period and beyond. This is included in the Clean Energy for All Europeans which puts forward a view of the EE first within the European Energy Union.

In the EC 2017 report to the European Parliament and the Council of MS progress to 2020, the EC noted that "Article 7 is a key energy saving measure of the EED and contributes to the EU EE target" noting that "some countries have put in place ambitious EE measures that deliver significant savings over the first few years of the obligation period, while a number of MS will need to increase their efforts if they want to meet their savings requirements due by the end of 2020. The EC further stressed the need that: "the policies and measures proposed in the 2017 National EE Action Plans (NEEAPs) are implemented effectively". In this context it is evident that to achieve the 2030 and interim targets, effective EE policies need to be implemented consistently across MS.

The abovementioned constantly increasing monitoring and verification requirements under the EED, increase the challenges faced by the majority of MS countries to meet with the higher energy savings target and under stricter eligibility, materiality and additionality pre-requisites. Having said that, the EE related budgets available across MS countries are often limited and mismanaged by public authorities, usually targeting more politically rewarding sectors yet with lower value energy savings(Amon and Holmes, 2016) . The Commission has also pointed out to the need to better understand the energy savings impact that is attributed to the use of MS' government spending under Article 7 (Europe Economics 2016).

When accounting for budgetary constraints, divergent interests and legal obligations, decision makers at the MS level, face major difficulties in the process of finding suitable and reliable solutions to save energy and reduce GHG emissions to meet with anticipated targets. The challenge not only relates to finding eligible energy conservation technologies, but is also relevant to energy management and strategic policy planning practices at urban and building infrastructures to avoid intensive energy needs (Haydt et al., 2014). The EU Green Paper on EE suggests that policy instruments[2] (PI) is a consistent way to promote and establish EE measures (EEMs) as part of EE plans (EC, 2005). To ensure that EEMs are adopted and deliver the anticipated energy savings, PIs and implementation procedures are established within the framework of NEEAPs. Most well-know and widely implemented PIs consist financial subsidies, minimum energy performance standards, building energy codes and

---

[1] The EE first principle prioritizes demand-side EE investments over supply-side investments, provided that they are more economical or deliver more value (Rosenow et al., 2016).

[2] Policy instruments are tangible means to achieve the overall objective that drives policy interventions (Hall, 1993). Other terms used in policy studies include programmes and policies or policy schemes (Spyridaki and Flamos, 2014), (Spyridaki et al., 2016b).

energy labelling (Haydt, 2011). According to the ODYSSEE-MURE DATABASE for EE the main types of EE PIs are the following (ODYSSEE-MURE, 2019):

- financial instruments including grants and subsidies, soft-loans and trading schemes
- fiscal instruments (i.e. taxes)
- regulatory instruments, i.e. performance standards and building regulations
- information such as voluntary labels or information campaigns for raising awareness
- voluntary/negotiated agreements

In reality, policy planning mainly uses non-standardized procedures, even if it is supported by a variety of scientific evidence and methodologies (De Marchi et al., 2016). Most national climate change mitigation plans and programmes are based on a portfolio approach which includes a mix of policy instruments, yet without a certain order or much consideration of complementarity or coherence (Casado-Asensio and Steurer, 2015). The same applies for EE action plans, for which the procedure for selecting among different PIs and EEMs is in general neither clearly defined nor transparent. Essentially the priorities and strategies for formulating and selecting EE PIs vary between stakeholders, influential over policy decision-making, and compete in multiple aspects. As a result of all aforementioned influences, PIs are often observed to yield different policy outcomes from those anticipated or they might produce a horde of unintended effects (Spyridaki et al., 2016a), (Fujiwara et al., 2017).

Besides the problem of selecting PIs, another issue is how to create an evidence base informative for effective policy instrument design. This relates to the choice of technical EE measures to operationalize the EE potential of a single PI. The problem of formulating PIs and selecting EE measures becomes even more complicated when considering the variety and specificities of the technical EE measures as well as the underlying mechanisms of PIs employed to promote them. Hence, it may be advisable to break the problem into two steps: the first on “the selection of implementation mechanism (e.g. PI)” and then “the selection of technical EEMs to materialize the savings potential of the selected PI” or vice-versa (Haydt et al., 2014). Practically, there might be some iterations between the two steps since the implementation of policy mechanisms may not go as planned impeding the adoption of EE technologies (i.e. EEMs) with great market and savings potential. Nevertheless, breaking the problem of EE policy planning in these stages is considered to add clarity as well as other benefits to the policy making and planning process.

1.1.2 Overview of EE policy evaluation practices

PIs are therefore the means to foster or oblige the energy-relevant behaviour and investment decisions of end-use consumers to meet desired policy targets and objectives. Policy target setting and (re-)design is also highly interlinked to the monitoring and evaluation steps of the policy cycle (see Figure 1). In view of higher energy savings target to be materialized under stricter eligibility, materiality and additionality pre-requisites there is a new for the introduction or re-design of policy instruments to meet these under the EED. Hence the necessity for regularly monitoring the progress towards target-achievement has become all the more essential (Schlomann et al., 2015).

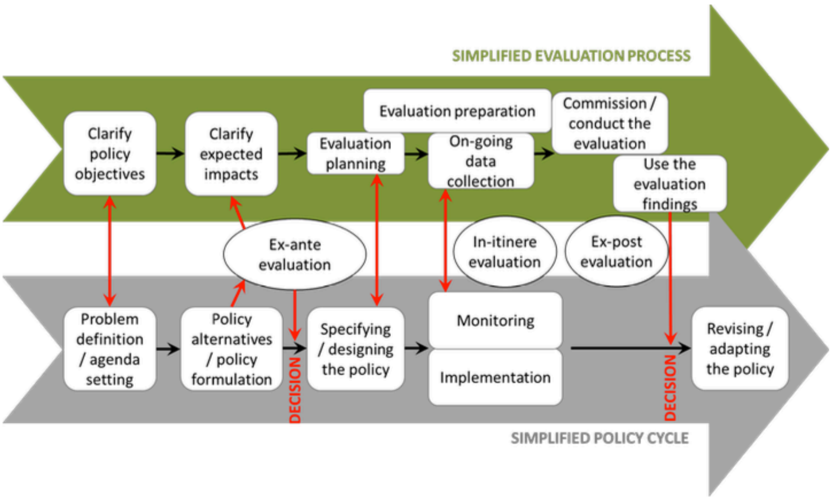


Figure 1.1 The policy cycle in parallel to the policy evaluation process. Source: (Broc et al., 2019)

A monitoring procedure is usually utilized first via the selection of evaluation indicators and the use of calibrated models. These procedures and evaluation approaches vary and are usually formed to serve the evaluation objective and according to the available evaluation means and resources (Schlomann, 2014). These can be broadly categorized into:

- ex post or ex-ante policy evaluations at the target or PI level
- top down evaluations based on aggregate data or bottom evaluations of individual EEMs and PIs.

Ex-ante evaluations primarily aim to facilitate policy design as well as PI selection (see Figure 1) (Broc and Cooremans, 2016), (Thomas et al., 2012), whereas ex post evaluations are important to evaluate the effectiveness of the PI itself and for planning or adapting the new PIs (Broc et al., 2018). All too often, these evaluation methods and reporting processes are combined to serve more than one evaluation objective. The Better Regulation toolbox of the EC suggests the following evaluation criteria as a good evaluation practice (EC, 2017):

1. Effectiveness: evaluating the effectiveness of a PI demonstrates the extent to which its intended or anticipated impacts are or have been attained. Effectiveness therefore refers to how successful a PI has been or will be in achieving or progressing towards the desired by the policy makers, targets. Underlying dimensions in the assessment of effectiveness entail the environmental performance, social effectiveness and economic opportunities and competitiveness that a PI can bring about (Spyridaki and Flamos, 2014).
2. Efficiency: The efficiency of a policy contemplates its desired or observed effects against its estimated or realized costs. Distinguishing among static and dynamic efficiency, we underline static efficiency as the ability of a PI of target achievement under the constraint of burden sharing across firms/plants/agents (Spyridaki and Flamos, 2014). In more general terms, efficiency relates the resources used by a policy intervention with the changes generated by that intervention.
3. Relevance: relevance explores the association between the needs and problems in society and the objectives of the PI or more broadly the policy intervention and hence includes issues relevant to its design.
4. Coherence: assessing coherence involves looking at a how well or not the mix of policy instruments performs altogether. It may highlight areas where there are synergies which improve overall performance or it may underline negative interactions e.g. contradictory targets, or procedural and implementation practices that are causing inefficiencies."

The difference between potential goal attainment and realized effectiveness lies in the causal role of policy rendering the meticulous evaluation of all the aforementioned evaluation criteria, as well as other intermediate evidence in the policy implementation stage essential. Yet these are rarely covered altogether by evaluations (Broc et al., 2019). In addition, when having to decide on the most appropriate new PI or the re-formulation of an existing one, decisions should be based primarily on insights about the causality and functionality of the instrument. In the case of financial support policies, where the efficient allocation of funding becomes crucial, these aspects should regularly be revised. In other words, determining whether a PI, can achieve its intended effects, becomes a pre-condition before addressing the overall performance of the policy or policy mix.

The potential policy outcome may also differ widely depending on the occurrence or lack of favourable or impeding factors. Explanatory factors behind the impact of a PI can result from: (i) broader contextual factors related to the economic, political and social context as well as (ii) the implementation procedure of a PI within a policy mix (Spyridaki and Flamos, 2014). Policy underperformance or unintended policy outcomes can thus be associated with various reasons, including assumptions embedded in policy design about the causality of policies in relation to their outcomes, as well as unexpected implementation and market barriers. Hence best-intended PIs may fail if process-wise they are poorly designed and implemented (Spyridaki et al., 2016b), (Spyridaki et al., 2016c). Recent evidence of EU wide EE policy evaluations also suggest that evaluation has to be done in all phases of policy lifecycle: ex-ante, during the effective life of the policy and ex-post (Broc et al., 2018). The need to focus on specific stages of the policy cycle when evaluating policy mechanisms has similarly been cited by several policy evaluation studies as well as "the need to look beyond the traditional goal-achievement model" and to fine tune the performance criteria in accordance to the context (Spyridaki et al., 2016b). An evaluation might aim to capture what has been achieved while also estimating future potential. EE Potential studies are most frequently conducted with an aim to support the uptake of EEMs and investment programmes. Either introduced by local or regional governments or conducted by energy providers and utilities, they provide quantitative evidence that EE investments can yield economic and/or ancillary non-energy benefits for the society as well as for government and private institutions (EPA, 2007). In other words EE potential studies aim to inform the main parameters, funding rates as well as the establishment of energy conservation targets for EE programmes and have contributed to recognizing cost-effective EEMs and programmes, which utilities and governments should promote and implement to achieve the mid-to long term savings and net benefit targets (Kramer and Reed, 2012). These can be categorized into the following main types:

- Technical potential evaluations assess the energy savings that could be reached based on the current or projected market availability of technologies over the timeframe under assessment.
- Economic potential studies limit the technical potential to measures and programmes that could be utilized and implemented cost-effectively over the same time frame. This mainly includes applying benefit/cost tests to assess the CE of measures to determine the ones that are economically viable to implement.
- Achievable or Programme potential assessments further limits the economically viable potential by asking what level of these savings could realistically be achieved, when accounting for the market failures and practical constraints that must be addressed to incentivize consumers to participate in EE programmes and adopt EEMs. These consist of EE savings that can potentially be achieved through specific incentive levels, program interventions or the adoption of increasingly stringent codes and standards.

The methodology used in these studies is to derive each successive level of EE potential as a subset of the previous level. Programme potential are thus usually determined as a subset of economic potential and consist the final output of the potential studies that are then used to inform goal-setting processes. Recent potential studies have added another subset of the market potential, the so-called "stranded potential" to capture the opportunities for EE that have not been attained historically by rebate programmes or codes and regulations. These reflect below-code or non-eligible savings for which no incentives exist for costumers to renovate their equipment given existing programme eligibility requirements and criteria (Navigant 2017), (EPA, 2007). More recently this strand of the achievable EE potential has been termed as "societal potential", denoting to the EE investments that have consistently been observed to lag behind the EE levels that are considered both achievable and economical to attain by EE PIs (Bukarica and Tomšić, 2017).

The number of achievable potential assessments is observed to be growing, since their results reflect more realistically what might occur within the framework of a certain context (e.g. market), due to the allocation of funding which can be insightful for EE planning purposes of public-support programmes or utility integrated EE plans. The design and scope of EE policy evaluations has in turn been largely driven by the need to improve the effective implementation of PIs to bring about the anticipated EE investments. This has led to growing attention by EE policy evaluations on exploring the national and regional effects of EEMs and PIs across economic sectors. Sequentially, the need to assess the potential "reach" of alternative EE PIs and determine their total national results has and continues to draw the focus of EE policy evaluations (Wade and Eyre, 2015), (Mundaca et al., 2010).

The policy "reach" has also been termed as "policy additionality" or "policy attribution" by numerous general as well as EE policy evaluation studies (Labanca and Bertoldi, 2016), (Rosenow et al., 2015), (Haug et al., 2010), (EEA, 2016), (Mundaca et al., 2010), (Ehrhardt-martinez and Laitner, 2010). The terms "**net effects**" is also used alternatively to "**additionality**" especially when the evaluation is set on the individual programme or PI level (Broc et al., 2018). It consists an 'ascription of a causal link between observed (or expected to be observed) changes and a specific intervention [...] taking account of other interventions, (anticipated or unanticipated) confounding factors, or external shocks' (OECD, 2010). Higher-level policy objectives may also require determining additionality as the policy outcomes that would be supplementary to other existing PIs or programmes in place. This is the case for the EED, that defines additional energy savings as the amount of savings that are realized as additional to the effects of the other EU legislation and regulations for EE. When the evaluation or analysis is conducted at a higher aggregate level, then policy additionality is not equivalent to policy net effects, as required by the EED (Broc et al., 2018).

Policy attribution or additionality becomes more complicated, the more policy-related (or other) factors intervene in the cause-effect relationship underpinning policy interventions. And the more interactions exist among such factors, the more difficult it is to credit the observed or anticipated changes to policy instruments. The challenges related to multiple factors and their interactions often impede the establishment of a baseline emissions scenario before the policy is initiated. In turn this constrains the construction of the counter-factual, i.e. what would have happened in the absence of a PI. A common but persistent difficulty also relates to the lack of quantitative data on savings effects and on other non-policy related factors which may influence the observed effects. Their availability usually relates to the lack of monitoring obligations and procedures which have only recently been established.

Besides these operational issues, there is also the analytical problem of attribution (Haug et al., 2010). The GHG emissions trajectory is constantly affected by a wide range of economic, technical and other factors. Examples of these factors include demographic trends, economic development, the energy intensity of different economic sectors and the fossil fuel share in the energy mix among others. Decomposition analysis can determine the relative effect of a pre-defined set of factors on GHG emissions (EEA, 2016). However the causal link between expected or observed changes in emissions to the multitude of policies directly and indirectly targeting their reduction remains a challenge (Boudet et al., 2016). The contribution of individual PIs, that is the additionality of the effect of a PI on an observed or anticipated change in emissions, has to be determined through bottom up evaluation indicators and approaches.

In essence, additionality relates to the determination of a baseline, against which additional energy savings being can be defined. The baseline can for instance be defined by comparing the energy consumption before and after a technology or policy intervention or the energy savings that may be the result of the installation of the technology in relation to a default technology in the market (Thomas et al., 2012). The method as well as the data and resources available usually determine the result of the policy additionality assessment. According to (Broc et al., 2018), two types of baselines are usually defined leading to different results on policy additionality:

(i) Technology baseline is considered the situation before implementing an EEM or technology, with no additional adjustment being considered. This approach leads the so-called gross energy savings estimated as additional effects.
(ii) Policy baseline is considered equivalent to a counterfactual scenario which represents the situation in the absence of the policy intervention. An assessment against the no-policy baseline can result to the net-savings estimates.

Assessing net energy savings becomes crucial to determine whether a PI has been successfully or whether it will reach its potential, especially when it comes to the efficiency of the PI. Determining the additional savings effects can essentially indicate whether the budget or resources spent on the PI have an impact on energy savings reduction or essential re-design and planning needs to take place to make better use of such resources. The evaluation of net savings has long been the central focus financial support programmes in the U.S.A so as to scrutinize the use of public budgets and legitimize the continuation of such programmes (Blasnik et al., 2014; Tonn and Hendrick, 2011). The evaluation of net energy savings is therefore fundamental and relies on a series of determinants such as data collection, stakeholder, experts' willingness to participate, as well as analytical and calculation methodologies with regards to baseline determination, consideration of adjustment effects and much required transparency in the evaluation assumptions (Broc et al., 2018).

Monitoring and evaluation procedures are increasingly being introduced and established at a PI level. At the EU level monitoring and evaluation requirements are gradually being developed to support the introduction of revolving national or EE funds and EEOs (Schlomann, 2014). These aim to improve the data collection and verification processes of such schemes as well as to improve their design and update the list of eligible actions and verify the realized energy savings (Broc et al., 2019). The EC H2020 EPATEE project has recently turned EU-wide attention to the status of EE policy evaluation, summarizing main challenges as well as best practices across EU EE policy makers and evaluators (Maric et al., 2018). The main difficulties that were underlined to pertain to EE policy evaluations were grouped into: lack of resources or time for early planning, methodological difficulties relevant to the evaluation objective (e.g. difficulty in determining policy additionality) and concerns over criticism. The large extent of resources required to conduct a policy evaluation was repeatedly highlighted along with the fact that policy evaluations is often prioritized for PIs that were formulated to have direct impacts and which often demand large public budgets (i.e. financial incentives to install EE solutions). Systematic evaluation requirements were reported to exist in only a few EU countries such the UK, Germany and Sweden and even so these concerned mostly ex-ante evaluations or impact assessments (Broc et al., 2018). This in turn leads to lack of quantitative data and restrains evidence-based policy analysis which is a prerequisite to single out effective from ineffective EE policies.

1.1.3 The case of financial support EE policies

Another significant change in EE policy design across EU countries, has been a shift towards incentives to support EE investments at the household level. Most policy interventions have thus focused on technological innovations to reduce the energy consumption of energy services provided in households and improve their energy performance. Therefore, the adoption of EEMs by residential end-users plays a key role in improving energy utilization and achieving the increasing energy savings target and obligations. Since individual householders are being incentivized to invest in EE through a financial return, it becomes increasingly important to assess the variety in the effectiveness of PIs and EEMs among different households instead of approximating an average overall effect. The need of understanding and predicting technology-relevant behaviour of residential end-users, including aspects relevant to technology ownership and adoption, holds significant implications for assessing the cost-effectiveness (CE) of policy interventions offering financial support (Boudet et al., 2016; Li and Just, 2018). This becomes even more urgent in light of the eminent transition in the European building sector from a centralized, fossil fuel-based and highly-energy-consuming system towards one that is more efficient, decentralized, and consumer-focused through the use of smart-home solutions (Shannon Bouton et al., 2010; Siano, 2014; Stragier et al., 2010). To this end, a marketing strategy promoting the adoption of new technologies should target the segments of consumers who will be more inclined to invest and use these technologies (Dua et al., 2016). From a policy perspective, policies and practices promoting new technologies risk of being ineffective or unsustainable, if they do not consider the relative characteristics of potential adopters in the market, along with their needs and preferences (Nikas et al., 2018; Papadelis et al., 2016). In fact, evaluation studies in the field confirm that variation exists in the effectiveness of PIs supporting EE investments at the household sector, however not much is being said about the determinants of this variation, nor are these usually incorporated in ex-ante EE policy evaluations. It is also noted that there are very few studies in the recent peer- reviewed literature evaluating low-income programmes, which do not provide an overall impression of the potential effects for this type of PIs (Wade and Eyre, 2015).

Financial support programmes, including low-income policies, have consistently formed a significant element of many governments' EE PIs, especially the ones targeting EE retrofits at the household sectors. These incentives have traditionally been provided by governments and in some EU countries by energy utilities under EEOs. Nevertheless, most of the peer-review literature focused on evaluating the cost and benefits of financial support PIs has thus been concentrated in the US, which is by large owning to the fact that monitoring requirements for this type of information and data to be collected were in place. Such requirements or policy evaluation practices are scarce in Europe even for PIs that demand large amounts of the public budget such as financial instruments. Likewise, EE potential assessments have mostly been developed and applied by programme implementers, both from the side of the government as well as from the side of utilities throughout the United States (US). The lack of this type of evaluation especially with regard to capital-intensive policy interventions may have and continue to undermine their effective and efficient implementation. In fact, a review from the International Energy Agency on financial policies promoting EE deducts that the number of thorough evaluations of financial PIs supporting the uptake of EE renovations is very limited which further restrains a benefit-to-cost ratio comparison (Broc et al., 2019).

1.1.4 The need for decision support in EE policy instrument planning

These sections have shown that in spite of the long history in the EE policy evaluation research and in view of the increasing monitoring, verification and evaluation requirements, there is a need for more realistic and transparent evaluation frameworks at the PI level, to guide and support their more pragmatic design and implementation towards target achievement. Existing evaluation frameworks and planning processes at the PI level thus need to be enhanced to account for aspects and rules of measurement that have been neglected in the past which have been identified to include:

(i) the need to focus on different stages of the policy cycle,

(ii) the need to better understand the additional effect that can be attributed to EE PIs, by considering the influence of the social context of EE related decisions and

(iii) the need to incorporate such evidence on policy additionality in ex-ante PI evaluation frameworks, under resource and data-availability constraints.

In the absence of such improvements the achievement of EE targets can be jeopardized both at the PI and national level.

1.2 Scope and objective of the thesis

The aforementioned research gaps appear to be quite complementary. On the one hand, the literature on multi-criteria EE policy evaluations has developed a variety of decision-support frameworks, yet these are rarely focused at the PI level and has not yet provided a Multi-Criteria Analysis (MCA) evaluation framework focusing on the implementation stage of the policy cycle. On the other hand, empirical EE policy evaluation research has long been concerned with the question of determining the additional effect that can be attributed to EE PIs. Nevertheless, most contributions have failed to adequately assess the exogenous policy effect while accounting for the influence of behavioural and societal aspects on EE related decisions. Less attention has also been drawn to the variation of the observed policy effects due to the greater heterogeneity of target groups (i.e. different income-level households). Finally, while the number of EE achievable potential assessments is growing, very few assessment frameworks have been developed under resource and data-availability constraints, which usually restrain policy makers, while including behavioural and social realism aspects in their estimates for potential energy savings.

1.3 Research questions & outline

The analysis of the previous chapter has led to a series of requirements as well as current needs for improving EE policy planning and evaluation practices to support the formulation of effective EE PIs. The research questions for this thesis were stemmed from the identified needs as laid out in the previous sections. The main research question that this thesis is focused on is:

- How can the policy planning and design of effective EE PIs be improved by evidence-based evaluation frameworks and practices?

To answer the overall research question this thesis comprises of four stand-alone research-chapters (i.e. Chapters 2, 3, 4 and 5), each of which contribute to the identified needs outlined above. These improve existing evaluation methods and practices in different ways and aim to support the policy decision-making process at different stages of the policy cycle of EE PIs, as demonstrated in Figure 1.2. First, we focus on the decision-making problem of comparatively evaluating and ranking policy mechanisms, as well as the need to monitor and evaluate these at different stages in their policy cycle in order to collect evidence, which will allow us to make an informed assessment and re-design. These issues are linked to the evaluation objectives and criteria used to make more informed judgments on policy instrument (re-)design and selection. It is also required that these move away from the traditional target model and include additional crucial aspects, such as coherence in implementation processes and consistency within the existing policy mix (EC, 2017) that pertain to their effective implementation. Therefore, the problem of PI re-design can be seen as a problem with multiple objectives to satisfy instead of just a fixed target in energy savings. In essence the first evaluation part is concerned with providing information on the functioning of the policies by providing answers to the question “what works and why”.

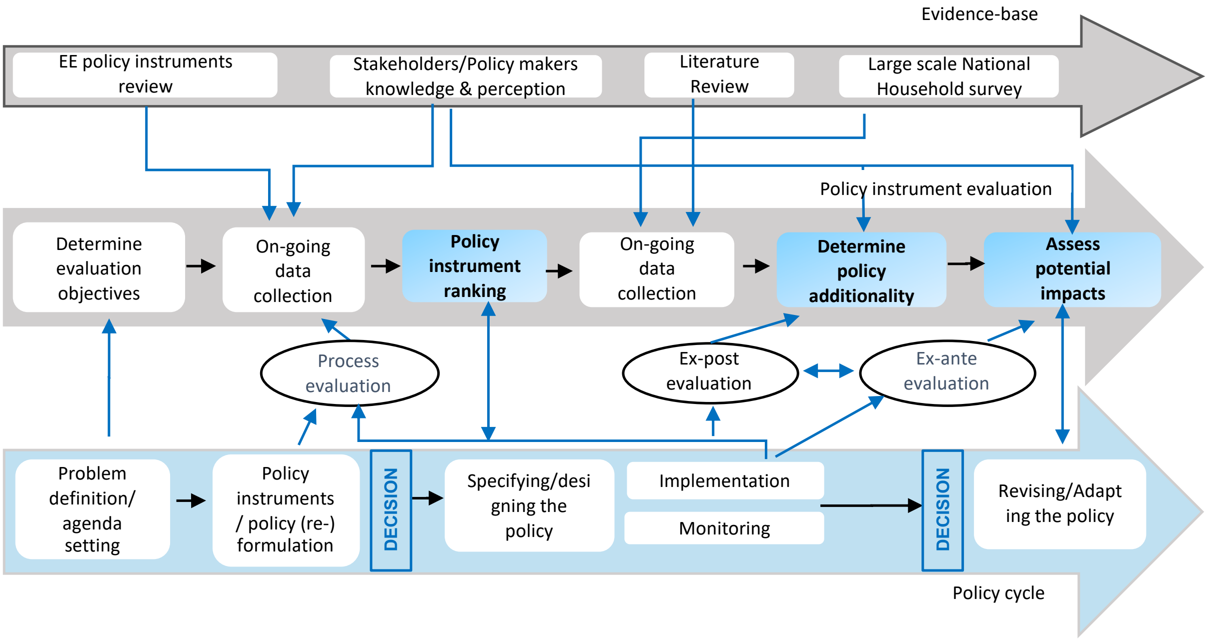


Figure 1.2 Conceptual framework and evaluation parts (i.e. process, ex-post and ex-ante evaluation) of the thesis. Adapted from (Broc et al., 2019), (EEA, 2016)

In turn, as we have highlighted in the previous sections, it is often not straightforward to identify let alone materialize, for a selected PI, the realistic EE potential that exists in different sectors of the economy (Zachariadis, et al. 2018). Behavioural and societal aspects of EE related decisions, need to pragmatically be considered, which further points out to the evidence that needs to be collected to adequately support the decision making process of formulating or adapting more effective PIs (see Figure 1.2). The evaluation attempt gets even more difficult under resource constraints and lack of quantitative data which impede the evidence base required to conduct such an assessment. In the second evaluation part we thus move from the policy learning stage to the policy delivery stage where we have identified the need to better understand the additional outcome that can be attributed to the selected PI from the previous step (i.e. financial subsidies), while accounting for the influence of behavioural and societal aspects of EE related decisions. The need to focus on financial subsidies was also justified from the fact that financial support programmes, including low-income policies, have consistently formed a significant element of many governments’ EE PIs, especially the ones targeting EE retrofits at the household sector. Yet the number of thorough evaluations of financial PIs supporting the uptake of EE renovations is very limited which undermines their cost-effective design and implementation (Broc et al., 2019). Hence, out of the multitude of PIs for EE, we focus on financial subsidies and aim to determine the additional outcome that these may bring about. Once the additional policy outcome (i.e. that can be attributed to financial subsidies) has been determined and quantified, we go on in the third and final evaluation part, where we translate the additional policy outcome to the achievable energy savings potential (i.e. additional policy impact).

Following the rationale described above, the four research chapters comprise an overall methodological framework that evaluates EE PIs at different stages in their policy cycle (i.e. during, ex-post and ex-ante) and explicitly accounts for social and behavioural barriers when estimating their future energy savings potential. Figure 1.3 depicts the flow chart of the proposed methodological approach.

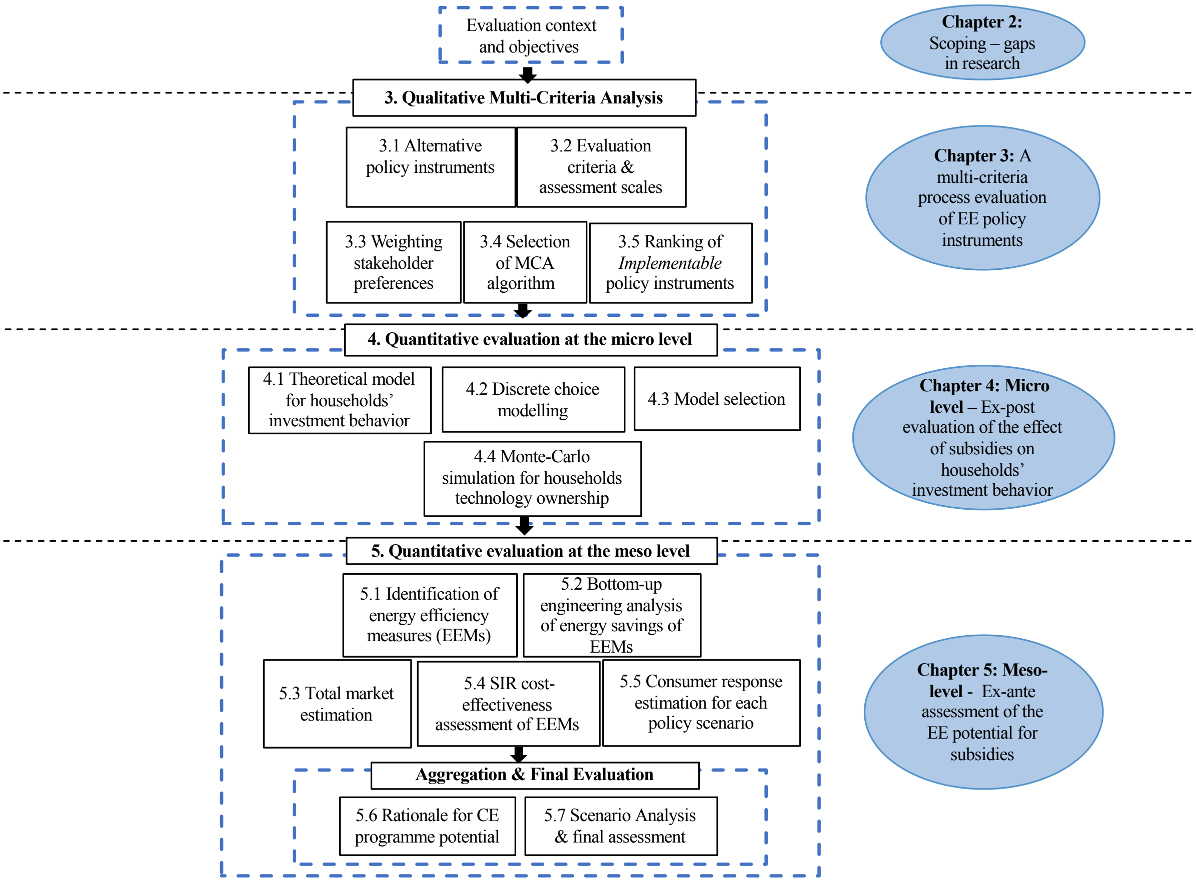


Figure 1.3 Flow-chart and steps in the proposed methodological evaluation framework of EE PIs

To answer the overall research question, we define several sub-questions. Each of these refer to the aforementioned evaluation contributions presented in Figure 1.3 and are dealt with in one or more of the following research chapters.

The following sub questions are defined:

1. How to evaluate energy PIs or PI mixes at different stages in their policy cycle?

2. How can the perspective of different actors and target groups be considered in the policy evaluation process to support the policy planning and decision-making?

3. Which key factors should be considered when designing effective EE PIs?

4. How to assess and quantify the effects that can be attributed to EE PIs, while accounting for non policy determinants and consumer heterogeneity?

5. What are the net effects that can be attributed to financial subsidies and how can these support the process of policy planning & (re-)design?

Each of the four research chapters comprising this thesis attempt to tackle more than one specific research question. The content of these research questions is discussed in more detail below in line with the respective research chapters of this thesis where they are dealt with.

1. How to evaluate energy PIs or PI mixes at different stages in their policy cycle?

In the previous section we have briefly discussed that there is a set of different ex-post and ex-ante evaluation methods which are utilized to evaluate EE PIs or policy mixes. Each of these methods has its benefits and limitations. In **Chapter 2**: Literature review: Evaluation approaches in energy & climate policy instruments and their interactions we give an overview of these methods and discuss the advantages as well as drawbacks of using each type for method, in relation to their evaluation focus and overarching evaluation design when applied to evaluate EE policies of policy mixes. The analysis of these methods is also concerned with their principal evaluation criteria that are used by these methods which not only indicates their evaluation objectives but also suggests at which stages in the policy cycle these methods turn their focus on.

In **Chapter 3**: A multi-criteria process evaluation of EE policy instruments we apply these considerations on which policy areas have been overlooked by existing EE policy assessments, to evaluate the main EE PIs applied in the building sector (e.g. Financial support measures, Voluntary Agreements, Building Codes, Energy Performance Certificates, Energy Performance Contracting etc.) by focusing on their implementation stage of their policy cycle. We present an ex-ante multi-criteria assessment framework that evaluates and ranks public policy mechanisms (i.e. PIs) based on stakeholders' understanding and perceptions of their functionality (see Figure 1.3). In the proposed framework, PIs are evaluated against process-related criteria, such as implementation costs, distributional effects, and coherence of policy processes, so as to highlight successful policy practices during their implementation phase as well as to unveil cases of policy under-performance or unintended policy outcomes. The objective is to shed light on the implementation of currently employed policy mechanisms that aim to achieve the 2020 energy savings targets and beyond, providing useful information to policy makers for future policy (re-)formulations. The ex-ante MCA assessment framework is then applied to evaluate public policy mechanisms promoting EE in the Greek building sector.

2. How can the perspective of different actors and target groups be considered in the policy evaluation process to support the policy planning and decision-making?

EE PIs are fundamental parts of broader EE action plans and are thus key elements of a broader strategy to accelerate emissions reductions as well as to achieve other ancillary objectives such as to improve energy security, or competitiveness, fuel poverty alleviation, employment, environmental and social benefits. Therefore the process of comparing and ranking EE PIs to be included in an EE action plan can be viewed as a multi-criteria problem (Spyridaki et al., 2016b), (Neves et al., 2008). At the same time the perspectives of different stakeholders as well as targeted actors, with regards to the route towards achieving these objectives is considered crucial for the efficient design and implementation of EE PIs. This research question is explored throughout our methodological framework. In Chapter 3: A multi-criteria process evaluation of EE policy instruments, a multi-criteria evaluation framework for assessing and ranking EE PIs is presented which incorporates actual preferences of decision-makers in the analysis. For this type of analysis, we rely on a stakeholder survey conducted among experts and policy makers in the field. In Chapter 4: An ex-post evaluation of the effect of EE financial subsidies, we take a deeper look at the one of the most important target groups of financial subsidies for EE, residential end-users to get more insights into the social and behavioural aspects relevant to targeted policy outcomes of EE investment decisions. We develop a theoretical model on factors driving technology ownership of various EEMs in the Greek household sector. We test this model empirically with more than 1500 observations from a recent on a National Household survey in Greece. We then use the empirical model to simulate the additional effect of financial subsidies on technology adoption trends for different income levels. The results and insights then are discussed to suggest ways for more targeted and effective programme design.

In Chapter 5 of this thesis we make use of the information from the National Household survey as well as additional evaluation studies from the literature to estimate programme participation rates for alternative financial subsidy scenarios which correspond to different income eligibility categories. We combine these estimates with a bottom up trend analysis to calculate the savings potential that can be pragmatically tapped by different subsidy rates in the household sector and for alternative EEMs (see

Figure 1.3). This approach allowed us to include a behavioural realism aspect to our estimates of potential savings for EEMs promoted through financial subsidies which is usually not included in engineering or techno-economic assessments (Ehrhardt-martinez and Laitner, 2010). The view from policy makers is embedded in this step in the form of support for the data-collection process best reflecting the past as well as the future implementation of PIs and in the form of external validation of the key outputs from the assessment framework.

3. Which key factors should be considered when designing effective EE PIs?

As highlighted in the previous sections, policy underperformance or unintended policy outcomes can be explained by a variety of external influences such as unexpected implementation hurdles, market barriers and the social context. This research question refers to key issues concerning the design and evaluation of EE PIs and for this reason is analyzed from different perspectives and is dealt in all evaluation components of our proposed framework. In Chapter 3: A multi-criteria process evaluation of EE policy instruments, we present an evaluation MCA framework, through which PIs can be evaluated against process-related criteria, such as implementation costs, distributional effects, and coherence of policy processes, so as to highlight successful policy practices during their implementation phase as well as to unveil cases of policy under- performance or unintended policy outcomes. In Chapter 4: An ex-post evaluation of the effect of EE financial subsidies, we recognize that EE PIs, all the more financial support PIs, promoting the adoption of energy savings technologies risk of being ineffective or unsustainable, should they do not consider the relative characteristics of potential adopters in the market, along with their needs and preferences. We thus introduce a theoretical model for predicting the technology-relevant behavior for residential end-users which accounts for a variety of contextual factors, such as dwelling demographics, socio-economics characteristics, householders' attitudes and behavior etc., alongside the influence of financial support policies. We test this model empirically to more than 1500 observations from a recent on a National Household survey in Greece, to get an estimate of the incremental effect of financial subsidies in the adoption of a variety of EE measures while accounting for the influence of aforementioned factors in driving the observed technology ownership rates. In Chapter 5, we apply the insights and evidence from analyzing the National Household survey data to estimate the long-term EE potential for financial subsidies while accounting for consumer preferences and technical as well as feasibility constraints for the different technologies realizing this potential.

4. How to assess and quantify the effects that can be attributed to EE PIs, while accounting for non-policy determinants and consumer heterogeneity?

This sub-question is similar to the previous one, but it turns the focus from the types of determinants and their influence on policy effects back to the methods applied to capture these within a policy evaluation framework. Additionality has been the focus of many researchers and policy practitioners in the field, yet it remains a very challenging issue. In Chapter 4: An ex-post evaluation of the effect of EE financial subsidies, we discuss econometric studies that have been applied in a variety of datasets to determine the additional effects for such PIs on the household sector and highlight the advantages and problems of these methods in determining the additional effect of policy interventions. Then we demonstrate a way to assess the additional effect of financial subsidies on households' technology ownership for EEMs by applying a discrete choice econometric model. The model is formulated appropriately so that the effect of the variable in question (i.e. the policy determinant) is treated as an explanatory factor among others influential over technology ownership. The empirical model is then applied to conduct Monte-Carlo simulations for different scenario formulations (i.e. with or without the policy) to further explore the additional effect of the policy and for different income level households. In Chapter 5, we focus on ex-ante assessment frameworks and present an overview of methodological approaches to quantify the additional EE savings that can be attained by EE PIs. In efficiency potential studies, the technologies market share is often calculated as a function of the payback time, benefit to cost ratio or other CE metric (e.g. levelized measure cost) of the efficient technology relative to the inefficient technology. Although such evaluation methods include considerable limitations, they are directionally reasonable and straightforward enough to allow estimating of the market share for the multitude of technologies that are assessed in efficiency potential assessments (Navigant, 2017). Then we present a bottom-up economic-engineering framework for assessing and quantifying the long-term programme savings potential for a financial subsidy. It focuses on the direct and indirect price effect that a financial subsidy may bring about on efficient technologies in the market, which can affect the diffusion of energy-efficient technologies and their CE in the long-run. The proposed framework: (i) enables the attribution of energy savings to EEMS for which a direct link can be established between the causality mechanism of financial subsidies (i.e. cost reduction) on the acting decision (i.e. technology adoption) and (ii) allows the inclusion of empirical observations to increase transparency and validity in the evaluation results.

5. What are the net effects that can be attributed to financial subsidies and how can these support the process of policy planning & (re-)design?

Policy makers and practitioners recognize EE potential assessment and policy evaluation in general as tools to optimize policy portfolios or to prioritize policy objectives and means to achieve them (i.e. PIs) (Broc et al., 2018). In Section 1.2 we have discussed that EE potential assessments facilitate the development of EE plans and are relevant especially for the (re-)design of single PIs promoting EE, as they can offer a realistic view of what might occur within a certain context due to a policy interventions and essentially due to the allocation of funding, which can be useful for EE planning purposes of public-support programmes or utility integrated EE plans.

In Chapter 4: An ex-post evaluation of the effect of EE financial subsidies we adopt a survey-based approach and conduct an ex-post evaluation for quantifying the additional policy outcomes (i.e. technology adoption) of financial subsidies, accounting for the diversification of these outcomes across EEMs and characteristics of target groups.

In Chapter 5: An ex-ante evaluation of the EE potential for financial subsidies, we use a bottom-up, economic engineering approach to calculate the achievable potential that can be attributed to alternative policy scenarios, characterized by alternative subsidy rates characterized by different participation rates. We have used the best available information describing the Greek household sector. Past sales data were used for each EE measure category to account for current market saturation, technical feasibility issues as well as future trends based on EU-wide databases, official market reports as well as national data and statistics when available. We then relied on past programme participation evidence to derive estimates on the share of sales that can be credited to the implementation of financial incentives offered to consumers in the Greek household sector. This allowed the quantification of energy savings that can potentially be achieved by alternative subsidy rates in view of the national target under Article 7 of the EED. Most importantly these are discussed within the frame of the EEO scheme, introduced in Greece under Article 7. Such market-driven incentives are thought to be more in line with the generation of markets for EE than regulatory or governmental-support measures.

1.4 Structure of dissertation thesis

The dissertation thesis consists of six (6) chapters, as depicted in Figure 1.4. More specifically, the content of each of the chapters is described in more detail below.

Chapter 1: It consists the present chapter of the dissertation thesis, in which the research problem is presented justifying for the need of developing an enhanced methodological evaluation framework at a policy instrument level that improves existing evaluation practices and supports policy decision-making during the stages of policy planning and re-design for EE PIs. The chapter concludes with the presentation of the thesis objective and the research questions that the work entailed in this thesis contributed to.

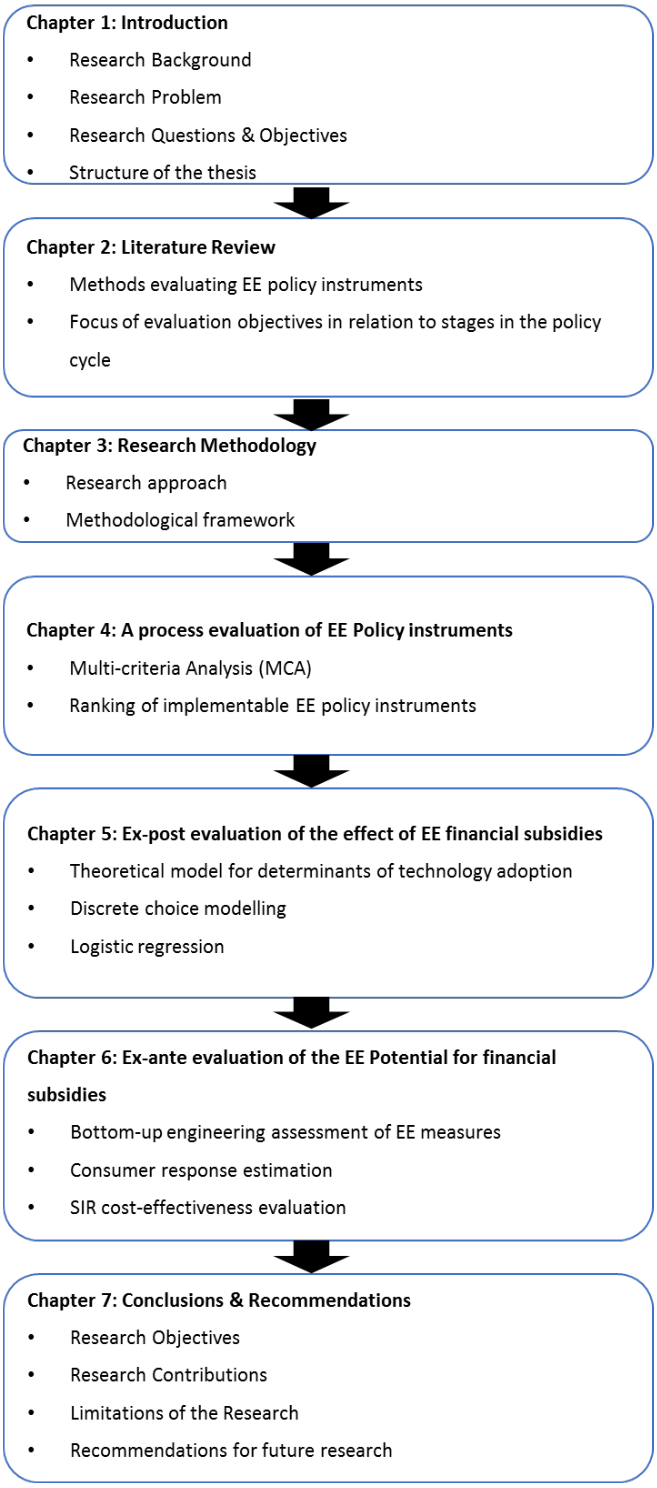
Chapter 2: In continuation to chapter1, considering the challenges identified as well as the need to develop enhanced evaluation practices and decision-support frameworks, in Chapter 2, we present the multitude of evaluation approaches that have been developed and which are used to assess energy PIs and policy mixes. Essentially, a review of the main research and academic studies in the field of energy policy evaluation is presented. The chapter concludes with the justification for the added-value and innovation of the proposed evaluation methodological framework in relation to addressing the research questions and problem identified.

Chapter 3: In Chapter 3: A multi-criteria process evaluation of EE policy instruments, we present the details of the first evaluation part of our proposed methodological framework that addresses the issue of policy instrument ranking and comparative assessment. We present the objective and the problem of ranking alternative policy instruments with regards to their ease of implementation. Next, we outline the methodological steps including: the determination of alternative PIs under assessment, the means for conducting the impact assessment, the elucidation of stakeholders' preferences, the MCA algorithm developed to utilize the assessment problem and finally the sensitivity analysis conducted to test the evaluation results. Finally, we apply the proposed evaluation framework for EE PIs focused on the Greek building sector and discuss the implications as well as recommendations steaming from our assessment.

Chapter 4: Chapter 4: An ex-post evaluation of the effect of EE financial subsidies concerns the development of an ex-post evaluation methodological framework for quantifying the additional policy outcomes (i.e. technology ownership) of financial subsidies, accounting for the diversification of these outcomes across EEMs and characteristics of target groups. This includes the development of the theoretical framework for technology ownership and adoption as well as the econometric approach formed to test the theoretical model empirically. The econometric model is then applied on the results from a national survey on Greek households.

Chapter 5 then, goes a step further and presents an ex-ante methodological approach for quantifying the additional savings potential for alternative subsidy scenarios, accounting for the direct policy effect, the indirect policy effect, as well as for the autonomous developments that would have happened in the absence of the subsidies. The results are analysed for a multitude of EEMs and an approach for determining the final portfolio of EEMs is developed. The assessment framework is then applied to determine the savings potential for financial subsidies in the Greek household sector.

Chapter 6: Finally, in the last chapter of this dissertation thesis, we present the methodological advances of the proposed step-wise methodological framework which steam from both the underpinnings of each evaluation step and methods applied, as well as from the evaluation results when applied to address the problem of EE PI planning and evaluation in the Greek national context. The Chapter concludes with a series of considerations on limitations of the proposed evaluation framework and most importantly on concrete suggestions for further research in the field of EE policy planning and evaluation at a policy instrument level.



Chapter 1: Introduction

- Research Background
- Research Problem
- Research Questions & Objectives
- Structure of the thesis

Chapter 2: Literature Review

- Methods evaluating EE policy instruments
- Focus of evaluation objectives in relation to stages in the policy cycle

Chapter 3: Research Methodology

- Research approach
- Methodological framework

Chapter 4: A process evaluation of EE Policy instruments

- Multi-criteria Analysis (MCA)
- Ranking of implementable EE policy instruments

Chapter 5: Ex-post evaluation of the effect of EE financial subsidies

- Theoretical model for determinants of technology adoption
- Discrete choice modelling
- Logistic regression

Chapter 6: Ex-ante evaluation of the EE Potential for financial subsidies

- Bottom-up engineering assessment of EE measures
- Consumer response estimation
- SIR cost-effectiveness evaluation

Chapter 7: Conclusions & Recommendations

- Research Objectives
- Research Contributions
- Limitations of the Research
- Recommendations for future research

Figure 1.4 Thesis Structure

References

Amon, A.D.A., Holmes, I., 2016. Energy Efficiency as Infrastructure: Leaping the Investment Gap.

Blasnik, M., Dalhoff, G., Pigg, S., Mendyk, A., Carroll, D., Ucar, F., 2014. National Weatherization Assistance Program Impact Evaluation: Energy Impacts for Single Family Homes.

Boudet, H.S., Flora, J.A., Armel, K.C., 2016. Clustering household energy-saving behaviours by behavioural attribute. Energy Policy 92, 444–454. https://doi.org/10.1016/j.enpol.2016.02.033

Broc, J.-S., Cooremans, C., 2016. What did we recently learn about the evaluation of energy efficiency policies and programmes? Insights from IEPPEC 2014 in Berlin. IEPPEC 2014 Berlin. Energy effi-ciency 9, 843. https://doi.org/10.1007/s12053-016-9457

Broc, J.-S., Oikonomou, V., Dragovic, M., 2019. Guidelines on how to integrate evaluation into the policy.

Broc, J.-S., Thenius, G., di Santo, D., Schlomann, B., Breitschopf, B., van der Meulen, J., van den Oosterkamp, P., Marić, L., Matosović, M., 2018. What can we learn from sharing experience about evaluation practices? Background and objectives of the EPATEE project, in: International Energy Policy & Programme Evaluation Conference. European Comission, Brussels.

Bukarica, V., Tomšić, Ž., 2017. Energy efficiency policy evaluation by moving from techno-economic towards whole society perspective on energy efficiency market. Renew. Sustain. Energy Rev. 70, 968–975. https://doi.org/10.1016/J.RSER.2016.12.002

Casado-Asensio, J., Steurer, R., 2015. Climate Policy Bookkeeping rather than climate policy making: national mitigation strategies in Western Europe Bookkeeping rather than climate policy making: national mitigation strategies in Western Europe. https://doi.org/10.1080/14693062.2014.980211

CRES, 2017. ΠΡΟΣΔΙΟΡΙΣΜΟΣ ΤΗΣ ΕΞΟΙΚΟΝΟΜΗΣΗΣ ΕΝΕΡΓΕΙΑΣ ΑΠΟ ΜΕΤΡΑ ΒΕΛΤΙΩΣΗΣ ΤΗΣ ΕΝΕΡΓΕΙΑΚΗΣ ΑΠΟΔΟΣΗΣ ΣΤΟ ΠΛΑΙΣΙΟ ΤΟΥ ΚΑΘΕΣΤΩΤΟΣ ΕΠΙΒΟΛΗΣ ΤΗΣ ΥΠΟΧΡΕΩΣΗΣ ΕΝΕΡΓΕΙΑΚΗΣ ΑΠΟΔΟΣΗ. Centre for Renewable Energy Studies. Athens.

De Marchi, G., Lucertini, G., Tsoukiàs, A., 2016. From Evidence-Based Policy-Making to Policy Analytics. Anal. Ann. Oper. Res. 236. https://doi.org/10.1007/s10479

Dua, R., White, K., Lindland, R., 2016. Understanding Adoption of Technologies : A Case Study of Battery Electric Vehicle Adoption in the U . S .

EC, 2018. A Clean Planet for all A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy, European Comission. Brussels.

EC, 2017. The Better Regulation toolbox. Brussels.

EC, 2005. GREEN PAPER on Energy Efficiency or Doing More With Less. Brussels.

EEA, 2017. Trends and projections in Europe 2017.

EEA, 2016. Environment and climate policy evaluation.

Ehrhardt-martinez, K., Laitner, J.A. "Skip," 2010. People-Centered Initiatives for Increasing Energy Savings. Am. Counc. an Energy Effic. Econ. 202–507.

EPA, 2007. Guide for Conducting Energy Efficiency Potential Studies A RESOURCE OF THE NATIONAL ACTION PLAN FOR ENERGY EFFICIENCY.

Fujiwara, N., Williges, K., Tuerk, A., 2017. D6.3: Report on the knowledge gaps about key contextual factors.

Hall, P.A., 1993. Policy Paradigms, Social Learning, and the State: The Case of Economic Policymaking in.

Haug, C., Rayner, T., Jordan, A., Hildingsson, R., Stripple, J., Monni, S., Huitema, D., Massey, E., van Asselt, H., Berkhout, F., 2010. Navigating the dilemmas of climate policy in Europe: Evidence from policy evaluation studies. Clim. Change 101, 427–445. https://doi.org/10.1007/s10584-009-9682-3

Haydt, G., 2011. A multi-objective decision support methodology for developing national energy efficiency plans.

Haydt, G., Leal, V., Dias, L., 2014. A multi-objective approach for developing national energy efficiency plans. Energy Policy 67, 16–27. https://doi.org/10.1016/J.ENPOL.2013.06.133

IEA, 2014. World Energy Investment Outlook 2014 Special Report.

IEA, 2012. WORLD ENERGY OUTLOOK 2012 EXECUTIVE SUMMARY.

Kramer, C., Reed, C., 2012. Ten Pitfalls of Potential Studies.

Labanca, N., Bertoldi, P., 2016. Title: Energy Savings Calculation Methods under Article 7 of the Energy Efficiency Directive. https://doi.org/10.2790/855880

Li, J., Just, R.E., 2018. Modeling household energy consumption and adoption of energy efficient technology. Energy Econ. 72, 404–415. https://doi.org/10.1016/j.eneco.2018.04.019

Maric, L., Kojakovic, A., Bukarica, V., Matosovic, M., Broc, J.-S., 2018. Synthesis Report on Evaluation Practices Report on the synthesis between the knowledge base.

Mundaca, L., Neij, L., Worrell, E., Mcneil, M., 2010. Evaluating Energy Efficiency Policies with Energy-Economy Models ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY, LBNL NUMBER TIMES NEW ROMAN.

Navigant, 2017. Energy Efficiency Potential and Goals Study for 2018 and Beyond Final Public Report.

Neves, L.P., Martins, A.G., Antunes, C.H., Dias, L.C., 2008. A multi-criteria decision approach to sorting actions for promoting energy efficiency. Energy Policy 36, 2351–2363. https://doi.org/10.1016/J.ENPOL.2007.11.032

Nikas, A., Stavrakas, V., Arsenopoulos, A., Doukas, H., Antosiewicz, M., Witajewski-baltvilks, J., Flamos, A., 2018. Barriers to and consequences of a solar-based energy transition in Greece. Environ. Innov. Soc. Transitions 1–17. https://doi.org/10.1016/j.eist.2018.12.004

ODYSSEE-MURE, 2019. Energy Efficiency Trends & Policies | ODYSSEE-MURE [WWW Document]. EC. URL http://www.odyssee-mure.eu/ (accessed 5.12.19).

OECD, 2010. Glossary of Key Terms in Evaluation and Results Based Management.

Papadelis, S., Stavrakas, V., Flamos, A., 2016. What do capacity deployment rates tell us about the efficiency of electricity generation from renewable energy sources support measures in Greece? Energies 9. https://doi.org/10.3390/en9010038

Rosenow, J., Bayer, E., Rososińska, B., Genard, Q., Toporek, M., 2016. EFFICIENCY FIRST: FROM PRINCIPLE TO PRACTICE REAL WORLD EXAMPLES FROM ACROSS EUROPE.

Rosenow, J., Cowart, R., Bayer, E., Fabbri, M., 2017. Assessing the European Union's energy efficiency policy: Will the winter package deliver on 'Efficiency First'? Energy Res. Soc. Sci. 26, 72–79. https://doi.org/10.1016/J.ERSS.2017.01.022

Rosenow, J., Fawcett, T., Eyre, N., 2015. Energy efficiency and the policy mix 1–17. https://doi.org/10.1080/09613218.2016.1138803

Schlomann, B., 2014. Design of Effective Energy Efficiency Policies.

Schlomann, B., Rohde, C., Plötz, P., 2015. Dimensions of energy efficiency in a political context. Energy Effic. 8, 97–115. https://doi.org/10.1007/s12053-014-9280-8

Shannon Bouton, Creyts, J., Kiely, T., Livingston, J., Nauclér, T., 2010. Energy efficiency : A compelling global resource. McKinsey Sustain. Resour. Prod. 1–74.

Siano, P., 2014. Demand response and smart grids - A survey. Renew. Sustain. Energy Rev. 30, 461–478.

https://doi.org/10.1016/j.rser.2013.10.022

Spyridaki, N.-A., Banaka, S., Flamos, A., 2016a. Evaluating public policy instruments in the Greek building sector. Energy Policy 88, 528–543. https://doi.org/10.1016/J.ENPOL.2015.11.005

Spyridaki, N.-A., Banaka, S., Flamos, A., 2016b. Evaluating public policy instruments in the Greek building sector. Energy Policy 88, 528–543. https://doi.org/10.1016/J.ENPOL.2015.11.005

Spyridaki, N.-A., Flamos, A., 2014. A paper trail of evaluation approaches to energy and climate policy interactions. Renew. Sustain. Energy Rev. 40, 1090–1107. https://doi.org/10.1016/J.RSER.2014.08.001

Spyridaki, N.-A., Ioannou, A., Flamos, A., Oikonomou, V., 2016c. An ex-post assessment of the regulation on the energy performance of buildings in Greece and the Netherlands—a cross-country comparison. Energy Effic. 9, 261–279. https://doi.org/10.1007/s12053-015-9363-1

Stragier, J., Hauttekeete, L., Marez, L. De, 2010. Introducing smart grids in residential contexts : Consumers ' Perception of Smart Household Appliances Introducing Smart Grids in Residential Contexts : Consumers ' Perception of Smart Household Appliances 1–8. https://doi.org/10.1109/CITRES.2010.5619864

Thomas, S., Boonekamp, P., Vreuls, H., Broc, J.-S., Bosseboeuf, D., Lapillonne, B., Labanca, N., 2012. How to measure the overall energy savings linked to policies and energy services at the national level? Energy Effic. 5, 19–35. https://doi.org/10.1007/s12053-011-9122-x

Thomas, S., Rosenow, J., 2019. Energy consumption in Europe : why is it increasing and what are the policy implications ? ECEEE Summer Study Proceedings 2019, pp. 503–512.

Tonn, B., Hendrick, T., 2011. Evaluation of the National Weatherization Assistance Program during Program Years 2009-2011 (American Reinvestment and Recovery Act Period).

Wade, J., Eyre, N., 2015. Energy Efficiency Evaluation : The evidence for real energy savings from energy efficiency programmes in the household sector.

2. Chapter 2: Literature review: Evaluation approaches in energy & climate policy instruments and their interactions

Abstract

Focal point of this review is to provide a comparative display of methodologies employed for the appraisal of interacting energy and climate policies, underlying their key features while presenting the most critical issues and limitations not addressed so far. In doing so we classify them into the broad categories of qualitative, quantitative and hybrid. We find that qualitative design approaches contribute to the assessment of the diversity and complexity of policy interactions affecting the impacts of PIs to be assessed in relative terms, whereas modelling (i.e. quantitative) approaches provide absolute numbers and economic trends that affect them. Research analysis of energy and climate policy interactions is still young in comparison to the broad field of policy evaluation and impact assessment. Consequently, the sub-field of interacting PIs is largely organized around substantial concerns rather than methodologically oriented assemblies. However, infants inherently tend to grow. Endeavours for an improved methodological framework that would allow for a systematic exchange of data between qualitative and quantitative approaches and would also include the relevance of the context as well as key casual relationships behind policy combinations, would provide the basis for further growth of knowledge in the field.

2.1 Introduction

Researchers & policy makers face formidable obstacles in seeking to understand, let alone analyze, the impacts of environmental, economic and social features of energy and climate policies. It gets worse by adding inherent difficulties such as irreversibility, data scarcity and uncertainty, non-linear behavior and multiple (usually conflicting) objectives. To this respect an array of methodologies and tools are employed in an effort to incorporate as many underlying features of energy and climate PIs bound to affect the resulting outcomes, as well as hindering barriers. Literature provides a broad range of methodologically diverse techniques (e.g. case studies, survey research, statistical analysis, model building etc.) assessing mainly the operational effects of single energy and climate PIs, or parallel comparisons of those, for the most part, emissions trading schemes with taxes or additional instruments. (EmployRES, 2009, González,2009, Konidari and Mavrakis, 2007, Klessmann et al. 2011, Neij and Astrand, 2006, Oikonomou, 2011a,b, Rogge et al. 2011). However, policies always come in a mix (Fischer and Preonas, 2010) and therefore they would have to be assessed in that fashion. Recent studies are seeking to provide an integrated assessment of energy and climate policy interactions and they have applied a multitude of varying methodologies setting different focuses (IEA, 2011a, OECD, 2011, Hen et al. 2011). A number of reviews that have addressed research on interacting policies are mainly concerned with static and dynamic sustainability impacts of combined PIs upon a regulated market system and potential conflicts among findings (Fischer and Preonas, 2010, Gonzalez,2007, OECD, 2011, IEA, 2011a,b). Recent studies highlight the need for an improved methodological framework for ex-post and ex-ante assessment of energy and climate policy mixes in a realistic policy interactions environment (Boonekamp, 2006, De Jonghe et al. 2009, Levinson, 2010). Taking into consideration the above cited situation, within the framework of the EC FP7 project "Assessment of Policy Interrelationships and Impacts on Sustainability in Europe (APRAISE)"- grant agreement 283121, we explore recent representative paradigms of evaluation approaches and methodologies endeavoring to point out what has been left out and what needs to be done next in addressing the compound matter of energy and climate policy interactions.

In this regard, main scope of this article is to provide a unified framework for the comparison of employed approaches and to review recent energy and climate policy and economics literature on the interactions between PIs and their respective impacts, leaving out studies addressing or comparing single types of policies. Our focal point through this review is to provide a critical display of the evaluation approaches and methods developed and employed underlying their key features and characteristics while presenting the most critical issues not addressed so far. In doing so we prefer to classify those into the broad categories of qualitative, quantitative and hybrid evaluation approaches in an attempt to provide a comparative overview of their underlying dimensions.

The rest of this paper is structured as follows. A unified assessment framework is introduced in section 2.2 upon which the review is structured. Section 2.3 provides an analytical outline of evaluation approaches and different evaluation means (i.e. methods) in the area of energy and climate policy interaction evaluation. A cross comparison of the different approaches in conjunction to their methods and views on policy interactions is presented in Section 2.4. Section 2.5 examines those approaches with respect to their impact focus and identified explanatory factors behind their impacts. Finally, section 6 provides an overview of the underlying dimensions each approach brings forward in the evaluation of energy and climate policy interactions, leading to concluding remarks and directions for future research.

2.2 A unified assessment framework

Our scope is to present in parallel an overview of those approaches with their underlying methodological components in relation to their research focus, in an effort to identify principal issues not adequately addressed yet in policy interactions appraisal and impact assessment, instead of concentrating on the ensuing outcomes of research so far. Drawing upon Peter Hall's (1993) three-fold division of policy into elements we consider a policy to comprise the overall objective that drives policy interventions, the PIs by which these policy objectives3 are achieved and the design characteristics of these instruments that determine their functioning and implementation. Throughout the review we thus consider that policy interactions can take place at two basic levels.

- PI level: interactions effects can be identified at the level of PI goals and/or due to their specific policy design provisions (Hall, 1993, Urwin and Jordan, 2008). In other words, interaction of PIs may occur when the targets or design characteristics of a PI may affect the functioning or result of another PI.
- Market/Stakeholders level: PIs may interact due to stakeholders' response to their concurrent implementation, which is often driven by conflicting interests and objectives. (Oikonomou, 2012).

Throughout the review we have structured our research under the two main themes of:
(i) Different evaluation approaches and primary methods employed in relation to the aforementioned views on energy and climate policy interactions (i.e. interaction levels).
(ii) Impact focus, looking at what aspects of the performance of an integrated policy mix, has been assessed so far and to what extent, as well as which explanatory factors behind those impacts have been identified.

2.2.1 Impact focus of evaluation approaches

This section refers mainly to the objectives of each evaluation approach when seeking to identify the impacts of integrated policy mixes against a set of criteria, variables and primary factors, (e.g. evaluation criteria, target group, sectors addressed, and sustainability impacts).

The performance and interactions of PIs have been assessed against several criteria (Boonekamp, 2006, Konidari and Mavrakis, 2007, Oikonomou and Jepma, 2008). Departing from the empirical work conducted within INTERACT project (INTERACT, 2003) and previous research we define the three focal points of our review in an effort to clarify our evaluation framework regarding the impact focus of each research. Hence the points of reference in our review, regarding the impact focus of recent literature in the area of interacting policies, are the following three performance criteria:
- **Effectiveness:** Evaluating the effectiveness of a (set of) PI(s) demonstrates the extent to which its intended impacts were attained. Effectiveness therefore refers to attaining desired by the policy makers, targets. (Pablo del Rıo, 2010) Underlying dimensions in the assessment of effectiveness entail the environmental performance, social effectiveness and economic opportunities and competitiveness that a (set of) policy (instruments) can bring about.
- **Efficiency:** The efficiency of a policy or mix of PI(s), contemplates its desired effects against its estimated or realized costs. Distinguishing among static and dynamic efficiency, we underline static efficiency as the ability of a PI of target achievement under the constraint of burden sharing across firms/plants/agents. Dynamic efficiency refers to the ability of an instrument to generate a continuous incentive for technical improvements and costs reductions in technologies (Pablo del Rıo, 2010).
- **Efficacy** refers to the direct impact of policy cycle activities of one or a set of PIs compared to the baseline case (i.e. stand-alone PIs or no PIs at all). In other words, the efficacy of a (set of) PI(s) refers to its potential impact that was intended (and expected) by the policy makers involved in its design and initiating its implementation (Oikonomou, 2012).

---

[3] Throughout the review, for means of simplification we consider a policy objective to be translated into policy instrument targets guiding the operation of policy instruments.

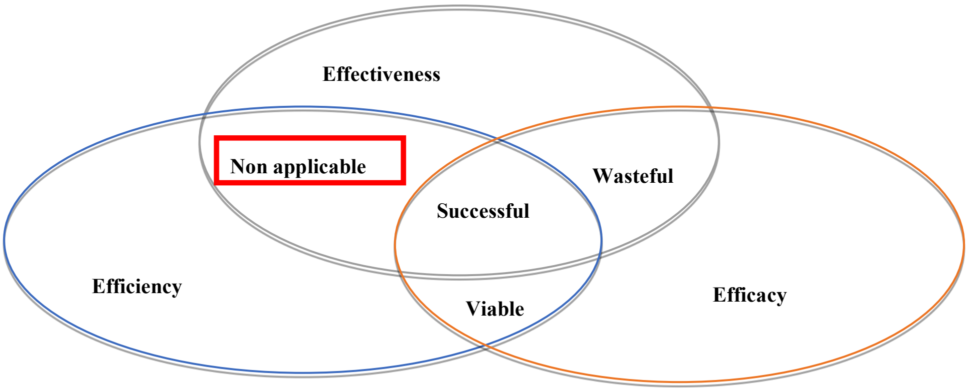


Figure 2.1 The core performance indicators of a policy or policy mix (source own elaboration)

UNEP suggests that when having to decide on the most appropriate new PI, the option should be based primarily on the efficacy of the instrument (i.e. environmental efficacy) (UNEP,2004). At the same time, OECD notes that when it comes to earmarking environmental tax revenues for funding purposes, their efficacy should be regularly be revised (OECD, 2008).

The difference between goal attainment and effectiveness lies in the causal role of policy. Thus, it is essential that an evaluation of policy effectiveness is conducted meticulously (Cobbre and Leroy, 2008). Determining whether a PI, let alone overlapping ones, are able to achieve their desired (i.e. intended) effects, is a pre-condition before addressing the overall performance of the policy mix. The potential outcome can hence differ widely depending on the occurrence or lack of favorable or impeding factors. It is rather the way the detailed implementation of these instruments is designed, or even the context in which they are developed, which can be attributed to its potential impacts (RES Beyond 20/20/20).We thus argue that in a step-wise performance assessment of policy mixes, the first step to deal with should by all means entail the efficacy of a policy mix (see Figure 2.1).

Explanatory factors (i.e. efficacy factors) behind the impact of a (set of) PI(s) can result from:

- Broader contextual factors related to the economic or political context that may evolve differently than expected and can thus favor or hinder the intended course and effect of a (set of) PI(s),
- The implementation procedure of a PI that was hindered or facilitated unpredictably,
- Interactions between policies and PIs, where one PI could potentially reduce the effectiveness of another instrument or joint implementation of PIs could result in complementarities due to their interaction.

Along these lines, we review assessment approaches to energy & climate policy interactions, with specific consideration to the performance criteria listed above, in order to describe the impact focus of different evaluation approaches, but more importantly to explore the explanatory factors behind their impacts.

2.2.2 Classification of evaluation approaches to energy and climate policy interactions

PIs addressing energy and climate challenges can be characterized by high complexity levels due to their usually compound design details that are not easily understood by relevant stakeholders. It is also the case that the formulation of such policies is quite often affected by the objectives of various groups of stakeholders and their ability to influence the final process of policy design. As a result, their launch and implementation is followed by a series of cause impact relationships driven by different actors with usually conflicting interests. (Harmelink et al.2008, Niang-Diop andBosch, 2005, Passey and McGill, 2009).

Hence on the basis of the abovementioned distinction on different evaluation views on policy interactions (i.e. interaction levels), we seek to find what evaluation approaches and methods have been employed to elucidate cause impact relationships behind policy interaction as well as market-relationships affected.

This review is concerned with approaches and supporting methods identified within overarching evaluation designs. An evaluation design refers to the primary logic of how research is conducted (King et all,1994). We have focused on the different approaches and complementary methods that support assessments of energy and climate policy interactions.

According to Cobbre and Leroy (2008) there are several approaches to the evaluation of environmental policy (e.g. Need analysis, Programme theory evaluation, Experiment and quasi experiment, Impact assessment, Cost effectiveness analysis and cost to benefit analysis, Multicriteria analysis, etc.). The list of approaches presented here is by no means exhaustive but instead it provides key diverse approaches, methods and techniques of environmental policy assessment that have been applied to investigate energy and climate policy interactions in current literature.

Different evaluation designs may share similar approaches and methods. In addition, some methods tend to adopt a more simple and straightforward mode not being able to employ all the stages of an incumbent methodological framework (e.g. Multicriteria analysis, Cost Benefit and Cost Effectiveness analysis) while others tend to comprise of a combination of approaches supporting and supplementing each other's results. (Grafakos et al. 2010, Oikonomou et al. 2011c, Del Rio, 2010). What keeps them together is the overarching logic of a design framing different approaches and methods employed.

We structure the overall assessment of approaches applied so far by classifying those into three underlying categories based on the type of data each one of them employ and elaborate upon that is to say qualitative, quantitative and hybrid assessment designs. We consider an evaluation design dealing with numerical data, employing a modeling framework to result in a calculative description, as a quantitative evaluation design, whereas qualitative evaluation designs are considered the ones resulting in explanatory descriptions (i.e. prose or textual forms) allowing for qualitative estimations and empirical observations. (Cobbre and Leroy, 2008).

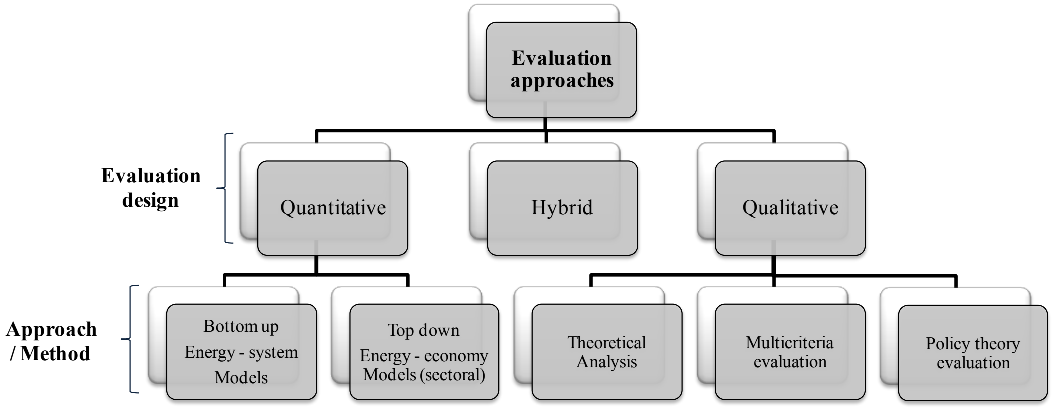


Figure 2.2 Classification tree of evaluation approaches to energy and climate policy interactions

The distinction is important as it maintains attention on the complementary methods and techniques employed to address policy interactions, within each evaluation design. A parallel overview of those approaches and methods in relation to their different views on policy interactions enables a better understanding of what pieces in the puzzle of evaluating energy and climate policy interactions are addressed by each approach (see section 2.5).

Finally, in an effort to demonstrate the underlying difference among qualitative and quantitative evaluation approaches, regarding the evaluation timeframe they adopt, we classify the impacts upon a regulated subject as well as upon the surrounding market system in intratemporal evaluation time frame, intertemporal short to midterm and intertemporal long-term evaluation timeframe. An intratemporal evaluation time frame is used when the study only provides a static picture of the interacting system among policies in the market area, intertemporal short to midterm evaluation timeframe is considered when the research provides a short to medium term forecast of the way coexisting policies in the system are evolving and lastly intertemporal long term when the researcher allows for a long term forecasting vision of policies coexistence and their respective impacts on the market forces.

2.3 Evaluation approaches and methods addressing energy and climate policy interactions

The radically increased policy-makers awareness of the issue of overlapping policies has initiated a growing number of energy and climate policy interaction studies (Boonekamp, 2006). This survey is intended to provide an overview of approaches in the field, therefore we do not provide an exhaustive description of the latter. We rather describe a limited number of representative evaluation approaches to illustrate the present state of the art in energy and climate policy interactions appraisal.

2.3.1 Quantitative evaluation approaches

Energy models able to deal with combinations of PIs have already been applied (Anandarajah and Strachan2010), as economists and policy makers acknowledge the fact that policies have begun to pile up and interact in complex ways (Boonekamp, 2006, Levinson, 2010). Two major clusters have been distinguished in order to structure our analytical review: bottom up energy system models and top down sectoral modelling approaches. The later concentrate on the interactions of the energy sector with the rest of the economy. On the contrary bottom-up energy system models usually focus on the energy sector entirely and apply highly disaggregated data to describe thoroughly energy end-uses and technology production options to meet energy demand (Van Beeck, 1999). Different types of bottom up energy system models have been applied to investigate energy and climate policy interactions. The MARKAL bottom-up energy system model has been widely used to investigate energy system implications regulated by renewable and/or climate change policies in different countries. Kannan and Strachan (2009) and Strachan et al. (2009a) have examined the cost-effective technology and energy mix under binding CO_2 reduction targets. The MARKAL elastic demand (MED) variant was applied by Anandarajah and Strachan (2010) to assess the impacts of different renewable support PIs upon long-term carbon reduction targets. Demand functions in the model determine how each energy service demand varies as a function of the market price and the elasticity parameter of that energy service. Gotzet al, (2011) used the integrated MARKA-EFOM system to examine the coexistence of the German Feed in Tariff (FiT) system with the Emissions Trading System (ETS). The FiT system was endogenously modeled by integrating the tariffs directly in the model and by assigning the corresponding levy to the end-use electricity prices through an iterative process of several model runs.

Top-down modelling evaluation approaches used to examine interactions in the energy and climate package usually consists of input–output models, or Computable General Equilibrium (CGE) models. As such, Morris (2009) applied a top down CGE energy system (Emissions Prediction and Policy Analysis) model to assess the same set of Renewable Portfolio Standard (RPS)scheme in the U.S. market and aCap and Trade (C&T) scheme and their effects on economy wide sectors. Each generation technology was represented by a constant elasticity of substitution (CES) production function input vector of capital, labor and fuel.

Less technological details of the energy system and more aggregated data are used by Tsao (2011) with the same objective of analyzing the interactions of markets in the co-existence of a C&T and a RPS scheme. In this case the top down approach emphasized on the comprehensiveness of endogenous market adjustments. Three types of power producer (coal, natural gas, and renewable producers) who face price-responsive electricity demand were considered. Similarly, a top down Generation Expansion Planning (GEP)model based on game theory was also employed to assess the coexistence of a Cap-and-Trade (C&T) scheme and four modifications of carbon tax policies and their resulting impacts upon new investments in renewable energy generation capacity. (He et al. 2011). The main scope of the approach was to endogenize behavioural relationships of Generating Companies, Grid owners and policy makers in order to capture major factors in the electricity market competition.

Identified strengths and weaknesses between the two quantitative approaches explain the wide range of mixed modelling approaches also in the field of renewable and climate change mitigation policy interactions appraisal (Hourcade et al., 2006). Abrell and Weight (2008) combined both top down and bottom up analytical views by using a CGE model to examine the interactions of the coexistence of an ETS and a Fit system for large offshore wing generation in the German electricity market. Each technology was characterized by a Leontief unit input vector of capital, labor, and fuel input associated to base, mid, or peak load. Similarly, Linares (2008) used a GEP model for the Spanish power sector to examine the interaction effects among Tradable Green Certificates (TGC) and the Emissions Trading Scheme (ETS) on the electricity utility operation, and expansion planning investments. He focused on incorporating oligopolistic firm behavior while also including disaggregated data to realistically describe energy end-uses and technological options of the Spanish power sector. He demonstrated that under oligopoly, different results are obtained when incorporating the allowance price into the price of electricity compared to a perfect competition assumption.

2.3.2 The use of theoretical economic models in energy and climate policy interactions appraisal

A number of studies have also examined the impacts of the coexistence of climate change and energy policies on the market by applying top down theoretical models that allow market equilibriums to be solved analytically, without however including case-study based numerical simulations (Fankhauser et all. 2011). Theoretical economic models represent economic processes by a set of variables and a set of logical and/or quantitative relationships between them. Such econometric models are generally used in ex-ante impact assessment of interacting PIs, providing a simplified framework designed to demonstrate complex processes, often but not always incorporating mathematical techniques and structural parameters (Wallis, 1995). Bohringer and Rosendahl

(2010), focusing on the relative stringency of a C&T scheme with a RES obligation[4] concluded that the excess cost of imposing a green quota on top of a C&T scheme can be quite substantial and that emission levels might also be increased.

Simplifications in important market and technology details when representing supply and demand analysis enable those approaches to turn their focus on representing different design characteristics of PIs. Thus, the importance of such design features in the final outcome of the combined implementation of PIs is underlined. Like so, Fankhauseret all, (2011) focused on the trading option of climate change policies in various combinations with other renewable & climate PIs to achieve a given environmental target. He concluded that a thorough design and implementation of such PIs is imperative in order to guarantee that such PIs only target market failures of an incumbent ETS system such as EE and innovation and avoid carbon policy redundancy (Sorrell, 2009).

Oikonomou et al, (2008) addressed, a neglected by most quantitative approaches combination of PIs, that of climate change and EE PIs. The authors used a theoretical economic model to analyze the behavior of energy producers and suppliers under different market conditions. They concluded that different sorts of taxation when combined with a White Certificate Scheme (WhC) lead electricity suppliers to different optimizing behaviors. Various aspects of the PIs were integrated in the interactions assessment with the help of Multicriteria analysis, such as transaction, administrative costs and flexibility of the respective policies in exogenous changes. Overall such theoretical models tend to provide a more explanatory analysis under a quantitative evaluation framework of interacting policies by examining various, usually untapped, combinations of the latter whilst also drawing attention on the importance of design and implementation of PIs in the final outcomes of the integrated energy & climate package.

2.3.3 Qualitative evaluation methodologies

Qualitative research is considered to probe those relationships, that quantitative analysis can describe by producing data and predict how those will evolve, and to explain contextual differences in those relationships (Garbarino and Holland, 2009).Qualitative design approaches applied to evaluate interacting policies tend to focus on their simultaneous implementation and conditions under which a policy package is functioning or not. Therefore, approaches applied such as theory-based evaluation or conceptual analyses tend to evaluate whether the interacting policies are effective in terms of whether they impede or facilitate their joint implementation (Cobbre and Leroy,2008).

Most qualitative approaches reviewed examining overlapping instruments incorporate more than one basic method or technique. Del Rio (2010) provides a conceptual incentive analysis while also evaluating PIs' design elements within a Multicriteria framework. These types of qualitative assessments vary significantly with respect to the focus of each research and they are defined in a broader manner. We attempt to classify such studies on the grounds of their central methods applied which can be clustered under Theoretical - Conceptual Analysis, Multicriteria and Theory-based evaluation, while considering additional techniques as supporting appraisal methods. A brief description of the denotations we give for each technique within this review will assist classifying and assessing them.

Multicriteria evaluation has been applied in energy and climate policy impact assessment widely evaluating different policy options (see among others, EmployRES, 2009, González,2009, Konidari and Mavrakis, 2007). However, the majority of papers addressing interacting PIs apply a simpler approach wherein the impacts of the interactions between those instruments are assessed by investigating how they affect a number of criteria and variables. (Del Rio, 2010).

Based on the principles of Multicriteria Analysis, studies assessing interacting PIs provide an evaluation framework consisting of various criteria and diverse variables against which the impacts of alternative PIs are evaluated and compared. INTERACT project (2003) was based upon an ex-ante explanatory analysis of interactions supported by empirical findings and ex post observations providing a common framework for comparing different policy options. Based on empirical evidence the appropriateness of alternative policy combinations was evaluated within a Multicriteria framework against a numerical scale from 1=poor to 5=good that allowed for a semi-quantitative evaluation. Similarly, Del Rio (2010) evaluated how different design elements affect those impacts against a set of three criteria, namely, effectiveness, cost effectiveness and dynamic efficiency. Multi-criteria-based evaluation also allows for participatory analysis but is subject to caveats such as subjectivity and value-laden findings. As such Oikonomou et al, (2010) forms a decision support tool to assess the coexistence of EE support PIs and taxation policies. The key notion is that policy makers state their preferences, both when it comes to different design elements of PIs (i.e. by stating the respective significance in a merit order), as well as to assessment criteria of pair-wise instruments (i.e. by assigning weighting factors); shaping in this way the outcome of policy interactions.

---

[4] The RES obligation, in other words green quota, requires a binding share α of total power production to be covered from renewables.

Policy theory evaluation has also been one of the main contributors in current research investigating interaction among PIs. In other words, Theory-based policy evaluation establishes a rational theory on how a PI was intended to reach its objectives while also accounting for its interrelationships with other PIs in the policy mix. Like so, Hamerlink et al. (2008), addressed interrelationships of EE promotion PIs, in terms of identifying cases of essential policy combinations and cases of policy redundancy, while drawing the theory of all steps in the implementation process of identified EE PIs.

The last cluster of qualitative methodologies, namely Conceptual analysis, is considered to refer to a multitude of qualitative approaches employed in the field of policy interactions all presenting a rather abstract, theoretical analysis that elaborates upon the various impacts of interacting PIs upon a number of prime variables. In most cases graphical techniques support the conceptual approach, strengthening the resulting estimations and observations while allowing for a more detailed appraisal of alternative design elements included in the functioning of policy mixes. (Sorrell et al. 2009, Del Rio, 2010).

2.3.4 The use of hybrid methods in evaluation of energy and climate policy interactions

Many scenario studies using energy models, cope with combinations of PIs; however, their effects due to their simultaneous implementation are hardly treated explicitly. According to Sorrell (2001), interaction analysis still calls for a systematic approach and new methods to investigate possible interaction effects in sets of PIs are required both in a quantitative and a qualitative manner (Boonekamp, 2006).

Piet Boonekamp used a qualitative matrix for addressing all different combinations of past EE PIs implemented in the Netherlands. His qualitative analysis was based on characteristics of the implementation process and on reported effectiveness of combinations of PIs in practice leading to an identification of the most important interacting combinations of those. Quantitative insight into those interaction effects in the past was gained by a household energy bottom up simulation model employed for the selected PIs for household EE in the Netherlands for 1990-2003. In the same fashion, De Jonghe et al. (2009) applied a simulation model to quantitatively assess the effects of the coexistence of an ETS and a RPS scheme on renewables deployment and CO_2 mitigation, demonstrated originally through graphical analysis. Then a regional simulation model was applied to represent France, Germany and Benelux, regions with significantly conflicting features, enabling for a comparative analysis of impacts and interactions of PIs implemented in different regions. Bohringer et al, (2008) also used a graphical equilibrium analysis to develop an analytical framework which was then translated into a numerical multi regional partial equilibrium model of the EU ETS carbon market. The quantitative analysis provided was based on the parameterization of the marginal abatement cost curves for the ETS sectors and the rest of the economy for EU MS countries.

The aforementioned approaches are considered as hybrid evaluation designs since they generate both quantitative and qualitative data and analysis. The quantitative data comprise numerical simulation results of the effects of combined PIs on pre-determined key variables compared to the reference (i.e. stand-alone PIs). Applying hybrid evaluation approaches in assessing energy and climate policy interactions can help to identify who benefits from the concurrent implementation of energy and climate PIs and who is burdened with extra costs and why. A hybrid evaluation that combines qualitative and quantitative methods can generate both a statistically reliable measure of the magnitude of the impact of interacting policies as well as a greater depth of understanding of how and why a (set of) PI(s) was or was not effective and how it might be reconfigured in the future to make it more cost effective.

2.4 A cross comparison of different approaches, methods and views on energy and climate policy interactions

This section provides a comparative display of how each evaluation category (i.e. design) investigates interaction effects of different combinations of instruments in the energy and climate policy package. A bottom up overview of what evaluation methods and techniques have been used in current literature to examine policy interactions is provided. The majority of the methods applied, either within a quantitative, qualitative or a hybrid design framework tend to evaluate PIs and their potential combinations as a course of a rational process in the sense that they form the basis in order to identify effective and efficient combinations of PIs (Cobbre and Leory, 2008).

When it comes to quantitative interactions assessment, the application of energy models tend to focus on the impacts identified at a market level, adopting a view on policy interactions that relatesto the motives and the nature of the stakeholders and interests involved who look for the best possible solutions (see Figure 2.3).

Optimization analytical methods adopted by energy models are used to optimize energy investment decisions endogenously. The outcome represents the optimal solution for given variables, while meeting the given concurrent constraints of PIs implemented in parallel. Optimization is usually used by competing electricity generating firms (i.e. energy producers), grid operators or municipalities to derive their optimal investment strategies (Oikonomou et al, 2008, Zhong et al, 2009, Fankhauser et all, 2011).Similarly economic equilibrium analytical methods, tackle energy and climate policy interactions also at the level of equilibriums between energy demand and supply (i.e. partial) or are concerned with the conditions (i.e. constraints) which allow for simultaneous equilibrium in all markets (i.e. general equilibrium) (Van Beeck, 1999).

Numerical simulation models developed within policy scenario analysis in energy models to investigate interactions among energy and climate policies, have mostly dealt with the issue of the relative stringency of coexisting PIs and its microeconomic and offsetting impacts on one another by simulating scenarios with different targets being set. Simulated scenarios generate outcomes upon different variables such as carbon reduction, CO_2 emissions, electricity generation mix, (Anandarajah and Strachan, 2010), production levels of different fuel types (Tsao et al, 2011) or upon renewables penetration (Palmer, 2011). Evaluation of policy interactions is seen as an assessment of policy outputs[5] owing to the coexistence of PIs. Few attempts have been made to account for issues that relate to, alternative design provisions of PIs and resulting implications. Indicatively in terms of administrative and transaction costs, Moriss (2009) incorporated additional costs of existing policies in the modeling formulation.

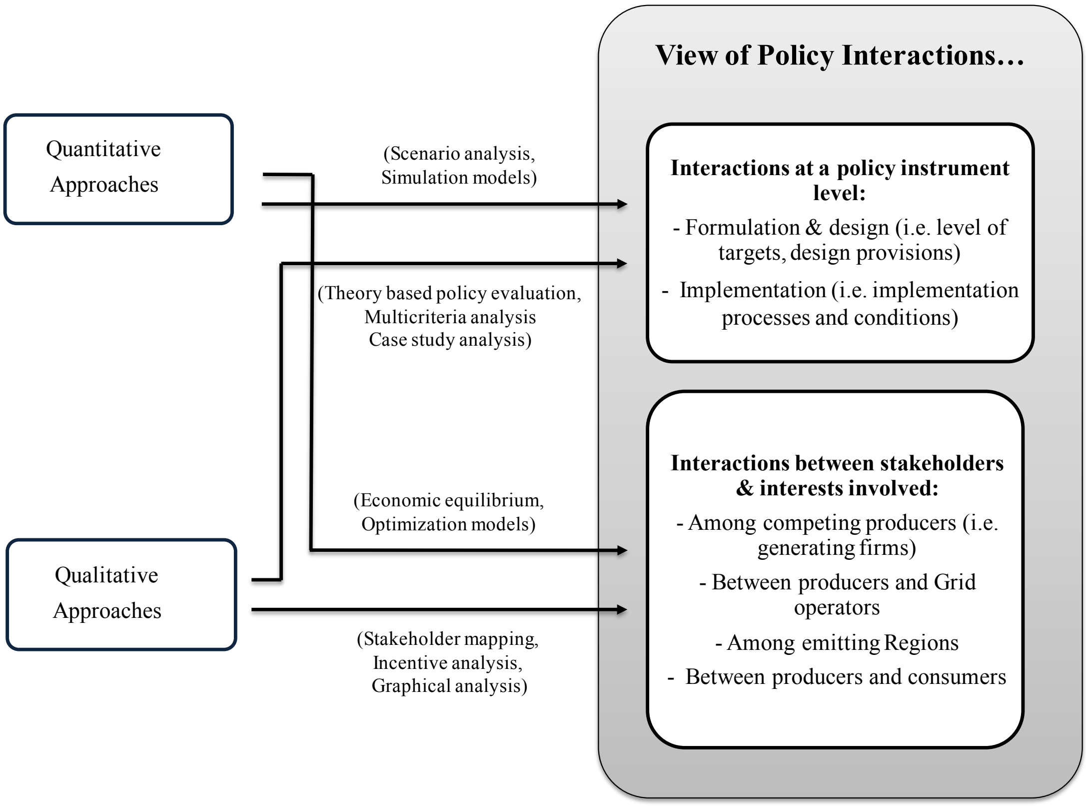


Figure 2.3 Principal evaluation approaches and assessment methods towards policy interactions assessment.

On the other hand, qualitative research is not only limited to assessing achieved effects of and resulting policy products due to different policy combinations. Instead recent qualitative analyses of energy and climate policy interactions turn their focus on exploring the conditions under which a policy package is functioning or not.

Theory based evaluation draws on the theory of policy implementation steps and identifies cause impact relationships and success factors referring to the response of targeted industry groups to the respective energy and climate policy package considering also interrelationships with other instruments in the package. Hamerlink et al. (2008), when applying an ex-post theory-based policy evaluation of EE PIs identified conditions related to:
- Challenges (e.g. behavior, size characteristics) in addressing different target groups,
- Challenges in addressing different scopes (e.g. sector, different technology features),

---

[5] Policy outputs are considered to be the products, capital goods and services which result from a policy intervention; may also include changes resulting from the intervention which are relevant to the achievement of outcomes (Gabardino and Holland, 2009).

- Addressing a financial, institutional, knowledge barrier,
- Internalizing externalities (i.e. external costs),
- Addressing market competition (e.g. low hanging fruits),
- Conditions under which a policy combination is required and
- Conditions of policy redundancy (i.e. incumbent policy potential for development and market transformation).

Another method widely applied to support qualitative evaluations of interacting PIs in their specific context of implementations, is case study analysis explaining how a PI as a part of the policy mix, is functioning and why.

Accordingly, Ropenus et al (2011) provided an ex-post historical evolution of RES support PIs building on country-based analysis of the different regulatory areas in five selected Member state countries. The case study analysis was applied to weigh up different policy alternatives of RES support instruments and network regulation on distributed electricity generation. In this way increased credibility supports the conceptual analysis of the interaction effects of policy dimensions of connection charging regimes and RES support policies providing a qualitative understanding of the latter.

Qualitative research is also largely driven by the same rational view of interactions that of interrelationships among targeted stakeholders and interests involved. Stakeholder mapping and incentive-oriented analysis offer useful frameworks for explaining and assessing the choice of different policy combinations, including understanding of the effects of alternative policy design features in the simultaneously implementation of policies. Transaction costs originating from the combined policy life cycle, baseline constructions and the issue of additionality are some of the PI design specifics due to which combined EE PIs may overlap (i.e. double counting or double coverage) or act in synergy. These effects are likely to be identified via graphical incentive analysis and market mapping methods (Sorrell et al. 2009, Oikonomou et al. 2009).

As a final point, only a few examples (Sorrell et al. 2003, Oikonomou et al. 2010) of research in the field of policy interactions have incorporated alternative pluralistic paradigms of policy evaluation. Participatory methods elicit more qualitative and interpretive information and are used to improve outsiders' understanding of complex policy context (Garbarino and Holland, 2009) and would provide significant insights in the field of policy interactions helping to explain contextual differences in the quality of policy interrelationships. A detailed analysis of recent studies on evaluating energy and climate policy interactions is provided in the Appendix of this review.

2.5 Impact focus and efficacy factors behind the impact

Recently a number of reviews have addressed the area of research for interacting policies mainly focusing on the impacts addressed and potential consensus and conflicts among resulting findings (Fischer and Preonas, 2010, IEA 2011a,b,c, OECD, 2011, Del Rio, 2007). The analysis is based on the principal evaluation criteria identified in the assessment framework (see Section 2.2). Special attention is paid to what types of factors determining the efficacy of PIs have been ascertained by research in the field of energy and climate policy interactions.

2.5.1 Impact focus when assessing interaction in the energy and climate policy mix

The most important energy/environmental targets in Europe are the CO_2emissions reduction, renewable energy deployment and EE promotion (Del Rio, 2010). In terms of effectiveness, mainly environmental benefits and microeconomic impacts of interacting policies have been addressed quantitatively through exploratory scenarios examining the impacts of RES support and carbon policies upon key market variables, by and large representative of targeted stakeholders' costs and profits (e.g. carbon emitting firms, consumers, electricity producers etc.) (Abrell and Wieght,2008, Anandarajah and Strachan, 2010, De Jonghe et al. 2009, Morris, 2009, Linares et al. 2008, Palmer et al. 2011, Tsao et al. 2011, Hen et al. 2011). Change in welfare (i.e. welfare loss) due to the imposition of an RPS instrument on top of an existing Cap and Trade system has been identified mostly with the application of CGE models. Simulations showed an increase of welfare loss due to a more costly generation mix in the short term (i.e. until 2030) which is however decreased in the long term, since investments in renewable technologies in the later years bring down costs (Abrell and Wieght, 2008, Moriss, 2009).

Social impact assessment has scarcely being addressed with energy simulation models as changes in consumer's and producers' surplus due to the incidence of overlapping RES and carbon reduction PIs (Anandarajah and Strachan, 2010), whereas the application of multicriteria analysis within energy economy models can enhances ocial impact assessment by addressing a variety of impacts on society such as: equity and fairness for direct parties and indirect parties, employment effects, increase in environmental awareness and political acceptability (Oikonomou et al. 2008).This combination however has only been applied to a very limited extent in energy models.

Similarly, effectiveness and efficiency have been and still remain the focal points in the bulk of qualitative approaches (Gotz et al. 2011). Effectiveness in terms of macroeconomic impacts and environmental benefits of combined PIs is most frequently translated into market price signals, energy effectiveness (e.g. energy security of supply), RES-E and EE investments etc. (Fischer and Preonas, 2010, Jensen and Skytte, 2003, Oikonomou and Jepma 2007, Oikonomou et al, 2007, 2010,2011a, Ropenus et al. 2011, Del Rio, 2006, 2010, Sorrell & Sijm, 2005).

On the other hand; impact analysis in qualitative approaches is a lot more extensive mainly due to the wide application of Multicriteria analysis that tries to incorporate all (conflicting) criteria simultaneously within the analysis (Cobbre & Leroy, 2008). Societal effects in terms of improved quality of life, strengthened empowerment and enhanced prosperity have been raised and addressed more frequently than quantitative approaches, in terms of social equity, social costs and political acceptability, or through the standard measure of consumer and producer surplus in qualitative frameworks of policy interaction impact appraisal (Sorrell at al. 2003, Sorrell, 2009, Oikonomou et al, 2010).

Although the effectiveness and efficiency performance indicators have been adequately addressed by researchers, social effects and costs (e.g. employment generation) on the other hand have not (Bassi., M., A., 2010). Sorrell & Sijm (2005) in their attempt to explore the justifications of inducing EE promotion policies argue that rationales supporting employment benefits are not so persuasive as jobs are being frequently created in priority sectors and locations, while economists suggest that the cost effectiveness of this employment creation is relatively small (UKACE, 2000). The table[6] below (Table 2.1) summarizes a qualitative evaluation of the contribution level of qualitative and quantitative approaches in the impact assessment dimensions of interacting policies.

Table 2.1 Contribution levels of qualitative and quantitative approaches in the impact assessment dimensions of interacting policies

Impact focus	**Effectiveness**			**Efficiency**	
Evaluation approach	Environmental effectiveness	Economic opportunities and competitiveness	Social effectiveness	Static efficiency	Dynamic efficiency
Quantitative	■	■		■	▨
Qualitative	■	▨	▨	■	
NOTE: Darker shading indicates a high contribution level of evaluation approaches to the respective impact(s); lighter shading indicated a medium contribution of approaches in addressing the impact and no shading indicated a low level of contribution.					

Regarding costs related to technology and innovation push, model based approaches have also started to incorporate operations & maintenance fixed and variable costs for a more accurate representation of compliance costs of proposed combined PIs (Moriss, 2009, Palmer et al, 2010).With the same focus, Del Rio (2010) applied a Multicriteria analysis framework to evaluate proposed instruments against their dynamic efficiency i.e. their ability to generate continuous incentive for technological improvements. With the same objective on the costs of investing in innovation and new technology deployment support combined policies, Levinson conducts a meta-analysis of past research to argue that investment in R&D should be carefully addressed as empirical results demonstrate that the industry-wide return to R&D is just about two to four times as high as the returns to any other firm, implicating underinvestment in R&D (Jones and Williams, 1998, Levinson, 2010).

Overall energy and climate policies tend to focus on the energy sector although they influence society, economy, environment and technology to a great extent (Bassi., M., A., 2010).Drawing on the abovementioned conclusions of recent literature, that the impacts of policy combinations upon societal welfare, technology costs and innovation can be uncertain or sometimes even greater, it becomes imperative that future research emphasizes on social and technology impacts into their future analytical frameworks.

---

[6] The qualitative evaluation of the contribution levels of approaches was based on a detailed analysis of the sum of research studies under review against the effectiveness and efficiency criteria. The shadings were the outcome of a comparison of impact assessment dimensions addressed by the sum of qualitative and quantitative research studies. The detailed tables of the aforementioned analysis are available upon request.

2.5.2 Efficacy factors behind the impact of the energy and climate policy mix

As already discussed (see section 2.2) the desired effects policy makers expect to achieve via a given PI or mix of PIs deviates in most cases from the actual outcome after their implementation. Such deviations between the intended and observed policy course and effects may be attributed to unexpected circumstances and conditions related to:

i. The economic or political context
ii. The implementation procedure of the PI
iii. Interactions of the PI with other incumbent PIs that lead to shortcomings or synergies

In this section we seek to identify to what extent, such information has been incorporated in evaluation approaches of policy mixes so far and provide a comparative overview of the most significant factors identified (or not) by each approach in order to enable a more realistic assessment of the effectiveness of PIs in the future.

When it comes to general contextual factors, related to the national context where RES support and climate PIs are being imposed, the majority of energy system models are likely to incorporate significant market parameters, determinants of supply and demand equilibria simulated for the energy market. Those factors influence the extent of the effects of the simultaneous implementation of PIs that usually relate to generating extra costs or revenues for the associated market players (Abrell & Wieght, 2008, Linares et al. 2008, Moriss, 2009, Anandarajah & Strachan, 2010). On the other hand, energy economy models, as already stated (see section 2.3), tend to provide a less detailed representation of the energy system focusing on the comprehensiveness of endogenous market adjustments.

Like so, a partial equilibrium model simulating equilibriumsfor21 regional electricity markets (i.e. United states) was employed by Palmer et al, (2011) to analyze how RES and Cap and Trade policies affect the generation mix, electricity prices and consumption, and greenhouse gas emissions at both the national and regional levels. Each region was classified based on its method for determining electricity prices and reserve services as either market-based competition or cost-of-service regulation. The findings showed that the electricity price effects of PIs depend on the regulatory structure of electricity markets, which varies across each country.

Appart from economic factors, Fankhauser et al, (2011) speak about the political context in which PIs are imposed, in an effort to identify effects and associated costs resulting from the concurrent implementation of climate policies. He points out to the fact the combination of climate policies may result in spending scarce political capital with very low abatement effects to reason it; by serving an artificial perception that “more is being done”. In such a complex policy setting, qualitative approaches mostly contribute to the assessment of the diversity of different design characteristics of PIs and to the complexity of policy interactions affecting the effectiveness of the (set of) PI(s) under assessment in relative terms.

Qualitative approaches, due to their exploratory focus tend to concentrate on the identification of typical circumstances in which to apply a set of PIs (Boonekmap, 2006, Hamerlink et al. 2008). Information of economic trends governing the implementation of PIs is rather straightforward in the majority of qualitative approaches. Such studies focusing on how market and economic trends affect environmental and welfare impacts of interacting PIs, tend to provide explanatory representations by focusing on a small number of price, quantity and distributional variables. The impacts of the PIs on each variable are explored through simple trend analysis and graphical techniques (Sorrell, 2009). Table 2.2 below provides a comparative overview of factors considered in recent evaluations approaches of energy and climate policy interaction.

Regarding design and implementation characteristics of PIs, qualitative approaches such as INERACT project (Sorrell et al. 2003) addressed a variety of design and implementation features affecting the impacts of policy combinations. Administrative simplicity in terms of administrative burden on the target group, the implementation organizations, political acceptability, and compliance measures were some of them in the intratemporal assessment framework. Likewise, Oikonomou et al. (2009), when exploring the potential of a proposed PI of a Voluntary Agreement (VAs) with a TWC considered in detail the institutional set up of interacting PIs under assessment that is regulated bodies for the setup, administration, verification and registration of the individual PIs. He considers the proposed combination of PIs to be overlapping with regard to its institutional set up, if different institutional bodies are assigned to regulate each PI owning to the reduced administrative simplicity and co-ordination. Evaluation approaches of interacting PIs, qualitative and descriptive in nature, thus are likely to allow for complex analysis of often non-quantifiable cause-and-effect processes during the design and concurrent implementation of PIs.

Although qualitative approaches such as Multicriteria analysis, are able to include several variations and details related to the design and implementation characteristics of interacting PIs (Sorell et al. 2003, Oikonomou et al. 2009, 2010) they develop an intra temporal evaluation framework accounting for only current effects of combined instruments. On the other hand, quantitative approaches have mainly explored how interaction impacts vary based on the distinction between price-based or quantity-based PIs with variations in prices and quotas for commodities, trading and banking options. The importance of flexible design mechanisms, in terms of providing corresponding abatement options to the target groups have also begun to gain attention in recent quantitative approaches. An alternative compliance payment mechanism incorporated in a RPS PI seems to substantially affect renewables penetration (Palmer et al, 2011) while Moriss (2009) points out that by removing the flexibility to pursue the least costly emission reduction strategy, a RPS PI becomes significantly more costly.

In one of the first studies to evaluate interacting PIs within a hybrid evaluation design, allowing for more empirical based examination, Boonekamp (2006) assessed the contribution of different EE PIs to the conditions for implementation and proper utilization of saving options; by examining whether the PIs in question are available for application, known to appliers, lift potential restrictions and provide motivation to investors. Finally, Palmer et al (2011) acknowledged the fact that "The efficacy and CE of different policy approaches depend on the combination of policies that are adopted, the particulars of the policy design, and the goals that the policies seek to achieve".

Table 2.2 Overview of efficacy factors considered in impact evaluations of energy and climate policy interaction

Efficacy factors identified behind the impact of energy and climate policy mixes		
	Economic and political context	**Policy cycle**
Quantitative evaluation design	**1.** Electricity market structure and design **2.**Interconnection of domestic electricity markets in Europe **3.** Primary factors: Labor, capital, conventional and non-conventional resources **4.** Supply & Demand parameters[7] **5.** Incumbent policy framework included in the reference scenario **6.** Different RES penetration levels **7.** RES potential **8.** Efficiency of the whole electricity system (grid loss from production to transmission and distribution) **9.** Emissions of other (than GHG) air pollutants **10.** Discount rate for investments	**Design** **1.** Trading option (i.e. certificates, allowances) **2.** Banking of emissions **3.** Alternative compliance payments **4.** Distinctions between price-based or quantity-based PIs with variations in prices and quotas for commodities (i.e. Stringency levels) **5.** Uniform/Differentiated Feed in Tariff scheme per technology type **6.** Phase in of Renewable Portfolio Standard **7.** Annual degression rate of Feed in Tariff rate **8.** Limitation of the payment period **9.** Tariff reduction due to inflation **Implementation** **10.** Technology specific hurdle rates reflecting market barriers, consumer preferences and risk factors limiting purchase of new energy technologies)

---

[7] Representative examples of such parameters identified within recent modelling studies are: rich technology mix, generating costs per technology type, maximum capacity per generating unit, reserving generating capacity, slope of energy demand & supply curves, RES intermittency, different RES penetration levels, CO_2 emissions rate per generating type, different load segments in electricity production, substitution possibilities among energy and other commodities, cost-disadvantage for initially inactive technologies and capacity limits due to technological and political constraints.

[7] For instance it is demonstrated that the magnitude of the price signals of cap and trade policies largely depend on whether emissions allowances are allocated by auction or by grandfathering

	11. Firm behavior **12.** Allowance trade patterns among regions	
Hybrid evaluation design	**Economic and political context**	**Policy cycle**
	1. Socio demographic and lifestyle trends **2.**Interconnection of domestic electricity markets in Europe **3.** Political context in which PIs are imposed **4.** Supply & Demand parameters **5.** Firm behavior	**Design** **1.** Distinctions between price-based or quantity-based PIs with variations in prices and quotas for commodities **2.**International emissions trading **3.** Uniform and unilateral imposition of carbon taxes across all EU ETS regions **4.** Lump-sum treatment of additional tax revenues **5**. Stringency levels **6.** Different application scope (upstream/downstream) **Implementation** **5.** Conditions for implementation and proper utilization of saving options: - Technology/equipment availability - Familiarity with the policy - Overcoming barriers (remaining lifetime of the existing energy using systems, the split incentive between ownership/investment) - motivation to invest **6.** Specific implementation of PIs with regard to their funding (i.e. by the government or by end-users). **7.** Transaction costs **8.** Stability & credibility in the policy regime

	Economic and political context	**Policy cycle**
Qualitative evaluation design	**1.** Simplifications in technology production options and load segments of electricity production **2.** Limited analysis of constraints in output **3.** Slope of demand & supply curves **4.**Electricity market structure and design **5.**Technology market failures and other externalities related to electricity generation design	**Design** **1.** Nature of targets, the target groups, the policy- implementing agents, the available budget, the available information on the initially expected energy savings impact, and the cost effectiveness of the instrument. **2.** Distinctions between price-based or quantity-based PIs **3.** Different RES-E support design elements: FiTs: Fixed premium versus tariff, Floor, Cap, Support tied to electricity prices; Stepped FIT (technology-specific);Degression, Banking and borrowing; TGCs: Immature technologies excluded, Low penalty, Minimum prices, Existing plants non eligible, Technology specific quota **4.** Variable scenarios in the short and long run for key policy parameters such as price of Certificate, level of obligation, level of sales tax and the level of penalty **5.** Fixed-price policies (those in which the price variable is chosen directly) and endogenous price policies (markets set the effective taxes or subsidies through the values placed on tradable credits) **Implementation** **6.** Implementation period of the PI **7.** Circumstances in which to apply a PI - Challenges (e.g. behavior, size characteristics) in addressing different target groups, - Challenges in addressing different scopes (e.g. sector, different technology features), - Addressing a financial, institutional, knowledge barrier, - Internalizing externalities (i.e. external costs), - Addressing market competition (e.g low hanging fruits), - Conditions under which a policy combination is required and - Conditions of policy redundancy (i.e. incumbent policy potential for development and market transformation). **8.** Implicit and explicit assumptions in the policy implementation process and mapping the cause–

		impact relationships. **9.** Transaction costs related to the combined policy cycle **10.** Regulatory decisions on the additionality of energy savings from individual projects: - Environmental additionality/ Financial additionality - Fixed Baseline/ Dynamic baseline - Crediting lifetime

Overall the integration of socio-political (e.g. socio demographic and lifestyle trends, political context) and environmental factors (e.g. RES penetration levels, emissions of air pollutants etc.) in addition to economic ones, in accordance with the geographical characteristics and the electricity market structure of the area under assessment, would allow for a broader analysis of interacting PIs by identifying potential market failures and hurdles to socio-economic development that extend over time (Bassi, 2010). As a final point longer evaluation timeframes are essential in order to account for policy implications such as delays and impeding factors in the implementation process, policy resistance and redundancy elements that usually extend over time.

2.6 Concluding remarks

Summing up the additional aspects of quantitative and qualitative research to fit into our original definitions of quantitative and qualitative as describing the types of data and analysis produced, a set of six dimensions that characterize the two traditional evaluations in the field of energy and climate policy interactions is presented in Table 2.3 These broader aspects consist of useful points of reference when we consider the potential of different approaches to allow for an integrated evaluation of the diversity and complexity inherent in policy interactions and resulting market implications.

Table 2.3 Quantitative and qualitative dimensions in energy and climate policy interactions appraisal

Quantitative evaluation	**Qualitative evaluation**
1. Numerical data estimating the extent of policy combination impacts	**1.** Descriptive explanatory analysis of often non quantifiable processes in policy interactions
2. Forecasting of outcomes of interacting policies on market-relationships	**2.** Explanation of contextual differences and cause impact effects
3. Work best for narrowly specified policy combinations	**3.** Appraisal of diversified and complex policy interactions
4. Sufficient market and technology details representing supply and demand equilibriums	**4.** Focus on the role of implementation context and design characteristics in the effects of interacting policies
5. Enhanced support of Effectiveness and Efficiency judgments in policy combinations	**5.** Easier to integrate participatory analysis allowing for a better understanding of assumptions and key structural relations.
6. Intertemporal evaluation framework (short to mid-term, mid to long-term)	**6.** Intratemporal evaluation framework

Overall qualitative design frameworks contribute to the assessment of the diversity and complexity of policy interactions affecting the impacts of PIs to be assessed in relative terms, whereas modelling (i.e. quantitative) approaches provide absolute numbers and economic trends that affect them. Regarding untapped issues in recent research approaches assessing overlapping energy and climate policies we argue that the issues summarized above need to become the focal points of the research to follow.

- A large share of recent approaches applies a partial equilibrium approach to frame their analysis, address the multi-actor and multi-level nature of interacting policies to a limited extent. They mostly adopted a rational view of policies and policy interactions leaving out a systemic evaluation of the institutionalism of interacting policies.
- Diversity in the assessment of policy combinations is still narrow. RES-E support and carbon policies are easier to quantify unlike EE ones that are not as mature in the market lacking significant data and information.
- Research in significant inter-sectoral interactions of energy and climate PIs with other environmental policies still remains untapped since evaluation approaches are mainly focused on the energy sector.
- Regarding sustainability within impact assessment of overlapping policies the social and technological dimension have scarcely been examined. Especially social impacts of interacting PIs, which are not reflected in price signals, supply and demand curves, or in the large economic measures of inflation, Gross Domestic Product, and other measures of aggregate demand and savings need to be assessed via meso conomic thinking.

- Ex-post evaluation can reflect to a higher extent reality whereas ex-ante is more restricted denoting that it projects impacts of policy interactions compared to a speculative future scenario and estimates the results against a set of fixed criteria. (OECD, 1997, Oikonomou and Jepma, 2008). Only a few approaches (INTERACT,2003, Boonekamp, 2006) manage to incorporate both views in conjunction testing their theoretical analysis with empirical observations.
- A hybrid evaluation that combines ex-ante qualitative and quantitative analysis based on empirical observations, can generate both a statistically reliable measure of the magnitude of the impact of interacting policies as well as a greater depth of understanding of how and why a (set of) PI(s) was or was not effective and how it might be reconfigured in the future to make it more efficacious and cost effective in the end.
- The political context is often not included in evaluation approaches, especially quantitative ones and significant side-effects regarding (i) useless political funds for insignificant environmental benefit, (ii) altered distributional effects and equity issues, (iii) emasculated regulators' credibility that may result in more policy intervention (Fraunkhauser, 2011) are not considered all together. Participatory analysis has been incorporated into almost all stages of individual policy design and evaluation and would provide significant insights in the field of energy and climate policy interactions regarding the political context of implementation.
- There is an increasing effort from researchers to switch from static representations to longer term evaluation timeframes generating fewer interim results concerning the impacts of overlapping policies by encompassing market dynamics, future socio-political trends as well as delays and implications during their implementation that usually extend over time.

All things considered, one may argue that in practice, the analysis of efficacy would be related to those cases where one PI or mix of PIs shows different degrees of effectiveness in countries or different sectors. It is yet the ease of difficulty of implementation that can play the decisive factor for its effectiveness altogether. Endeavors for an improved methodological framework that would allow for an orderly exchange of data between qualitative and quantitative approaches and would also include the relevance of the context as well as key casual relationships behind policy combinations, would provide the basis for further growth of knowledge in the field.

Appendix

Table A1. Outline of quantitative approaches

Enegy Model category	Study	Approach	Bottom-up/Top down	Evaluation timeframe	Type of assessment	Case study based	Sectors included
Energy System Models	**i.** Linares, 2008	Generation Expansion Model/ Linear Optimization	Both	Intertemporal Short to mid-term (2005–2020)	ex-ante	YES (Spanish power sector)	End use sectors (services, industry, transportation, households)
	ii. Abrell and Wieght,2008 ,	Computable General Equilibrium (CGE) model	Both	Intratemporal	ex-ante	YES (Germany)	**Non-Energy** (Agriculture, Mining, Manufacture Energy Intensive Industries, Services, Transport) **Energy** (Electricity, Coal, Natural Gas, GAS Crude Oil, Refined Oil)
	iii. Moriss,2009	Computable General Equilibrium (CGE) model	Top-down	Intertemporal Long-term (2005-2050)	ex-ante	YES (United States)	**Demand Sectors:** Agriculture, Energy-Intensive Products, Other Industries Products, Services, Transportation, Household Transportation, Other Household Demand **Electric Generation:** Conventional Fossil, Hydro, Nuclear, Wind, Solar, Biomass, Advanced Gas (NGCC). Advanced Gas with CCS, Wind with Gas Backup, Wind with Biomass Backup **Fuels:** Coal, Crude Oil, Shale Oil, Refined Oil, Natural Gas, Gas from Coal, Liquids from Biomass, Synthetic Gas
	iv. Anandarajah and Strachan , 2010	MARKAL Elastic Variant (MED) model/ Linear Optimization	Bottom-up	Intertemporal Long term(2000-2050)	ex-ante	YES (UK)	Hydrogen, Electricity, Transport Services, Residential, Industry Agriculture
	v.Götz et al. 2011	Integrated MARKAL-EFOM system model / Linear Optimization	Bottom-up	Intertemporal Short to midterm (2005–2020)	ex-ante	YES (Germany)	Energy demand sectors (industry, residential, commercial/agriculture and transport), public & industrial electricity and heat production, refineries and other fuel conversion
Energy – Economy Model (integrated)	**vi.**Palmer et al.2011	Haiku Partial Equilibrium model/Non-Linear Optimization	Top-down	Intertemporal Long-term (2010-2035)	ex-ante	YES (U.S federal states)	Regional electricity markets and interregional electricity trade
	vii. Fankhauser et all, 2011	Partial equilibrium / Linear Optimization	Top-down	Intratemporal	ex-ante	NO	Electricity sector

		viii. Böhringer and Rosendahl,2010	Partial equilibrium / Linear Optimization	Top-down	Intratemporal	ex-ante	NO	Closed power market
		ix. Lecuyer and Bibas, 2012	Partial equilibrium / Linear Optimization	Top-down	Intratemporal	ex-ante	NO	-
		x. Oikonomou et al,2008	Partial equilibrium / Linear Optimization	Top-down	Intratemporal	ex-ante	NO	Electricity sector
		xi. Fischer and Preonas, 2010	Partial equilibrium / Linear Optimization	Top-down	Intratemporal	ex-ante	NO	Electricity sector (natural gas, coal, oil and renewables)
	(set of models)	**xi.**Tsao et al.2011	Partial equilibrium/ Linear Optimization	Bottom-up	Intratemporal	ex-ante	YES (California State)	Electricity generation sector

Table A2. Outline of qualitative approaches

Study	Qualitative approach	Supporting method	MainFocus - Criteria	Mainadresse	Policy Types included	Evaluation timeframe	Type of assessement	Case study based
i. Hamerlink et al. 2008	Theory based policy evaluation	Case stud analysis	Success and failure factors identified in all of the steps in the implementation process in order to improve the impact and cost effectiveness	All parties	EE support	Intertemporal (short to mid-term)	Ex-post	YES (Italy)
ii. Oikonomou et al. 2009	Multi-criteria-based evaluation	-	effectiveness, efficiency, innovation process, impacts on society	All parties (residential and commercial sector)	CO_2 emissions reduction EE support	Intratemporal	Ex-ante	YES (Netherlands)
iii. Oikonomou et al,2010	Multicriteria Decision Analysis (Energy & Climate Policy Interactions (ECPI) decision support tool.	-	Climate, Energy, Financial, Macroeconomic, Technological	Energy end users	CO_2 emissions reduction EE support	Intratemporal	Ex-ante	
iv. Pablo del Rio, 2010	Multi-criteria-based evaluation	Graphical equilibrium analysis	Effectiveness, Cost effectiveness, Dynamic efficiency	Electricity supply and demand	CO_2 emissions reduction	Intratemporal	Ex-ante	

					RES -E support EE support			
v. Ropenus et al, 2011	Conceptual incentive analysis	Case study analysis	Risks and costs allocated to Distribution Systems Operators and Distribution generators/RES operators	Distribution generators, Distribution system operators and RES producers	Network Regulations Res-E support	Intertemporal (short to mid term)	Ex-post	YES (Spain, UK, Germany, Denmark, The Netherlands)
vi. Jensen and Skytte, 2003	Conceptual incentive analysis	Case study analysis	Consumers' electricity price, Emissions reduction, RES promotion	RES-E producers Thermal Producers Electricity Consumers	CO_2 emissions reduction RES-E support	Intratemporal	Ex-ante	No
vii. Pablo del Rio,2006	Conceptual analysis (scenario building)	-	Incentives for the implementation of RE- CDM projects, RES-E deployment and sustainability benefits,CO_2 allowance prices, Welfare of electricity generators, GHG emissions, Final consumers' cost, Conventional Electricity deployment	Electricity producers, consumers in Non Annex I and Annex I countries	CO_2 emissions reduction RES-E support	Intratemporal	Ex-ante	No
viii. Levinson,2010	Conceptual incentive analysis	Graphical equilibrium analysis	The impact of environmental regulations that address the same pollutant, on one another, carbon prices, emissions prices and overall on abatement costs	Carbon emitting firms in the electricity sector	CO_2 emissions reduction RES-E support	Inter-temporal Short term	ex-post	No
ix.Sorell and Sijm, 2005	Conceptual theoretical analysis	-	CO_2 emissions, Static efficiency, Dynamic efficiency	Electricity consumers, suppliers, and shareholders	CO_2 emissions reduction RES-E support EE support	Intratemporal	Ex-ante	No
x.Sorell et al, 2009	Theoretical analysis	Graphical equilibrium analysis	Price variables: wholesale electricity prices, retail (consumer)electricity prices, EU-ETS allowance price, white certificate price Quantity variable: electricity demand, renewable electricity generation, non-renewable electricity generation, carbon dioxide emissions, investment in end user EE, investment in new renewable energy generation Distributional variables impacts on el. produces, impacts, on producers of EE equipment, impact on el. consumers	Electricity producers, Producers of EE equipment Electricity consumers	CO_2 emissions reduction EE support	Intratemporal	Ex-ante	No

Table A3. Outline of quantitative evaluation approaches in relation to their views of interactions

Study	**Evaluation approach**	**View of interactions**

i.Linares et al, 2008	Generation Expansion Model/Linear Optimization	**Policyinstrumentlevel: -**	**Stakeholder/Market level:** The electricity market (Short term): generation firms compete in quantity of output base on their conjectures about their competitors 'strategic decisions (Conjectural Variations approach). In the long-term electricity market, firms compete in generating capacity with regard to various simultaneous optimizations – for each firm e, the maximization of its profits is subject to its particular technical constraints (Cournot problem).
ii. Palmer et al.2011	Haiku Partial Equilibrium model/ Non Linear Optimization	**Policy instrument level:** Four scenarios of policy combinations are modeled and sensitivity analysis addressing the absence of alternative compliance payment provisions of a policy is considered.	**Stakeholder/Market level:** A deterministic partial equilibrium model simulates equilibrium in regional electricity markets and interregional electricity trade with an integrated algorithm for emissions control technology choices for sulfur dioxide (SO2), nitrogen oxides (NOx), and mercury. Electricity supply is represented as a model plant according to their technology and fuel source. The operation of el. system is based on the minimization of short-run variable costs.
iii. Tsao et al.2011	Partial equilibrium/Linear Optimization	**Policy instrument level:** Comparative statics on two policy parameters, binding emissions CAP and RPS constraint, estimate the marginal effect on the market outcomes related to these two policy parameters.	**Stakeholder/Market level:** To overview the interaction of markets in the co-existence of the C&T and RPS policies, three types of power producer, i.e. coal, natural gas, and renewable producers are considered, who face price-responsive electricity demand. Producers maximize their profits, which are equal to the total revenue (from the electricity or the RECs sale) minus the production cost and the payments for RECs and the CO_2 emission permits. A numerical model is then applied to take into account the spiningreseve market that compensates for uncertainty in wind production. Monte Carlo simulations are employed to examine the distribution of the potential market outcomes.
iv. Abrell and Wieght,2008,	Computable General Equilibrium (CGE) model	**Policy instrument level:** The impact of a pure emission trading policy instrument and two renewable support schemes on generation investment and market prices is identified.	**Stakeholder/Market level:** Each technology is characterized by a Leontief unit input vector of capital, labor, and fuel input. Each technology is associated to base, mid, or peak load and within the load patterns technologies are perfect substitutes.
viii. Moriss,2009	Computable General Equilibrium (CGE) model	**Policy instrument level:** Adding the various levels of Renewable Portfolio Standard requirements to the cap-and-trade policy	**Stakeholder/Market level:** Each technology is represented by constant elasticity of substitution (CES) production functions input vector of vector of capital, labor, and fuel.
x.Anandarajah and Strachan, 2010	MARKAL Elastic Variant (MED) model/ Linear Optimization	**Policy instrument level:** Exploratory analysis of the interactions of intermediate renewable policy (Renewables Obligation, Renewables Transport Fuel Obligation, and Renewable Heat Programme for buildings) on long-term carbon reduction targets	**Stakeholder/Market level:** Demand functions determine how each energy service demand varies as a function of the market price of that energy service. A combination of the proportional change in prices and the elasticity parameter(E) determines the changes in the energy service demand according to the step amount. The model maximizes producer surplus and consumer surplus by including the cost of demand reduction in the objective function.

xi.Götz et al. 2011	The German TIMES (Integrated MARKAL-EFOM system) model /Linear Optimization	**Policy instrument level:** Variation of - ETS emission reduction targets - Integration of the FIT system for renewable electricity	**Stakeholder/Market level:** A deterministic approach is used to endogenously model the tariff system by integrating the tariffs directly into the model and by assigning the corresponding levy to the end-use electricity prices through an iterative process of several model runs.
ix. Böhringer and Rosendahl,2010	Partial equilibrium /Linear Optimization	**Policy instrument level:** A combination of technology-specific production subsidies to green producers and a tax on electricity consumption setting a binding share of green emissions in black production is imposed on a binding emissions trading system.	**Stakeholder/Market level:** A competitive power market is considered, with renewable producers and producers of conventional power, where government has imposed a binding cap on total emissions from the power sector and a green quota which requires a binding share of total power production to be covered from green power. Producers maximize their profits subject to the policy constraints that may generate extra costs or revenues.
x.Fankhauser et all, 2011	Partial equilibrium /Linear Optimization	**Policy instrument level:** Simultaneous taxes and cap-and-trade (hybrid policy instruments): -Tax and trade -Trade and subsidy (permit trading system with a per-unit subsidy) - Trade and trade (two overlapping permit-based systems) - Standards (Renewable portfolio standards) and Trade With different assumptions (asymmetric policies where the second policy instrument applies only to a subset of firms or geographies): - Unilateral tax and trade -Technology policies and trade	**Market Stakeholder level:** Policy instruments that subject firms to multiple types of regulation at the same time are described as simultaneous and overlapping. Carbon-emitting firms' behavior is represented as an optimization problem, where each firm minimizes abatement costs, subject to different policy combinations affecting their marginal abatement costs.
xii. Lecuyer and Bibas, 2012	Partial equilibrium /Linear Optimization	**Policy instrument level:** - Microeconomic approach of interactions between three objectives and three instruments: a tax on emissions from fossil fuel, a subsidy on renewable production, a subsidy on EE. - Signs of the partial derivatives of both energy types, energy savings and market price with respect to variations in policy instrument levels (tax, RES and EE subsidy)	**Stakeholder/Market level:** Two energy types, the energy from a fossil fuel and renewable energy are combined to cover an exogenous demand in energy (D). This energy is assumed to be consumed through a non-specified energetic vector (e.g. electricity) in order to satisfy a service such as lighting, transportation or heating. The demand can be reduced by EE investments.
xiii. Oikonomou et al, 2008	Partial equilibrium /Linear Optimization	**Policy instrument level:** Different sorts of taxation combined with WhC lead electricity suppliers to different optimizing behaviors: - el. producers under a carbon ax - el suppliers under an electricity tax - el. suppliers with a WhC obligation	**Stakeholder-Market level:** The behaviour of energy producers and suppliers in three market conditions: a) a policy free environment, b) a carbon tax on fossil fuels as input for the electricity producers and a tax on sales for electricity suppliers (electricity tax), and c) a WhC obligation for electricity suppliers. The two markets (i.e. el. production and el. supply) are presented separately in the analysis since:

		- el producers under a carbon tax and el. suppliers with a WhC obligation -el suppliers under an electricity tax with a WhC obligation	- efficiency loss ratio in transmission and distribution of energy - wholesale market price and retail pricediffer because they belong to different markets where the output of one feeds into the other.
xiv..Fischer and Peronas, 2010	Partial equilibrium /Linear Optimization	**Policy instrument level:** - A price on carbon, a tax on fossil energy sources, and a production subsidy for renewables. - Different targets for RES support schemes (increased share of RES-E deployment and CO_2 emissions reduction) and implications on welfare and compliance costs. - Distinction between fixed-price policies and endogenous price	**Stakeholder-Market level:** Four different types of generation are considered: baseload technologies, natural gas, other fossil fuels, and renewable energy. A general model of economic equilibrium in energy supplies and demand is applied to demonstrate how the relative slopes of these curves determine the price incidence (i.e signal) of portfolio standards stand alone and then combined with a cap and trade scheme as well as other policies.

Table A4. Outline of hybrid evaluation approaches in relation to their views of interactions

Study	*Evaluation approach*	*View of interactions*	
i. Boonekamp, 2006	Conceptual analysis + Bottom up Partial Equilibrium model	**Policy instrument level:** All pairs of policy instruments are assessed with regard to the influence of one policy instrument on the energy saving effect of another, considering also different design characteristics. Important interaction effects identified within the qualitative assessment are quantified as to their influence on total efficiency gains among the following policies: - regulatory energy tax, - all subsidies, - regulation of gas use for space heating (building code and performance standards for new and existing dwellings).	**Stakeholders/Market level:** - EE is realized by purchasing systems or appliances with higher conversion efficiencies, or by applying demand reducing (i.e. wall insulation). - Then a cost/benefit formula (CBR) is applied to model the choice of more efficient systems and appliances or the decision to insulate dwellings. - The relation between the penetration of saving options and the CBR is modeled in the form of an S-shaped curve. - The simulation model then reproduces past energy developments, using the relationship between various policy instruments and the penetration of saving options (i.e. theoretical past trend).
ii. De Jonghe et al. 2009	Graphical equilibrium analysis + Regional Partial Equilibrium Model	**Policy instrument level:** The impact of price-based and quantity-based policy instruments concerning RES-Esupport and CO_2 mitigation is modeled with influences identified on the retail electricity price, as well as the price of commodities (allowances, certificates) in relation to the stringency (i.e binding or not) of quotas (i.e. targets) being imposed.	**Stakeholders/Market level:** A welfare maximization model of different interconnected regions is applied (the sum of consumer and producer surplus is estimated by withdrawing total costs from the total benefits involved with the power system of each region). When calculating welfare, the total amount of price -based policy instruments (premium and CO_2 tax), needs to be withdrawn from or added to the total welfare, accordingly after the maximization. Quantity-based policy instruments add a restriction to the model to enforce a certain percentage of renewables installed or a certain cap on CO_2 emissions.
iii. Bohringer et al.2008	Theoretical (qualitative) analysis + Computable General	**Policy instrument level:** Comparison of the before-tax and the after-tax situation: introduction of a carbon tax on top of an ETS allocation target acting as an additional reduction incentive on top	**Stakeholder/Market level:** The economic effects of an exclusive cap-and trade regulation under the EU ETS are compared to an overlapping regulation where the EU ETS is supplemented with an additional unilateral carbon tax in international as well as national

	Equilibrium model (PACE model)	of the allowance price,affects: - the level of emissions - the demand for allowances - the international allowance price	allowance markets. The effects on the marginal abatement costs for the respective EU member states subject to an additional carbon tax are compared to the marginal abatement costs for the remaining EU member states reflect the international allowance price (international allowance market).

Table A5. Outline of qualitative evaluation approaches in relation to their views of interactions

Study	Evaluation approach	View of interactions	
i. Hamerlink et al. 2008	Theory based policy evaluation	**Policy instrument level:** Interrelationships with other policy instruments in the EE policy package are included in the policy implementation theory of cause-impact relationships.	**Stakeholders/Market level:** Cause impact relationships and success factors referring to the response of target industry groups (companies, suppliers) to the EE policy package. Rebound and spill-over effects represented of interrelationships between market actors in response to a policy, were not taken into account.
ii. Oikonomou et al. 2009	Multi-criteria-based evaluation	**Policy instrument level:** **Policy instrument type** (mandatory/voluntary) **Objectives** (Nature of trargets, Direct/Indirect emissions, Energy or other environmental goals, Timing, Reference term (primary or final energy) **Scope** (Obligation bound entities, Sectors) **Market arrangements** (Non-obligated but eligible parties, Trading participants) **Market flexibility** (trading commodity, nature, lifitime of commodity, banking, borrowing provisions) **Accounting of environmental benefits** (Accounting of environmental benefits, Financing, Cost recovery, Government revenues raised) **Technological parameters** (Eligible technologies/project categories, Opt-in or opt-out for technologies, Accreditation ex-post or ex-ante, Issue of additionality) **Institutional setup** (Body for setting up the policy instrument, administration, verification, registration, project design, monitoring, reporting)	**Stakeholders/Market level:** Market mapping of participating entities that undertake EE actions and other entities or authorities responsible for monitoring or implementing the policy instrument: - market players that receive an energy obligation under WhC - non obligated market players (ESCOs, building companies, financial intermediaries), and - market players that can participate in negotiating a target under VAs to improve EE
iii. Pablo del Rio, 2010	Graphical analysis supported by Multicriteria assessment	Identification of whether the results of the interactions vary depending on the type of policy instrument (price based or quantity based). - Adding RES-E support to an ETS - Adding EE support to an ETS - Adding EE support to RES-E support - Adding RES-E support to EE support Additional analysis of the impacts of the different design elements of RES E promotion policy instruments on identified interactions.	**Stakeholders/Market level:** **-** In order to demonstrate different policy combinations against the effectiveness criteria, their impact is identified upon: CO_2 emissions, electricity demand and RES-E generation and investments. - Regarding static efficiency, the focus is set on consumer costs (as shown by variations in the retail el. price). - Dynamic efficiency is assessed by analyzing the impact on RES-E investments and on the currently least mature technologies.

iv. Oikonomouet al,2010	Multicriteria Decision Analysis	**Policy specifics level:** Policy makers express in a merit order the significance they attribute to design characteristics of a policy instrument. Policy makers in turn assign weights on evaluation criteria expressing their preferences helping to incorporate in the analysis the political context and contextual differences in policy interrelationships. The same design elements considered in Oikonomou et al. 2009 are also incorporated in this approach.	**Stakeholder-Market level:** Each policy instrument is broke down into its characteristics regarding also its target groups namely, obligated entities. Market flexibility for entities, eligible technologies, and additionality issues. A comparative overview of policy combinations based also on whether combined policies target the same group affecting thus distributional costs and benefits and thus market competition
v. Ropenus et al, 2011	Conceptual incentive analysis	**Policy instrument level:** The interaction of policy dimensions of connection charging regimes and support policy instruments is analyzed through a country based analysis of the different regulatory areas including case studies based on 5 EU MS(Spain, UK, Germany, Denmark, The Netherlands) leading to a comparative analysis of the implications of each county's current regulatory combinations. Network regulations: Shallow network charges, Shallowish netwrok charges, Deep network charges Support policy instruments regulation: Feed-in tariff, Price premium and Quota system	**Stakeholder/ Market Level:** Implications for the (partially conflicting) incentives of DG/RES producers and DSOs: - Conceptual analysis of different incentives of basic market actors (on DG producers and DSOs). - The impact of unbundling, access and network regulation as well as support policy instruments on DG producers and DSOs is analyzed based on their often-conflicting incentives. The effect and trade-off upon those two basic market actors and the direction of the effect (opposite/negative impact, same/positive impact) is discussed.
vi. Jensen and Skytte, 2003	Incentive and Graphical equilibrium analysis	**Policy instrument level:** - the use of one instrument to reach one goal, - two instruments to reach one goal, - two instruments to reach two goals simultaneously, c - effects of each scenario (i.e. stand-alone policy instruments and in combination) upon demand and supply curves,	A simple market analysis of the most significant participants in the power sector (Renewable power producers, thermal power producers and consumers) and the main drivers and reactions of those participants in the parallel power, green certificates and emissions permit market is analyzed. Market principles are derived on their behavior is thus described when different policies targeting energy and climate targets come into effect.
vii. Pablo del Rio,2006	Conceptual analysis (scenario building)	**Policy instrument level:** Four policy scenarios are developed: - ETS in Annex-I, no CDM (Clean Development Mechanism projects) - CDM, ETS, no TGC policy instrument -CDM, ETS, TGC policy instrument in AIC (annex I countries) - CDM, ETS, TGC policy instrument in AIC. Breaking down of those instruments into their principal design aspects: Type of instrument: (Market instrument- Project-based/Quantity based), Aim (Cost-effective GHG mitigation and sustainability of Non Annex I Countries/ Cost-effective deployment of RES-E), Target sector, Relevant Actors, Territorial scope (International/National), Unit of commodity. Additionally, possibilities to link the separate commodities (i.e. TGCs and	**Market Stakeholder level:** Analysis of Relevant Actors targeted by each policy instrument - Project proponent, investor Party, host country government, Designated Operational Entity and, CDM executive board - Demand side; Obligated actors: consumers, suppliers - Supply side: Generators, Public authority The TGC and CER (certificate emission credit) markets are separated The impact of policy scenarios on several variables

		CO_2allowances) are considered: Full fungibility, one-way fungibility and complete separation.	according to the interests of the abovementioned actors in both countries is discussed and compared: -Incentives for the implementation of RE-CDM projects countries - RES-E deployment and sustainability benefits - Conventional electricity deployment - Final consumer costs
viii. Levinson,2010	Conceptual incentive analysis	**Policy instrument level:** **- quantity regulations:** Tradable emission permits (Cap and Trade policy instrument) - **Price regulations**: Regulatory standards - Market based and non-market based - Cost levels of introducing each policy type - Abatement levels incurred by each policy instrument	**Market Stakeholder level:** Graphical analysis of Marginal Abatement Costs of polluters and meta-analysis of rationales behind introducing combined policy instruments. Possible changes in abatement costs are discussed based on the price signals of combined instruments compared to the price signals of stand-alone instruments.
ix. Sorell and Sijm, 2005	Conceptual theoretical analysis	**Policy instrument level:** - Cap-and-trade ETS + carbon/energy taxes; - support policy instruments for renewable electricity; - non-price instruments to overcome barriers to EE **Design specifics:** A distinction is made between : -**Directly and indirectly affected target groups:** Downstream/upstream implementation of an ETS: within a downstream policy instrument a distinction is made between direct and indirect treatment of electricity emissions). - Auctioning and free allocation of emissions Additionality issues are also discussed in terms of double regulation and double counting leading to either double coverage by a policy instrument or double counting. - The scope of each instrument (sectors, sites, portions of sites, and individual emission sources), objectives, operation (aggregate effect of the different obligations and incentives when applied in combination), the implementation (scope for rationalization and harmonization or regulatory responsibilities), timing (responses to 'triggers' and the scope for policy sequencing).	Market Stakeholder Level: Distinction between direct (directly targeted groups) and indirect(indirectly targeted groups) policy interaction: *- Direct interaction is where the target groups directly affected by two policies overlap in some way* *- Indirect interaction occurs when a target group is indirectly affected by one policy and either directly or indirectly affected by a second.* *-Trading interaction is where two policies influence one another by the exchange of an environmental trading commodity*
x.Sorell et al, 2009	Graphical equilibrium analysis	**Policy instrument level:** Price and quantity effects are identified for: - the EU ETS alone, compared to no regulatory intervention, - the EU ETS and TWC policy instrument in combination, compared to no regulatory intervention and - introducing a TWC policy instrument (i.e. the effect of the instrument combination compared to the EUETS alone).	**Market Stakeholder level:** A market for EE policy instruments (competitive, measures supplied at marginal cost), is considered parallel to the electricity market. Households are assumed to purchase the combination of electricity and EEM that maximize their welfare. Firms and commercial organizations are assumed to purchase the combination that minimizes their production costs.

References

Abrell, J., Hannes, W., 2008. The Interaction of Emissions Trading and Renewable Energy Promotion.Economics of Global Warming, WP-EGW-05.

Anandarajah, G.,Strachan, N., 2011. Interactions and implications of renewable and climate change policy on UK energy scenarios.Energy Policy 38, 6724–6735.

Bassi, A. M., 2010.Evaluating the Use of an Integrated Approach to Support Energy and Climate Policy Formulation and Evaluation. Energies 3, 1604-1621.

Bohringer, C., Rosendahl, E. K., 2010. Green promotes the dirtiest: on the interaction between black and green quotas in energy markets. Journal of Regulatory Economics 37, 316–325.

Bohringer, C., Koschel, H., Moslener, U.,2008. Efficiency losses from overlapping regulation of EU carbon emissions.Journal of Regulatory Economics 33, 299–317.

Boonekamp, P., G., M., 2006. Actual interaction effects between policy measures for EE - A qualitative matrix method and quantitative simulation results for households. Energy 31. 2848–2873.

Crabbé, A., Leroy, P. 2008. The Handbook of Environmental Policy Evaluation.Earthscan, London, Sterling, VA.

De Jonghe, C., Delarue E., Belmans R., D'haeseleer, W., 2009. Interactions between measures for the support of electricity from renewable energy sources and CO_2 mitigation. Energy Policy 37,4743–4752.

Del Rio, P., 2006. Linking renewable energy CDM projects and TGC schemes: An analysis of different options.Energy Policy 34, 3173–3183.

Del Rio, P., 2007. The interaction between emissions trading and renewable electricity support schemes.An overview of the literature. Mitigation and Adaptation of Strategies for Global Change 12:1363–1390.

Del Rio, P., 2010. Analysing the interactions between renewable energy promotion and EE support schemes: The impact of different instruments and design elements. Energy Policy 38 ,4978–4989.

Frankhauser, S., Hepburn, C., Jisung, P., 2011.Combining multiple climate policy instruments: how not to do it, Centre for Climate Change Economics and Policy, Working Paper No. 48.

Fischer, C., Preonas, L., 2010. Combining Policies for Renewable Policies: Is the whole less than the sum of its parts? Discussion Paper.Resources for the future, DP 10-19.

Garbarino, S. and J Holland J, 2009.Quantitative and Qualitative Methods in Impact Evaluation and Measuring Results Governance and social development Resource Center.

Grafakos, S., Flamos, A., Oikonomou V., Zevgolis, D. 2010. Multi-criteria analysis weighting methodology to incorporate stakeholders' preferences in energy and climate policy interactions, International Journal of Energy Sector Management, Vol. 4 Iss: 3, pp.434 – 461.

Götz, B., Voß, A., Blesl, M., Fahl, U., 2011.How to integrate feed-in tariffs in energy system models –the case of Germany. International Energy Week.

Hall, P.A., 1993. Policy paradigms, social learning, and the state: the case of economic policymaking in Britain. Comparative Politics 25, 275–296.

Harmelink, M., Nilson, L., Harmsen, R., 2008.Theory-based policy evaluation of 20 EEinstruments.EE 1, pp. 131-148.

He, Y., Wang, L., Wang, J., 2011. Cap-and-trade vs. carbon taxes: A quantitative comparison from a generation expansion planning perspective. Computers & Industrial Engineering,Vol. 63, Issue 3, pp. 708–716.

Hourcade, J., Jaccard, M., Bataille, C., Ghersi, F., 2006. Hybrid modelling: new answers to old challenges. The Energy Journal 2006 (2), 1–11.

IEA, 2011a.EE Policy and Carbon Pricing.*Information Paper*, IEA/OECD, Paris.

IEA, 2011b.Summing up the parts - Combining Policy Instruments for Least-Cost Climate Mitigation Strategies.Information Paper. Paris.

IEA, 2011c. Interactions of policies for renewables and climate change. Working Paper. Paris.

Jensen, G., S., Skytte, K., 2003.Simultaneous attainment of energy goals by means of green certificates and emission permits. Energy Policy 31, 63–71.

Jones, C. and J. C. Williams. 1998. "Measuring the Social Return to R&D". *Quarterly Journal of Economics* pp. 1119-1135.

Kannan, R., Strachan, N., 2009. Modelling the UK residential energy sector under long-term decarbonisation scenarios: comparison between energy systems and sectoral modelling approaches. Applied Energy 86 (4), 416–428

King G Keohane RO and Verba S (2004).Designing Social Inquiry: Scientific Inference in Qualitative Research.Princeton University PressKlessmann, C., Held, A., Rathmann, M., Ragwitz, M. 2011.Energy policy. Status and perspectives of renewable energy policy and deployment in the European Union—what is needed to reach the 2020 targets? Energy Policy 39, 7637–7657.

Konidari P., Mavrakis, D., 2007. A multi-criteria evaluation method for climate change mitigation policy instruments. Energy Policy Volume 35, Issue 12, Pages 6235–6257.

Levinson, A., 2010. The National Bereua of Economic Research. Belts and Suspenders: Interactions among Climate Policy Regulations. Working Paper No. 16109.

Linares, P., Santos, F.J., Ventosa, M., 2008. Coordination of carbon reduction and renewable energy support policies. Climate Policy 8, 377–394.

Mcvilly, R., K., Stancliffe, R., J., Paramenter, R.,T., Burton-Smith, R.,M., 2008. Remaining Open to Quantitative, Qualitative, and Mixed-Method Designs: An Unscientific Compromise, or Good Research Practice?International Review of Research in Mental Retardation 35, Pages 151–203.

Mankiw, N., G., 2007. Principles of microeconomics 4th ed. Tomson South Western. United States of America.

Morriss, F. J., 2009. Combining a Renewable Portfolio Standard with a Cap-and-Trade Policy: A General Equilibrium Analysis.Massachusetts Institute of Technology.

Niang-Diop, I., and Bosch, H., 2005. Formulating an Adaptation Strategy, Adaptation Policy

Frameworks for Climate Change: Developing Strategies, Policies and Measures, B. Lim, E.

Spanger-Siegfried, I. Burton, E.Malone and S. Huq, Eds. pp. 183-204, Cambridge University Press, Cambridge and New York

OECD, 2003. Institutional Capacity and Climate Actions, Case Studies on Mexico, India and Bulgaria.

OECD,2008. An OECD Framework for Effective and Efficient Environmental Policies.

OECD 2011.Interactions between Emission Trading Systems and Other Overlapping Policy Instruments. Paris.

Oikonomou, V., Jepma, C., Becchis, F., Russolillo, D., 2008. White Certificates for EE improvement with energy taxes: A theoretical economic model. Energy Economics 30, 3044–3062.

Oikonomou, V., Patel, M., K., VanderGaast, W., Rietbergen, M., 2009.Outcome indicators for the evaluation of energy policy instruments and technical change.Energy Policy 37, 1970–1982.

Oikonomou, V., Flamos, A., Grafakos, S., 2010. Is blending of energy and climate policy instruments always desirable? Energy Policy 38, 4186–4195.

Oikonomou, V., Flamos, A., Gargiulo, M., Giannakidis, G., Kanudia, A., Spijker, E., Grafakos, S. 2011a. Linking least-cost energy system costs models with MCA: An assessment of the EU Renewable Energy targets and supporting policies. Energy Policy, Elsevier, 39(5), pp.2786-2799.

Oikonomou, V., Flamos, A., Grafakos, S. 2011b. Combination of energy policy instruments: creation of added value or overlapping? International scientific Journal: Energy Sources, Part B: Economics, Planning and Policy, Taylor & Francis.

Oikonomou, V., Flamos, A., Zeugolis, D., Grafakos, S. 2011c.A Qualitative Assessment of EU Energy Policy Interactions. International scientific Journal: Energy Sources, Part B: Economics, Planning and Policy, Vol 7, Issue 2, pp. 177-187).

Oikonomou, V., Flamos, A., Spijker, E., Spyridaki, N.-A.,Van der Gaast, W.,2011d. Domestic Offset Projects in the built environment. EE.DOI 10.1007/s12053-011-9143-5.

Oikonomou, V., Flamos, A., Spyridaki, N., van der Gaast, W.2011e. White certificates and domestic offset schemes: Possible synergies, Journal of Mitigation and Adaptation Strategies for Global Change, doi:10.1007/s11027-011-9320-z.

OikonomouVlassis, 2012. APRAISE - Assess Policy Interactions through Enhanced System Understanding, Joint Implementation Quarterly, Groningen, the Netherlands, Vol. 18, No. 2, 8-10.

Palmer, K., Paul, A., Woerman, M., Steinberg, D., 2011. Federal policies for renewable electricity: Impacts and interactions. Energy Policy 39, 3975–3991.

Ragwitz, M., Rathmann, M., Resch, G., Nathani, C., Konstantinaviciute, I., Zagamé, P., EmployRES, 2009.Final Report to the European Commission, Brussels, Belgium.

Rogge. K., S., Schneider, M., Hoffmann, H., F., 2011.The innovation impact of the EU Emission Trading System — Findings of company case studies in the German power sector. Ecological Economics 70, 513–523.

Ropenus S, Jacobsen, K., H., Schröder, S., T., 2011. Network regulation and support schemes e How policy interactions affect the integration of distributed generation. Renewable Energy 36, 1949-1956.

Sorrell S. Interaction in EU Climate Policy—policy design and policy interaction: literature review and methodological issues. A report to DG Research under the Framework V project interaction in EU Climate Policy, University of Sussex; 2001.

Sorrell, S., Smith, A., Betz, R., Waltz, R., Boemare, C., Quirion, P., Sijm, J., Mavrakis, D., Konidari, P., Vassos, S., Haralampopoulos, D., Pilinis, C., 2003.Interaction in EU Climate Policy.INTERACT project. Final Report to the European Commission, Brussels, Belgium.

Sorrell, S., Sijm, J., 2005.Carbon Trading in the Policy Mix.Oxford Review of Economic Policy, VOL. 19, No. 3.

Sorrell, S., Harrison, D., Radov,D., Klevnas, P., Foss, A., 2009. White certificate schemes: Economic analysis and interactions with the EU ETS.Energy Policy 37, Pages 29–42.

Strachan, N., Balta-Ozkan, N., Joffe, D., McGeevor, K., Hughes, N., 2009a. Soft- linking energy systems and GIS models to investigate spatial hydrogen infrastructure development in a low-carbon UK energy system. International Journal of Hydrogen Energy 34 (2), 642–657

Tsao, C., Campbell, J., E., Chen, Y., 2011. When renewable portfolio standards meet cap-and-trade regulations in the electricity sector: Market interactions, profits implications, and policy redundancy.Energy Policy 39, 3966–3974.

UKACE (2000), RS06: Employment Impacts of EE Investment Programmes, London, UK Association for the Conservation of Energy.

Van Beeck, N., 1999. Classification of Energy Models, Tilburg University & Eindhoven University of Technology

Zhong, Y.,Cai, W.G., Y.Wu, H.Ren., 2009. Incentive mechanism design for the residential building EE improvement of heating zones in North China. Energy Policy (37) (2009) 2119–2123.

3. Chapter 3: A multi-criteria process evaluation of EE policy instruments

Abstract

This paper applies a multi-criteria analysis (MCA) to evaluate public policy mechanisms that foster EE and renewable energy sources in the Greek building sector, based on stakeholders' understanding and perceptions of the functionality of PIs. The objective is to shed light on the implementation of currently employed policy mechanisms that aim to achieve the 2020 energy savings targets and beyond, providing useful information to policy makers for future policy (re-) formulations. In this framework, PIs were evaluated against process-related criteria, such as implementation costs, distributional effects, and coherence of policy processes, to highlight successful policy practices during their implementation phase as well as to unveil cases of policy underperformance or unintended policy outcomes. To hedge uncertainties related to PI selection, the method employs probabilistic evaluations of every alternative against each criterion. The MCA results showed that the country is still missing significant energy saving opportunities that could be reached through more streamlined implementation practices and political support. In times of fiscal crisis, the Greek government should also revitalize the implementation of alternative funding mechanisms and support policy alternatives such as green public procurement, voluntary agreements, and energy performance contracting.

3.1 Introduction

European Union's (EU) buildings account for 40% of final energy consumption and 36% of greenhouse gas (GHG) emissions in the EU, while 35% of them are over 50 years old (European Commission (EC), 2013). Buildings in Greece are a major energy consumer since the majority of buildings was built before 1980 when the Regulation on thermal insulation was introduced (Ministry of Environment Energy and Climate Change (MEECC), 2011). For the household sector the average consumption (for years 2000 to 2012) per dwelling, scaled to EU average climate was about 23% higher than the EU average, while final electricity consumption of the tertiary sector (for years 2001 to 2009) per employee was about 6% higher than the EU average (ODYSSEE-MURE Database, 2012). The Greek building sector can largely contribute to GHG emissions reduction while according to a study produced by McKinsey (2012), there is a potential to reduce the sector's GHG emissions by about 15%.

Actions promoting EE (EE) and renewable energy sources (RES) technologies in the Greek building sector constitute key solutions to achieve energy savings and GHG emissions reduction as well as means to meet EU energy and climate targets for 2020, i.e. a 20% reduction in GHG emissions by 2020 compared to 1990 levels, increase of renewable energy share by 20% and 20% energy savings achievement, and beyond. The 20-20-20 EU targets and relevant Directives have been quickly adopted in Greece causing structural changes in the country's energy and climate policy over the last years (Spyridaki et al., 2014). Greek energy and climate policy mechanisms have been oriented to meet with the relevant European policy and objectives and have already introduced a number of measures fostering EE interventions and RES installations. More recently, in light of the new EE Directive (EED), the Greek government has proposed a set of eighteen alternative PIs, both from the existing PI mix as well as new ones to fulfil its national requirements (MEECC, 2014a). Reportedly, existing instruments continued in the new National EE Action Plan (NEEAP) submitted in December 2014, such as subsidy programs, demonstrate restrained participation levels both at the residential and tertiary sector, whereas other types of legislated PIs remain still in idle.

In the meantime, the economic slowdown continues to stroke the average household income and final consumption expenditure as well as general investment capacity. Increasing trends in governmental debt to gross domestic product (GDP) ratio over the last years (Eurostat) have hindered the funding and support of energy savings policies. Liquidity shortages have also restrained growth in the energy savings market, whilst restrained consumers' fundability and creditability still prevents them from participating in energy savings and RES installation programs. As a result, reduction observed in energy consumption levels has for the most part been related to the economic recession impacts, combined with escalating energy costs (MEECC, 2011a), and has been attributed to a lesser extent to the successful implementation of EE improvements.

In the framework of extended recession and budgetary constraints, divergent interests and legal obligations, decision makers in Greece face major difficulties in the process of finding suitable and reliable solutions to save energy and reduce GHG emissions. Often, the priorities and strategies for supporting energy saving interventions vary between stakeholders, influential over policy decision-making, and compete in multiple aspects. To overcome these challenges, policy makers make use of models and tools to support the process of identifying solutions.

However, PIs often yield different policy outcomes from those anticipated or they might produce a horde of unintended effects (van der Gaast and Lehtonen, 2015). Policy underperformance or unintended policy outcomes can be associated with various reasons, including assumptions embedded in policy design about the causality of policies in relation to their outcomes, as well as unexpected implementation and market barriers. Essentially, best-intended policies and instruments may fail if process-wise they are poorly designed and implemented. The need to focus on specific stages of the policy cycle when evaluating policy mechanisms has been cited by several policy evaluation studies (Crabbé and Leroy, 2008; Goulder and Parry, 2008; Gysen et al., 2006) as well as "the need to look beyond the traditional goal-achievement model" and to fine tune the performance criteria in accordance to the context (van der Gaast and Lehtonen, 2015).

In the above framework, this paper applies a multi-criteria evaluation on the grounds of stakeholder perceptions, in order to discuss and evaluate public policy mechanisms in Greece. The aim is to enlighten the scene of PIs employed for the achievement of 2020 targets. Empirical findings on the implementation of PIs, complementing the MCA results, were collected from an ex-post policy assessment of Greek EE and RES policy mechanisms, within the framework of the EC FP7 project 'APRAISE – Assessment of Policy Interrelationships and Impacts on Sustainability in Europe' (Tuerk et al., 2014), whose objective was to empirically assess existing environmental policies in selected sectors of EU Member States and enhance research on multiple design parameters of environmental policies. The aim of the present paper is to identify which PIs have been implemented more effectively, as perceived by related policy actors, against process effectiveness criteria such as implementation costs, distributional effects and coherence of policy processes. Addressing such effects in line with their incidence during the implementation phase can facilitate the understanding of the causal chains from policies to outcomes and impacts.

The structure of the paper is as follows: section 3.2 presents a literature review of energy and climate policy studies based on MCA applications. Section 3.3 elaborates on the main steps and concepts of the assessment framework adopted, the stakeholder survey conducted and the choice of the MCA method to be used for the evaluation. Section 3.4 then describes the fundamentals of the selected MCA method and section 3.5 presents the weighting method selected. Section 0 provides the results of the stakeholder survey and the MCA method. The paper concludes with a discussion on policy implications and recommendations.

3.2 Review of the literature and need for the analysis

Evaluations of climate change mitigation policies are multi-dimensional and complex problems (Grafakos et al., 2010; Oikonomou et al., 2014, 2012, 2011) that incorporate multiple, often conflicting, actors and objectives. In order to deal with these multifaceted decision-making problems and capture the complexity arisen, MCA provides a transparent tool to consider the multiple aspects of the decision problem (Gamper et al., 2006; Grafakos et al., 2010) allowing the inclusion of multiple criteria, policy priorities and goals. It is capable of integrating into the analysis different stakeholders' preferences so as to stress different perspectives (Grafakos et al., 2015). Furthermore, MCA represents a sound methodology that evaluates, compares and rates policies hence enabling the identification of successfully implemented practices, highlighting policies' success factors and weaknesses (de Melo et al., 2013; Tholen et al., 2013).

MCA approaches have been widely applied in technical planning (Kaldellis et al., 2013; Kaya and Kahraman, 2011, 2010; Løken et al., 2009; Mourmouris and Potolias, 2013; Ribeiro et al., 2013; San Cristóbal, 2011; Sliogeriene et al., 2013; Troldborg et al., 2014; Tsoutsos et al., 2009) and policy planning (Browne et al., 2010; Diakoulaki and Karangelis, 2007; Haydt et al., 2014; Javid et al., 2014; Kowalski et al., 2009; Stagl, 2006; Streimikiene and Balezentis, 2013), at either local or national levels. However, only a few multi-criteria evaluation approaches have been conducted focusing on evaluating the performance at a PI level (Spyridaki and Flamos, 2014) and these are summarized in Table 3.1.

The majority of multi-criteria policy evaluation studies adopt a rational view on policy, implying an ex-ante estimation of the possibility that desired policy impacts[8] will be achieved. They assess PIs by estimating their impacts and congruently their effectiveness as a result of their implementation. By looking at Table 3.1, one can observe that most multi-criteria evaluations tend to focus primarily on the assessment of policy impacts. More frequently the evaluations carried out use criteria, which concentrate largely on policy effects and to a lesser extent on policy processes and implementation[9]. Each phase in the policy cycle, such as the implementation one, should be evaluated in its own right, especially when one's aim is to shed light on the so-called "implementation deficit", which may clarify the differences between policy in paper and tangible policy effects (Crabbé and Leroy, 2008). The policy implementation process is of fundamental importance in determining a PI's effectiveness (Rogge and Reichardt, 2013) and may impinge on policy's success (Crabbé and Leroy, 2008). Hence, more studies should turn their focus on the evaluation of interim policy products (i.e. policy outputs or policy performance) produced during intermediate phases in the policy cycle. These "policy process outputs" should be regarded and treated with equal importance to final policy impacts like final environmental effects, since the former often prescript the attainment of the latter.

In this paper, policy is also considered as a goal-oriented rational process (Crabbé and Leroy, 2008), according to which, the purpose of the policy evaluation becomes rather clear: to assess policy processes and implementation using performance criteria played out in a series of straightforward indicators. Policy evaluation will therefore not focus on comparing goals with achieved effects. It will rather be seen as an assessment of policy products and processes produced throughout the implementation phase of the policy cycle. This is depicted onto the selected criteria set describing the functionality of PIs through indicators related to factors such as implementation hurdles, compatibility issues and coherence featuring coordination processes among pertinent authorities.

The functionality of PIs in terms of resources and capacities, as perceived by related policy and market actors, could influence future PI selection and adaptations (Hood and Margetts, 2007). Hence, we argue that policy makers' as well as other related stakeholders' perception of a PI's way of functioning remains an important source of knowledge for policy selection and design (Capano and Lippi, 2013; Crabbé and Leroy, 2008). The evaluation, thus, relies on the understanding and perceptions of PIs' functionality as expressed by policy makers and their consultants, providing sufficient insights for much needed ex-post policy evaluation in Greece to feed into future policy developments.

---

[8] According to Crabbé and Leroy (Crabbé and Leroy, 2008), policy effects may refer to policy outputs, policy outcomes or policy impacts. Policy outputs are defined as "the decisions on objectives and instruments meant to achieve policy goals", policy outcomes as "the behavioural changes and responses of actors in society, and policy impacts as "the environmental and other effects resulting from the outcomes" (Nilsson et al., 2012).

[9] Policy processes are defined by Nilsson et al. (Nilsson et al., 2012) as "the procedures and institutional arrangements that shape policy making" and are distinguished primarily between policy making and policy implementation (Rogge and Reichardt, 2013). Policy implementation is defined by Nilsson et al. (Nilsson et al., 2012) as "the arrangements by authorities and other actors for putting policy instruments into action".

Table 3.1 Performed multi-criteria evaluations of climate change mitigation PIs

Multi-criteria evaluation	**Evaluation criteria**	**Evaluation of**	**MCA method**	**Type of evaluation**	**Perspective of evaluation**
Konidari and Mavrakis (2007)	*Environmental performance* (Direct contribution to GHG emission reductions, Indirect environmental effects), *Political acceptability* (Cost efficiency, Dynamic cost efficiency, Competitiveness, Equity, Flexibility, Stringency for non-compliance), *Feasibility of implementation* (Implementation network capacity, Administrative feasibility, Financial feasibility)	EU ETS schemes at eight EU Member States	Multi-Attribute Theory (MAUT) Simple Multi-Attribute Ranking Technique (SMART)	policy impacts, policy processes (policy implementation)	ex-post
Blechinger and Shah (2011)		PIs for the power generation sector of Trinidad and Tobago	Simple Multi-Attribute Rating Technique (SMART)		ex-ante
Mundaca and Neij (2009)	Energy saving and environmental effectiveness, Economic efficiency, Cost-effectiveness, Transaction costs, Political feasibility, Administrative burden and Technical change	Trading White Certificates (TWC) schemes of Great Britain, Italy and France	multi-criteria evaluation (without MCA application)	policy impacts, policy processes (policy implementation)	ex-post
Oikonomou et al. (2010)	*Climate* (Reduction GHG emissions, Increase of environmental awareness), *Energy* (Security of supply, Reduction energy intensity), *Financial* (Compliance costs, Administration costs, Transaction costs, Governmental revenues), *Macroeconomic* (Market competition, Employment, Competitiveness, Business opportunities and trade), *Technological* (Innovation cycle, Diffusion of existing technologies)	Combinations of energy and climate PIs	Energy and Climate Policy Interactions (ECPI) tool – multi-criteria evaluation	policy impacts	ex-ante
Venmans (2012)	*Environmental effectiveness* (Abatement, Over-allocation, Predictability of environmental impact, Environmental side effects: carbon leakage), *Cost-effectiveness* (Cost-efficiency, Cost-effectiveness, Transaction, Dynamic cost-efficiency: innovation), *Distributional considerations* (Windfall profits, Social distributional effects, Intercountry and intersector transfers), *Institutional feasibility* (How the ETS gained support among the European Commission, industry and a number of NGOs, Technical complexity of trading, The ambiguous effect of free allocation on political acceptability)	EU ETS scheme	multi-criteria evaluation (without MCA application)	policy impacts, policy processes (policy implementation)	ex-post
de Melo et al. (de Melo et al., 2013)	Prior experience, Impacts demonstrated, Ease of implementation, Potential for market transformation, Cost to Society, Cost to Consumer, Compatibility with the strategic objectives of the government	PIs promoting EE and RES technologies in Brazilian building sector	PROMETHEE II	policy impacts, policy processes (policy implementation)	ex-ante
	CO_2e mitigation potential, Cost to society, Potential for employment generation, Ease of implementation	PIs promoting EE and RES technologies in Brazilian building sector	PROMETHEE II	policy impacts, policy processes (policy implementation)	ex-ante
Haydt et al. (Haydt et al., 2014)	CO_2 emissions savings, Payback period, Imported energy savings, Investment cost, Electricity savings, Total suspended particles (TSP) emissions savings, Lifetime, Potential final energy savings	EE measures	combination of NSGA-II (Non-dominated Sorting Genetic Algorithm II) with ELECTRE III	policy impacts	ex-ante

3.3 Steps in the policy evaluation approach

The rationale and logical steps followed in the assessment approach are presented in Figure 3.1. The first step lies on determining the research framework which can be decomposed to setting the research problem, selecting of an appropriate set of alternatives under assessment, defining evaluation criteria as well as the selection experts to support the participatory process of the analysis (Belton and Stewart, 2002; Gamper and Turcanu, 2007; Grafakos et al., 2010). No sooner than these components are determined, that appropriate means to serve the scope and needs of the analysis are explored. These are analyzed in detail in the sections to follow (please refer to sections 4.3.3.1 and 4.3.3.2). A step-wise process of evaluation and data acquisition is followed and finally, the MCA algorithm is applied in order to produce recommendations, which aid policy decision makers to make better-informed decisions regarding future policy adaptations of policy mechanisms promoting energy conservation in buildings.

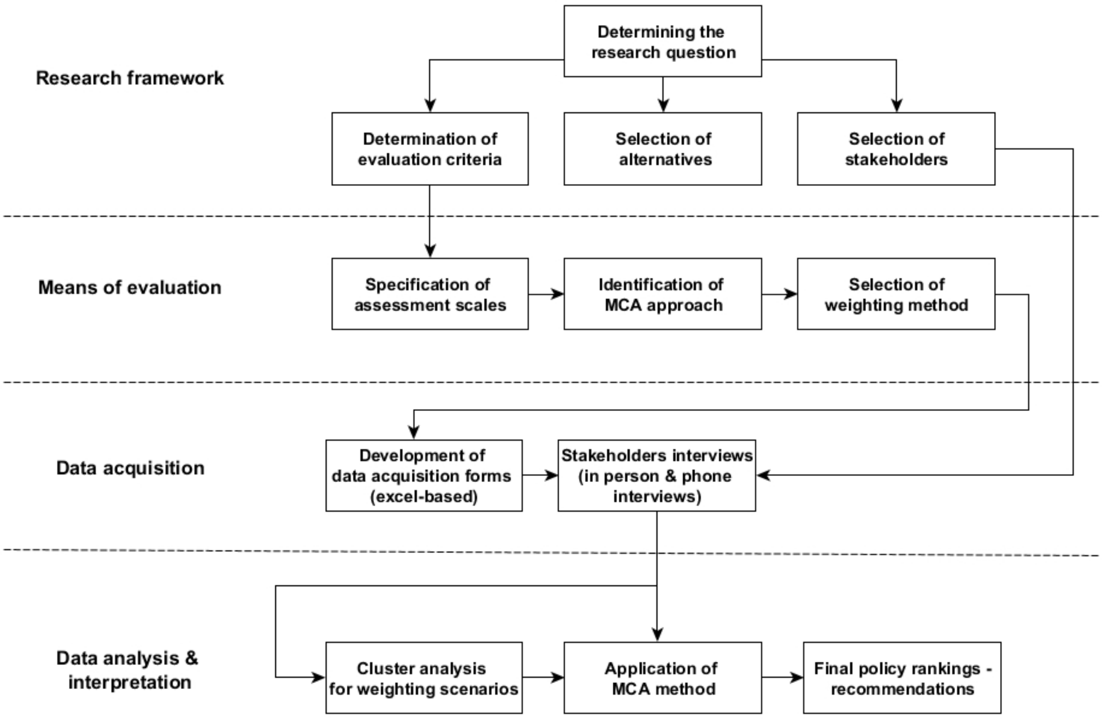


Figure 3.1 Steps in the assessment framework

3.3.1 Main concepts and objectives of the analysis

The main scope of this analysis is to evaluate how policy mechanisms promoting EE and RES in the Greek building sector have performed, gaining in this way a better understanding for future policy planning and evaluations. Policy mechanisms, which have been in effect in Greece in recent years, were screened based on literature review. PIs to be evaluated were selected according to the following criteria: 1) duration and timing in effect, 2) high to medium energy savings potential, 3) representation of several measure types. A short description of PIs under evaluation is summarized in Table 3.2 These are categorized following the classification of instrument types adopted by MURE Database.

Table 3.2 Summary of policy alternatives (PIs) under investigation

Alternatives	**Type**	**Description**	**Sector**	**Timeframe**
P1. Feed-in-tariff for small PV rooftop systems in buildings (≤10KW) (FiT)	Market-based	Program supporting electricity generation by roof-top photovoltaic (PV) installations through a guaranteed feed-in tariff (FiT)	Residential	2010 - 2019
P2. Subsidies for EE interventions in buildings (Subs)	Financial	Programs offering financial incentives to buildings' owners to carry out important EE interventions	Residential, Commercial	2011 - ongoing
P3. Tax reliefs for EE interventions / RES installations in buildings (TaxR)	Fiscal	Programs offering fiscal incentives to consumers for RES installations and EE interventions with the aim of promoting relevant technologies	Residential	2010 - ongoing
P4. Energy Performance Certificates (EPCert)	Informative	Energy performance rating of buildings with the aim of providing information on buildings' energy consumption and driving market demand for more energy efficient buildings	Residential, Commercial, Public	2011 - ongoing
P5. Energy Building Codes (EBCode)	Regulatory, Standards and Norms	National regulation that introduced integrated energy design in the building sector to improve EE and increase energy savings	Residential, Commercial, Public	2011 - ongoing
P6. Energy Labelling of appliances (ELabel)	Informative /Education	Energy labelling of electrical equipment with the purpose of promoting the penetration of energy efficient electrical appliances in the market	Residential, Commercial	2010 - ongoing
P7. Green Public Procurement (GPP)	Informative	Processes whereby public sector procure goods or services taking into account green criteria when evaluating tenders with the purpose of saving energy and driving market transformation towards more energy efficient products	Public	2008 - ongoing
P8. Energy Performance Contracting (EPContr)	Co-operative measures, Financial, Legislative/Informative	Contractual agreements between a provider (typically an ESCO) and a beneficiary to implement energy upgrade interventions in buildings which are funded from cost reduction resulting from energy savings	Residential, Commercial, Public	2012- ongoing
P9. Public Leadership Programs (PLP)	Regulatory	Programs promoting energy upgrade interventions or RES installations and demonstration projects in buildings of public sector accentuating its exemplary role	Public	2011- ongoing
P10. Voluntary Agreements / Co-operative measures (VA)	Co-operative measures	Public-private sector partnership – VAs with the market to provide better prices to consumers for implementing EE interventions	Residential, Commercial	2011- 2020

The evaluation of PIs was based on a set of criteria reflective of the objective of the policy evaluation, i.e. the assessment of interim policy products and processes related to their implementation phase of policy cycle. The evaluation criteria selected were those considered by Spyridaki et al. (Spyridaki et al., 2014) and their definitions (along with indicators used as benchmarks for assessing performance) are presented below:

Incentive to invest/comply is defined as the strength of the incentive provided to invest/comply with the policy. In case of financial instruments, it can be assessed through financial metrics such as return on investments or payback period. In case of regulations, it refers to the obligations binding target groups to comply.

Familiarity refers to public awareness regarding the existence, operation and terms associated with the PI as well as its yielded benefits. It evaluates the level of information diffusion about the PI through information campaigns/ advertisements/ updated websites, and/or internally among bodies and/or driven by the market.

Fairness in distribution principles is defined as the fairness of the PI in distributing compliance costs and benefits among target groups. It is examined whether the PI is characterized by fair eligibility criteria that proportionally favor members of society and is associated with fair distribution of costs without disproportional burdens, minimizing distributional effects on vulnerable or non-participating groups (based on Konidari and Mavrakis (Konidari and Mavrakis, 2007)).

Adaptability to exogenous changes is defined as the property of the PI to be flexible in case of exogenous market signals. The adaptability of the PI is translated into a) minimum adjustment time period, b) wide range of compliance actions, c) adaptable time period in achieving compliance, d) wide range of financial mechanisms for participation (based on Konidari and Mavrakis (Konidari and Mavrakis, 2007)).

Transaction costs are considered to be the costs accompanying transactions during execution of policies and do not concern costs directly related to project implementation (such as investment or administrative costs) (Mundaca, 2007). Transaction costs are created due to lack of policy coherence and harmonization of procedures (Spyridaki et al., 2015b). They are linked to financial, information or institutional barriers (Mundaca et al., 2013) and concern costs such as costs for information collection, additional costs for hiring/ training extra staff and additional administrative costs (administrative delays) due to lack of coordination (Mundaca, 2007).

Institutional management and coordination refers to the coordination and management links among pertinent governmental authorities that ensure regular information flows resulting in accelerating procedures. Assessment under this criterion examines evidence of cooperation and sound operation of communication networks among institutions/ actors responsible for implementing/executing the PI (Rogge and Reichardt, 2013; Spyridaki et al., 2014).

Compatibility with the national policy strategy refers to absence of contradictions or evidence of synergies with energy and climate policies as well as policies of the broader national policy framework. Compatibility is examined in terms of consistency of objectives as well as of legal acts (complementarities with existing legislation), assessing in this way PIs' integration in the entire/national policy mix (Rogge and Reichardt, 2013; Spyridaki et al., 2014).

Institutional set-up and capacity is defined as the capacity of governmental authorities to implement a PI. A sufficient implementation network depends on skilled and experienced personnel as well as on the availability and usage of techniques, able to support the implementation, operating in an accurate and transparent way (Konidari and Mavrakis, 2007).

Monitoring and control refers to the activities performed in order to identify non-compliance, delays or other barriers and enforce the PI. It examines on the one hand, the establishment and sufficient operation of mechanisms (e.g. penalties) responsible for identifying non-compliance/ participation and on the other hand, the effectiveness of monitoring activities offering market feedback resulting in timely policy updates (Konidari and Mavrakis, 2007).

Financial Viability refers to the ability of the instrument to be administered and funded with low overall costs by the regulatory authorities. These costs refer to administrative or operational costs (e.g. costs for PI preparation, implementation and monitoring) as well as funding costs (e.g. subsidies, tax exemptions) that can be derived either from state budgeting or European financing.

The table underneath (Table 3.3) summarizes the aforementioned evaluation criteria as well as the assessment scales created to assess the performance of each alternative. Due to the qualitative nature of the criteria, ordinal scales, that measure comparatively alternatives' performance, were defined. As shown in Table 3.3, different scales reflecting the heterogeneity of evaluation criteria (Figueira et al., 2005) were used for each criterion. Experts, having engaged in the process of establishing criteria definitions and judging alternatives performances across the selected criteria, have also contributed to determine the most appropriate scale per criterion. Consequently, a score was assigned to each level of the scale to facilitate the elicitation of data, as requested by several interviewees, and enable the application of the selected MCA method. One example of an ordinal scale defined to measure the performance of "monitoring and control" is presented in Table 3.4

Table 3.3 Evaluation criteria (adapted by Spyridaki et al. (2014)) and corresponding assessment scales

Criteria	Description
Incentive to invest/comply (Mot)	Strength of the yielded incentives to invest or comply due to policy intervention.
0: No incentive at all. **1**: Very low incentive. **2**: Low incentive. **3**: Neither high, nor low incentive. **4**: High incentive. **5**: Very high incentive	

Familiarity (Fam)	Public awareness associated with the PI through information/ advertisements/ official websites.
0: No familiarity. **1:** Very little familiarity. **2:** Little familiarity. **3:** Neither high, nor little familiarity. **4:** High familiarity. **5:** Very high familiarity	
Fairness in its distribution principles (Eq)	Distributional effects associated with relevant benefits and compliance costs among target groups.
0: Not at all fair. **1:** Very unfair. **2:** Less unfair. **3:** Marginally fair. **4:** Fair. **5:** Very fair	
Adaptability to exogenous changes (Adap)	Flexibility in case of exogenous market signals (required time for adjustment) and available options for participation / compliance.
0: Not at all flexible. **1:** Little flexibility. **2:** Marginally flexible. **3:** Flexible. **4:** Very flexible	
Transaction Costs (Trans)	Additional costs accruing of potential barriers (economic, information, or institutional barriers) during policy implementation.
0: Very High transaction costs (TCs). **1:** High transaction costs. **2:** Neither high, nor low transaction costs. **3:** Low transaction costs. **4:** Very low transaction costs. **5:** No transaction costs at all	
Institutional management & coordination (Coord)	Management structures existence of oversight bodies, coordination of policy targets, networks of communication and established information flows.
0: Not at all. **1:** Limited coordination. **2:** Neither limited nor adequate coordination. **3:** Adequate coordination. **4:** Very Adequate coordination	
Compatibility with national policy strategy (Comp)	Addressing relevant market barriers in a way that, synergies and/or contradictions among policies in pursuit of different policy targets and objectives are promoted.
0: No compatibility. **1:** Very little compatibility. **2:** Little compatibility. **3:** Compatible. **4:** Very compatible	
Institutional set-up and capacity (Inst)	Capacity (personnel, available technologies and previous experience of associated regulators) of regulatory authorities to administer and support the implementation of the instrument.
0: No capacity at all. **1:** Very low capacity. **2:** Low capacity. **3:** Neither high, nor low capacity. **4:** High capacity. **5:** Very high capacity	
Monitoring & control (MnC)	Sanctions, inspections and monitoring processes to identify barriers during the execution of the mechanism ensuring compliance are considered.
0: No monitoring & control at all. **1:** Very limited monitoring & control. **2:** Little monitoring & control. **3:** Marginally adequate monitoring & control. **4:** Adequate monitoring & control	
Financial viability (Fin)	The ability of the mechanism to be implemented with low overall costs (operational costs and total expenditure imposed on society).
0: No financial viability. **1:** Very low financial viability. **2:** Low financial viability. **3:** Neither high, nor low financial viability. **4:** High financial viability. **5:** Very high financial viability	

Table 3.4 Ordinal scale defined for the criterion “monitoring & control”

Level of scale/value	**Description**

0: Not at all	Complete absence of a monitoring plan or functioning of control mechanisms in place
1: Very limitted	Monitoring plan established, control mechanisms and ex-post verification inspections taking effect once per project, for only a few investment projects
2: Limitted	Monitoring plan established, rare checks and verification measurements (e.g. limited sample checks)
3: Marginally adequate	Minimum monitoring and control activities taking place sporadically (e.g. 3% of projects)
4: Adequate	Sufficient and periodic monitoring and control checks for a representative number of projects implemented

3.3.2 Implementation

Lack of ex-post policy evaluation studies in Greece urged the need of collecting information and data from experts. Hence a survey was carried out, which had a double purpose: (i) to enlighten the design and implementation process of PIs by evaluating their performance across related criteria and (ii) to explore the significance of different aspects in this process by determining criteria weights.

Stakeholder identification and key actors' selection preceded the actual engagement. However, key actors and experts, especially on a higher decision-level, may often be reluctant in sharing knowledge/information while certain stakeholder groups would provide biased information to strengthen their position (Gamper and Turcanu, 2007). To minimize the impacts of such inherent weakness of the governmental use of MCA over the research results, increased emphasis was placed on the selection of different stakeholder groups aiming for a wide stakeholder involvement. Representatives of each stakeholder group were chosen on the basis of their relevance with the policies under evaluation, as well as their capacity to provide credible information on the field of policy planning for energy efficient buildings overall. Stakeholders from different MEECC departments and energy agencies were the primary focus of the survey, representing policy makers in various decision-levels. To complete the spectrum of opinions, RES market actors and Energy Service Companies (ESCOs) were also selected to represent program beneficiaries. Finally, representative from the academia and Non-Governmental Organizations (NGOs), often participating in public consultations during policy (re-) formulation, also complemented the analysis. In total, forty-five bilateral interviews (twenty-two in person interviews and twenty-three over the phone), with duration of approximately half an hour to forty-five minutes each, were carried out.

The interview process was conducted with the use of data acquisition forms (excel based) consisting of both open-ended and close-type questions. Survey participants were requested to evaluate PIs' performance against the selected criteria and to provide criteria weights (see section 3.5). Following the acquisition of weights, participants were also asked to answer open-ended questions, designed to identify views on problems with implemented instruments as well as areas for improvement. Out of the forty-five interviews conducted, thirty-eight stakeholders agreed to provide quantitative information, whereas the rest participated by providing insights to open-ended questions. Given their influence on the decision-making process, their opinions were considered as providing insights into instruments' performance as well as future policy reformulations and were embedded in the discussion also through verbatim quotes to illustrate important points made.

Survey results were then statistically analyzed using Ward's hierarchical cluster analysis method (see Section 3.6.1) in order to recognize expressed stakeholders' priorities regarding the significance (i.e. weight) of evaluation criteria over policy effectiveness, distinguishing those in decision-making clusters. With respect to these groups, weighting strategies were established and finally the evaluation results were obtained by implementing a MCA for each strategy.

To select the MCA method to be employed, the objective and special characteristics of the problem were taken into account. No single instrument can be deemed as clearly superior along all the evaluation dimensions relevant to policy choice (Goulder and Parry, 2008). Therefore, the aim of the evaluation problem was not to identify the "best" performing policy since PIs under examination were not considered as mutually exclusive solutions to the problem (Roy and Bouyssou, 1991). Instead, the objective of the policy analysis was to rank actions (i.e. PIs) so as to exploit results obtained and elaborate on policy recommendations. A ranking problematic thus required for the decision-making problem, coupled with the necessary use of ordinal evaluation scales indicated towards the selection of the ELECTRE III method for performing the MCA analysis (Figueira et al., 2005). However, the uncertainty that is attached to evaluations of actions contradicted such a selection. Stakeholders' difficulty in providing their evaluations under the measurement scales, subjectivity that may be introduced due to their perceptions or incomplete information were recognized as uncertainty aspects (Antunes and Henriques, 2014; D'Avignon and Vincke, 1988). Variability among experts' judgments and imprecision in their evaluations relates also to the use of ordinal scales. As a result, each alternative evaluation with respect to each criterion is not known with certainty. To account for uncertainty of input data and provide more robust results, the probability distribution of the evaluations of each alternative with respect to each criterion had to be considered instead of a point evaluation (Martel and d' Avignon, 1982) (please refer to Section 3.4). Thus, the outranking relation method developed by Martel and d' Avignon (Martel and d' Avignon, 1982), which is an adaptation of the ELECTRE III method in cases of uncertainty (Siskos, 2008), was selected to address the uncertainty problem. This method has never been applied before, to the best of the authors' knowledge, for energy and climate policy evaluation.

3.4 The MCA method

The outranking relation method developed by Martel and d' Avignon is applied for information included in the impact matrix in the form of distributive evaluations. The authors of the method use the term "distributive evaluations" to explain that values filling the impact matrix take the form of probabilities obtained by applying the probability distribution function for each assessment scale per criterion (Martel and d' Avignon, 1982). This results in matrices of probabilistic evaluations (Siskos, 2008) instead of an impact matrix with point evaluations used in other ELECTRE methods. For the rest of the paper, the term probabilistic evaluation is also adopted. The fundamentals of the method are presented below:

Consider a finite set of actions to rank A={a,b,c,…} and a consistent family of criteria F={g1,g2,g3,…,gm}. Each action $a \in A$ is evaluated on each criterion g_i using a scale Ei (where g_i^j is the j level of the scale) assuming that the evaluation of each action with respect to each criterion is not a point evaluation but is defined through a probability distribution function (δ_i^a), such that $\sum_j \delta_i^a \left(g_i^j\right) = 1$ (Siskos, 2008). According to the method, the outranking relation is built as follows (Martel and d' Avignon, 1982; Siskos, 2008):

1) Confidence Index

First, for each criterion gi and each pair of actions $(a, b) \in AxA$ the following index is calculated:

$$c_i(a,b) = \sum_j \delta_i^b \left(g_i^j\right) \sum_{\kappa \geq j} \delta_i^a \left(g_i^\kappa\right)$$

that expresses the relevant frequency of values $g_i^j \in E_i$ which are at least as high for action a than for action b. Then, the confidence index for the pair of actions (a,b) is defined as:

$$C(a,b) = \sum_{i=1}^{m} w_i c_i(a,b)$$

where wi is the weight of the ith criterion being $\sum_{i=1}^{m} w_i = 1$. This index expresses the weighted concordance of all criteria for the assertion "a outranks b".

2) Doubt Index

For each criterion gi and each pair of actions $(a, b) \in AxA$ the doubt index is defined as:

$$D_i(a,b) = \frac{1}{R_i} \sum_j \delta_i^a \left(g_i^j\right) \sum_{\kappa > j} \left({g_i}^\kappa - {g_i}^j\right) \delta_i^b \left(g_i^\kappa\right)$$

where Ri is the range of the scale Ei[10]. This index expresses the "average" discordance of criterion gi for the assertion "a outranks b". This index does not take into account a veto threshold, but emphasizes on the range of the scale, assuming measurable scale. In case of ordinal scale, its quantification, although somewhat arbitrary, is required (Siskos, 2008).

3) Degree of credibility

The credibility degree of outranking is defined by the credibility index σ(a,b) as follows:

---

[10] $({g_i}^* - g_{i_*})$ where gi* is the level of the scale Ei representing the worse value can be given to the criterion gi and gi* the level of the scale Ei representing the best value.

$$\sigma(a,b) = \begin{cases} C(a,b) \quad if\ C(a,b) \geq D_i(a,b)\ \forall i = 1,2,\dots,m \\ \dfrac{C(a,b)}{1 - C(a,b)} \prod_{i^*} [1 - D_{i^*}(a,b)], i^* \in \{i / D_i(a,b) > C(a,b)\} \end{cases}$$

The credibility indices are in the range [0,1] and their values are reduced in the presence of discordant criteria when $D_i(a,b) > C(a,b)$. For each pair of actions (a, b), the credibility index expresses a measure of affirmation for the assertion “a outranks b”. The credibility values indicate a measure of credibility of the assertion “a outranks b”, however a greater credibility index for a pair of actions than another one, e.g. σ (a, b) > σ (c, d), does not necessarily conclude in a stronger argument for the claim that “a outranks b” than that “c outranks d” (Belton and Stewart, 2002).

4) To obtain the complete ranking of the alternatives the ELECTRE III ranking algorithm (Roy, 1978) is applied exploiting the fuzzy outranking relation constructed in the previous step. The final rank stems from the so-called distillation, a process which provides two orders of outcome, using the concepts of cutting levels λ and discrimination threshold s(λ). “The cutting levels λ are used to define the successive λ cuts of the fuzzy relation. The distillation algorithm proceeds by lowering the cutting level λ from an initial value, λ0, to zero” (Tervonen et al., 2004, p. 6). The final ranking of alternatives is the outcome of the intersection of the two distillation results (i.e. two pre-orders obtained in the ascending and descending distillations). For each pair (a, b), the comparison between a and b can result in four different cases: a) a may be better than b, b) b may be better than a, c) a and b may be indifferent, d) a and b may be incomparable[11].

3.5 Weighting method

The method selected to determine the criteria weights was the “resistance-to-change grid” (Rogers and Bruen, 1998), one of the four weighting methods that can be applied within ELECTRE (Rogers et al., 2000). It is a practical method, based on the “Personal Construct Theory” (Kelly, 1955), while the obtained weights reflect actual preferences of stakeholders in respect of criteria importance. In order to obtain weights all criteria were compared in pairs with the use of a matrix, the resistance-to-change grid. For each comparison, stakeholders expressed their opinion on the relative importance of criteria according to the degree of how undesirable a change in one parameter would be. The relative importance of criteria was obtained by counting how many times each criterion resisted being changed (Rogers and Bruen, 1998).

3.6 Results

After conducting the survey, the related inputs to the MCA method were defined. Experts’ evaluations of actions resulted in matrices of probabilistic evaluations, one for every criterion, where each row represents the probability distribution of each action evaluations (in total 10 matrices of probabilistic evaluations of alternative policy options - please refer to Appendix.

---

[11] If a is better than b, the symbol at the intersection of the row for a and the column for b is P; if a is equivalent to b, the symbol I; if a is as good as b, the symbol P ; if a is incomparable to b, the symbol R.

3.6.1 Clustering priority strategies

The average weights of criteria were calculated in total and per each stakeholder group and are presented in Table 3.5. Incentive to invest/comply and financial viability are the highest weighted criteria, followed by fairness in distribution principles and monitoring and control. In fact, incentive to invest/comply attained high preferences across all stakeholder groups. On the other hand, familiarity and transaction costs are less prioritized, perceived to be the least important criteria.

Policy makers and energy agencies expressed similar preferences for criteria importance, considering incentive to invest/comply, financial viability, fairness in distribution principles and monitoring and control as the most significant performance criteria, reflecting in this way their common priorities and collateral role in energy and climate policy decision making in Greece. Naturally, RES market actors also assigned a high priority to economic criteria, as well as to monitoring and control provisions. On the other hand, institutional set-up and capacity, management and coordination seem to be the major concerns for the ESCOs market, as implicated by high weights allocated to the corresponding criteria from ESCOs' representatives. ESCOs' particular prioritization over such implementation features reflects the fact that recent PIs promoting the ESCO market are not yet framed by a smooth implementation and subsequent administrative delays caused problems for ESCOs business activities (Douvara et al., 2013).

Table 3.5 Average weights of all criteria (%)

Stakeholder groups / Criteria	Policy Makers	Energy agencies	RES market actors	ESCOs	Academia	NGOs	Total
Mot	13	16.1	15.8	11.4	15.4	27.3	14.9
Fam	5.9	5.1	9.9	6.8	0.8	9.1	5.1
Eq	15.2	13.0	7.7	13.6	8.3	22.7	12.5
Adap	6.4	8.3	9.9	4.9	7.8	9.1	7.6
Trans	5.6	4.9	3.0	5.8	12.9	4.5	6.7
Coord	7.7	9.4	7.5	12.9	7.9	0	8.2
Comp	7.9	10.2	11.5	8.0	9.9	13.6	9.5
Inst	9	7.6	8.9	16.3	9.6	0	8.9
MnC	14.3	11.8	13.8	12.6	10.1	0	12.2
Fin	15.2	13.5	12.1	7.7	17.2	13.6	14.4

Notwithstanding the fact that certain criteria were given similar priority by the majority of stakeholder groups, the resulting weighting vectors are rather diverse among the different stakeholders. To determine group priorities and trigger the discussion on how certain "types" of stakeholders tend to prioritize over certain policy parameters (i.e. criteria), the various stakeholder profiles were considered for the application of cluster analysis (Field, 2005). First, each individual case (i.e. actor) was considered as its own cluster, and then clusters were joined using Ward's method and the squared Euclidean distance to measure the distance between different observations so as to reduce the variability of observations within a cluster. Ward's method has been used in energy and policy related studies (e.g. Hollanders et al., 2012; Thomas et al., 2014) as it maximizes the differences between different clusters tends, avoiding to show general patterns.

After having discussed the respondents' profile as well as the similarities and differences in expressed priorities, the individual weights were clustered into three groups. Towards this decision, the descriptive statistics of all potential clusters were taken into consideration and the resulting groupings were checked for their conceptual validity. The average values of group weights are illustrated in Figure 3.2. According to cluster weighting factors and their average values, three decision-making priorities strategies were created, indicating rather standout concerns in the range of expressed opinions:

Strategy A) - Practical priorities concerned: The first group of actors put most emphasis on issues concerning the practical implementation of PIs. Their concern is reflected in higher weights allocated to monitoring and control, compatibility with national policy strategy and institutional set-up and capacity, which are criteria related to practical hurdles during implementation processes. A prioritization is also expressed about institutional management and coordination, with highest weights allocated compared to the corresponding weights of the other two clusters.

Strategy B) - Holistic cost-effectiveness concerned: This group of actors allocates emphasis on intended or unintended policy effects as well as on the associated costs incurred due to policy intervention. Actors of this cluster are concerned primarily with the financial viability and incentive to invest/comply. These weights reflect their concern over potential high administrative and funding costs burdening the national budget as well as the response from target groups to the PI (participation levels, effects), respectively. They also prioritize fairness in distribution principles, indicating a great concern over unintended effects (i.e. distributional effects) on non-participating third parties or vulnerable members of society (e.g. unfair distribution of costs and disproportional burden).

Strategy C) - Cost and market competitiveness concerned: Finally, the last group considers that successful policy implementation heavily relates to the return on investments (i.e. yielded benefits and costs on investment-projects due to policy intervention). This concern is reflected in the high weights allocated to the incentive to invest/comply and transaction costs criteria, which shape investment return. A height weight is also expressed on monitoring and control provisions, which regulate a fair competition in the market, having a positive impact on business activities among different actors, having a positive impact on business activities among different actors.

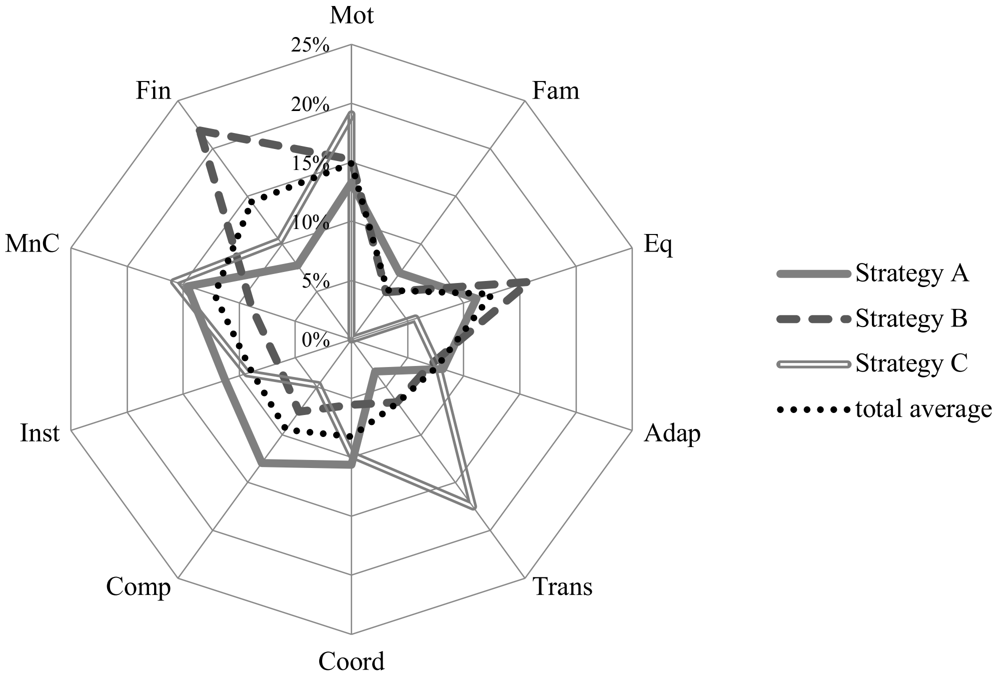


Figure 3.2 Distribution of weights for all criteria among the three cluster groups

Regarding the homogeneity of stakeholder groups resulting from the cluster analysis (see Table 3.6) the following observations can be noted. The ESCOs' group presents the highest homogeneity, where 2 out of 2 respondents of the group are clustered in the same cluster, the first one, which concerned primarily practical implementation issues. The energy agencies' group is relatively homogenous, where 6 out of 10 respondents are concerned with practical feasibility parameters, while policy makers are almost equally concerned over practical implementation issues and overall CE of policies (Strategies A and B respectively). RES market actors are equally split between cluster 1 and 2 emphasizing both on practical issues as well as on overall policy efficiency (Strategy B). Finally, academics are divided between prioritizing over overall policy CE features (Strategy B) and more specifically over costs and market competitiveness related to and influenced by implemented policies (i.e. 3 out of 8).

Table 3.6 Type of stakeholders in each cluster (decision-making strategies)

Strategies	Policy Makers	Energy agencies	RES market actors	ESCOs	Academia	NGOs	Total
Strategy A	5	6	2	2	1	0	16
Strategy B	6	4	2	0	4	1	17

Strategy C	2	0	0	0	3	0	5
Total	13	10	4	2	8	1	38

3.6.2 Resulting MCA policy rankings

Having carried out all the calculations and applied the steps in the process of the methodology chosen using Matlab (version R2014b), a ranking matrix for each strategy were created (see Appendix). Each of the three final ranking matrices offer a synthesis of the results of the ranking method, as do the final graphs (Figure 3.3) in line with the three strategy weights.

As shown in Figure 3.3 tax reliefs is one of the best ranked PIs, placed first under the "cost and market competitiveness" priorities strategy and second under the other two weighted priorities strategies. Tax reliefs for EE and RES systems in buildings have gained significant ground when they started to take effect in 2006 by Law 3522/2006, as suggested by both RES and EE market actors participating in the survey. They provided an income tax relief for natural and legal persons who have performed an energy upgrading of their building either on their own or as participants of National Programs (such as Exoikonomo). Tax exemptions have traditionally been favored by market actors due to their simplicity and ease of implementation, as reflected in high performances against administrative capacity, transaction costs and monitoring and control criteria, as shown in Table A10, Table A13 and Table A14 (Appendix). As stated by stakeholders, the PI's inherent attractiveness and political acceptance was also evoked by the word "tax exemption", yet the measure has remained inactive for the last two years when state resources from the national budget had started to drain. However, it becomes worthy of note that market and policy actors consider tax exemptions as relatively unfair (Table A8), which may also explain for its lower ranking under the first two strategies. In fact, tax-reliefs promoting RES and EE in the Greek building sector have undergone successive policy amendments with the more recent one by Law 3842/2010 "Restoring tax fairness, tackling tax evasion and other provisions" aiming to correct for higher financial benefits and impose stricter eligibility criteria to mitigate free-ridership effects.

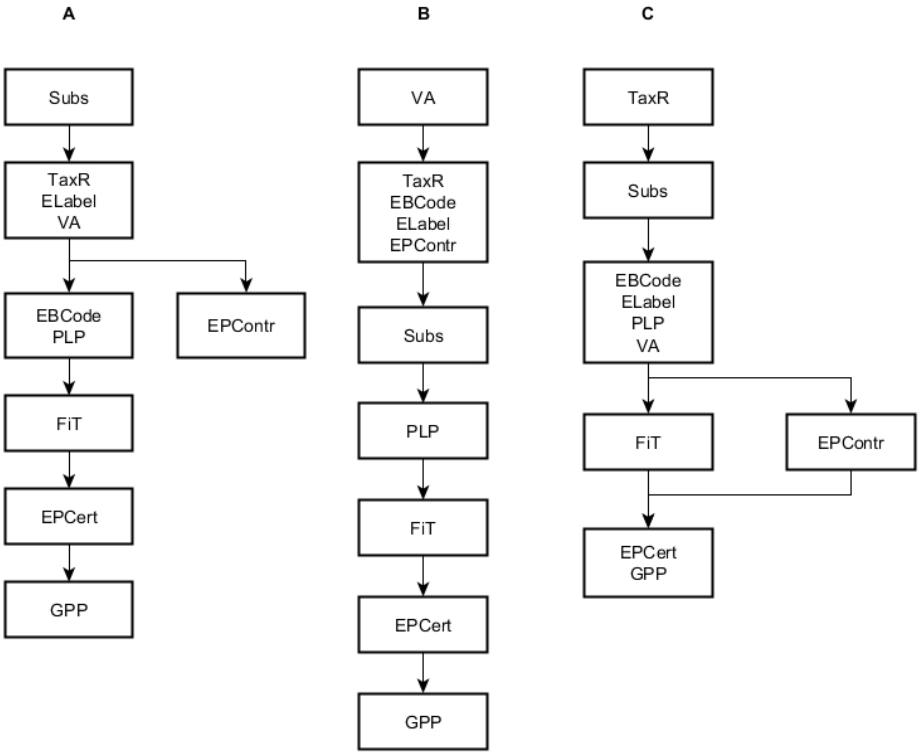


Figure 3.3 Final rankings of PIs in line with the three weighting scenarios (A, B, C)

Policy options also highly placed in rank across all three strategies are EE subsidies and voluntary agreements (VAs). Subsidy schemes received a high score by the majority of experts under monitoring and control, institutional set-up and policy compatibility criteria, all considered as highly important by the actors of Strategy A and placed first under their priorities. Pertinent authorities implementing subsidy programs were in fact reported to be well staffed, while involvement of participating banks in the loan approval and application assessment procedures proved to be beneficial in terms of adequate transparency throughout the evaluation and monitoring procedures of the program. Yet high administrative and funding costs deem the financial viability of such schemes rather low. In fact, representatives from the Energy Agency and the ministry's implementation unit for such programs emphasized on the "off and on" implementation of those programs, that is primarily dependent on state-budget availability. This viewpoint can also be reflected in the lower ranking of this policy alternative under Strategy B, where financial viability was considered a top priority when evaluating policy performance.

VAs also present a high relative strength in this analysis, ranked 1st under the "holistic cost-effectiveness" priorities strategy. VAs received a high score by the majority of experts against almost all criteria except for familiarity, institutional coordination and induced incentive. Their latter poor performance is reflected in their moderate ranking under the "cost and market competitiveness" priorities strategy (i.e. third among others). Notably, a number of VAs has been introduced in Greece since 2011[12]; however, no progress has been reported on their implementation since then. As stated by stakeholders, in view of the prolonged economic recession, this policy mechanism has gained limited political support thus far, while priority was given on more traditional measures yielding straightforward incentives.

Next, as illustrated in Figure 3.3, green public procurements (GPP) and energy performance certificates are placed last or second to last across all strategic rankings, having performed poorly across almost all criteria, except for fairness in distribution principles and financial viability. In essence the absence of a National Action Plan (NAP) for GPP has constituted a major weakness that is reflected in their low performance especially regarding their policy consistency (CRES, 2014). Understaffed ministerial services have slowed down the formulation process framing the poor institutional capacity of the measure. Interviews with market actors also revealed that both the public and private sector were discouraged from participating; budgetary constraints were the reason for the former while insufficient information flows between them inhibited the latter.

---

[12] "Building the Future" project is a typical example; it was launched in 2012 but its implementation did not progress, as stated by NGOs representatives (Energypress, 2014). Moreover, various relevant programs are presented in MURE database as recently introduced; however its implementation status is still to be determined (MURE Database).

The Greek energy performance certificates scheme has also shown to be weak in overall performance. Interviews with representatives from the Ministry's special unit for energy inspectors (EYEPEN) revealed that limited administrative capacity of pertinent authorities and understaffed inspection services monitoring compliance with the scheme were detected as crucial implementation hurdles and are reflected in low scores given by the majority of experts against the relevant criteria. EYEPEN was established to regulate all issues related to energy inspectors, however comprised a total of nine personnel members instead of forty members initially foreseen (Spyridaki et al., 2015b). Finally, energy performance certification has yielded a much lower signal to property owners, principally of existing building stock thus far, since observed compliance levels were limited to the compulsory issuance in case of property transaction (sale or rental)[13].

On the whole, it is important to note that there are not significant differences among the three rankings of PIs. That is to say, rankings are not significantly altered under different weights, thus results are not sensitive to the different groups' weightings and different stakeholders' perspectives.

3.7 Policy Implications – Conclusions

The methodological approach presented in this paper can simultaneously evaluate PIs under suspected sources of uncertainty, related to often imprecise or biased information, and determine what went right or wrong during the implementation of PIs. Adopting an ex-post viewpoint, we have analyzed the performance of public policy mechanisms in Greece during their implementation stage of their policy cycle, through process criteria important for different decision strategies, resulting in PIs rankings. Based on our study outcomes, practices to follow or to avoid are identified, triggering the discussion on policy implications during the planning and re-design of national policies, especially in view of the government's efforts to comply with the new EED requirements and the 2020 goals and to overcome a prolonged economic slowdown.

Tax reliefs were ranked on top of measures implemented thus far in Greece by policy makers and related market actors. Currently the measure remains inactive due to extreme shortages in the state budget, as reported by MEECC's representatives and market actors participating in the survey. The resulted policy rankings may reflect the measure's perceived ease of policy implementation and inherently lower monitoring and control requirements, which feature fiscal policies in general, usually supported by the existing taxation system and budgetary policy (Schwarz, 2009). Despite the popularity of the measure, its low fairness in distribution principles as perceived by related actors becomes noteworthy. Cautious design is thus needed, should the scheme be reactivated in the future, to adjust the financial benefits offered and eligibility criteria to avoid free-ridership and reduced government revenues, especially within an extended recessionary environment with high-income inequalities (Kosonen and Nicodeme, 2009). Policy makers in Greece should thus carefully consider the use of mechanisms operating in an analogous manner (i.e. minimizing administrative requirements), by ensuring financing is collected or allocated through on-bill charges/reliefs or property taxes, such as a Property Assessed Clean Energy financing program (IEA-RETD, 2013).

Despite the recessionary environment, actors with implementation and feasibility priorities ranked financial support programs supporting EE installations in public and residential buildings on top of the list, as quite functional. Interviews with several representatives from the Energy Agency and MEECC, responsible for the overview of such schemes, revealed that EE subsidies operating with tight budgets, have been carefully designed, closely administered and monitored. This also relates to the fact that subsidy mechanisms implemented thus far in Greece by way of soft loans and grants have been primarily financed from EU funds as well as from the state budget (MEECC, 2012a). Their high evaluation may also reflect their deemed necessity to drive demand for such investment from building owners and municipalities, from both market and policy actors, especially under an unfavorable investment climate. Reportedly, their high overall evaluation relates also to non-financial factors such as the inclusion of local actors (i.e. cooperating banks and municipalities) fostering trust and capacity while also sharing some of the administrative burden. However, as suggested by MEECCs' officials, Greece still faces significant budgetary constraints due to the prolonged negative economic conditions and limited additional financing is expected to come from the public purse. Financial incentives should preferably be provided in the form of soft loans, guarantees or smaller grants for measures with a shorter payback time so as to relieve the pressure put on the already drained national budget (EC, 2013). In essence, attention needs to be drawn to alternative funding and market stimulation options so as to release and facilitate the investment potential of the private sector. Alternative ways of financing EE actions, such as on-bill financing (OBF) or the set-up of an EE revolving fund, could work towards overcoming significant budgetary constraints also in the longer run (EC, 2013; IEA , 2011).

---

[13] However, at this time energy performance certificates are only optionally included for electronic submission of rental contracts (Sirouni, 2015).

VAs are also perceived as quite functional by decision makers in Greece (top-ranked in the first strategy and third in the last strategy), despite the fact that VAs are still embryonic in Greece. The results indicate the popularity that VAs have gained, on the one hand, due to their inherent design in terms of voluntary participation principles and thus lower administrative requirements. On the other hand, its voluntary nature may imply a smaller upfront incentive as well as a less ambitious target setting. VAs should thus be used in conjunction with other support schemes, such as fiscal measures / subsidies, or green financing instruments. While following the example of other EU Member States, such as the Netherlands, strengthening the involvement of the private sector via long-term agreements could prove to be beneficial to unlock further private investment potential in the field (Spyridaki et al., 2015a).

Regarding middle ranked policies, such as energy performance contracting, there is still a long way to go. Greek ESCO market is still in its infancy (MEECC, 2014a) while only few energy performance contracting projects have been implemented due to legal and regulatory barriers as well as financial ones related to the unfavorable/uncertain investment environment during this period in Greece (Bertoldi et al., 2014). In essence the moderate ranking of this policy option indicates its potential in the Greek building market denoting its implementation discrepancies that have hold back its diffusion thus far. The enhancement of the ESCOs market share by means of financial support is foreseen and has been included as a provisional alternative measure in the 3rd NEEAP. Specific information on how it will be formulated and implemented, or its implementation timeline is still to be determined.

As regards the least successful PIs against process-wise criteria, the country is still missing significant opportunities of increasing EE by greening its public procurements. It is noteworthy that GPP ranked last across all decision-making strategies. Absence of a clear regulatory and legal framework, inadequate training of staff and lack of coordination were observed to be the main obstacles having prevented the modernization of public procurement procedures. A starting point to overcome them could be the establishment of the NAP for GPP, which is under development (EC, 2014). The NAP will establish specific GPP targets regarding the percentage of GPP contracts of the total public procurement contracts, specific quotas for certain product groups and will specify concrete measures to be introduced to achieve these targets. Training of responsible authorities' personnel and communication flow between demand and supply side concerning legislative issues and technical necessities need to be considered as well (CRES, 2014).

Similarly, a failure to exploit high energy savings potential offered by energy performance certificates was also observed due to coherence issues and deficiencies in implementation process. In this case, efforts need to be made by the government to strengthen control mechanisms and improve penalty systems for non-compliance. In addition, improving coordination among pertinent authorities (e.g. by interconnecting the national site for electronic submission of Tax Returns (TAXISnet) with the Hellenic Energy Inspectorate) would also facilitate verification and monitoring procedures and should not be overlooked (Spyridaki et al., 2015b).

Finally, the opposite of a success story was the case of the FiT for small PV rooftop systems in buildings. It was a typical example of inflexible policy design (Spyridaki et al., 2015a) since inequitable high FiT rates and payments impacted the financial resources availability that could have been used for the implementation of other programs (e.g. financing R&D policies or other policies for energy savings). In response to this case, Greek authorities have recently introduced legislation to establish net metering for solar PV systems, including rooftop systems. Net-metering allows residential and commercial consumers who produce electricity on-site from PV rooftop systems to cover a part or the sum of their electricity consumption with their own-produced electric energy, whereas any excess electricity (i.e. electricity they do not use) is fed back into the grid. The scheme aims to reduce consumers' costs for their energy needs as well as to protect them from future costs from possible increases in electricity consumption tariffs (MEECC, 2014b; SEIA, 2015). Introduction of net metering was praised by the Greek PV stakeholders and is considered to potentially spur the development of the shrunk Greek PV sector.

This type of analysis has allowed us to pint-point strengths and weaknesses of policy mechanisms employed to promote energy conservation in buildings so far in Greece, on the grounds of stakeholder perceptions supplemented with empirical observations over policy performance criteria, determined to concentrate on the policy implementation stage. Overall evaluation rankings suggest that Greece is still missing significant opportunities of energy saving that could be reached through more streamlined implementation practices of policy mechanisms in effect. At times of fiscal crisis, the Greek government should also revitalize the implementation of alternative funding and other mechanisms such as GPP, VAs and energy performance contracting, backed by strong political will and support.

Our analytical approach highlights the need to distinguish between policy outcomes and final policy impacts (related to target achievement) in the evaluation of policy programs. We suggest that different stages in the policy cycle should be examined in a more systematic manner through policy performance criteria in their own right to better capture how and why actual policy outcomes differ from intended ones. MCA can facilitate the consideration of a wider set of policy outputs and outcomes-based indicators enabling policy makers to quantify and assess the results of policy decisions in a wider context.

The weakness of the selected MCA, in comparison to other methods, regarding time-consuming data-collection processes, inherent also to qualitative assessment methods, is offset by the insights that can be gained through the establishment of operational assessment scales and indicators. Most importantly, the selected MCA demonstrates how probabilistic evaluations instead of discrete evaluations can be considered to hedge uncertainties inherent to input data, due to incomplete, inconsistent or biased information, often used in policy evaluation and participatory assessment studies. Policy makers should thus incorporate and better reflect different uncertainty aspects in policy monitoring and evaluation processes in a similar manner. The policy monitoring and evaluation system can then be re-built so that progress towards interim policy outcomes and final impacts will be assessed discretely through the establishment of appropriate indicators, providing more robust results feeding back into more realistic policy (re-) formulations.

Acknowledgments

The authors would like to thank the European Commission (EC) DG Research for supporting the research activity APRAISE ("Assessment of Policy Interrelationships and Impacts on Sustainability in Europe")—Grant agreement 283121. The authors would also like to thank all policy makers and experts who participated in interviews providing their feedback as part of the participatory analysis, as well as Professor Yannis Siskos for his valuable feedback and methodological validation. Finally, authors are also thankful to partners of the APRAISE consortium, who have contributed for the successful implementation of the project.

Appendix

Table A6. Matrix of probabilistic evaluation of actions under “Incentive to invest/comply” criterion[14]

Incentive to invest/comply						
	0: No incentive at all	**1**: Very low incentive	**2**: Low incentive	**3**: Neither high, nor low incentive	**4**: High incentive	**5**: Very high incentive
P1	0.00	0.00	0.00	0.05	0.25	0.70
P2	0.00	0.00	0.05	0.42	0.32	0.21
P3	0.00	0.00	0.26	0.37	0.32	0.05
P4	0.05	0.45	0.30	0.15	0.05	0.00
P5	0.00	0.00	0.40	0.20	0.25	0.15
P6	0.00	0.00	0.05	0.68	0.21	0.05
P7	0.00	0.67	0.06	0.17	0.06	0.06
P8	0.00	0.00	0.56	0.11	0.28	0.06
P9	0.11	0.05	0.11	0.05	0.63	0.05
P10	0.00	0.05	0.74	0.11	0.11	0.00

Table A7. Matrix of probabilistic evaluation of actions under “Familiarity” criterion

Familiarity						
	0: No familiarity	**1**: Very little familiarity	**2**: Little familiarity	**3**: Neither high, nor little familiarity	**4**: High familiarity	**5**: Very high familiarity
P1	0.00	0.00	0.05	0.10	0.35	0.50
P2	0.00	0.00	0.11	0.11	0.63	0.16
P3	0.00	0.00	0.58	0.11	0.21	0.11
P4	0.00	0.20	0.20	0.30	0.30	0.00
P5	0.00	0.30	0.30	0.20	0.20	0.00
P6	0.05	0.00	0.16	0.42	0.32	0.05
P7	0.00	0.89	0.11	0.00	0.00	0.00
P8	0.22	0.72	0.06	0.00	0.00	0.00
P9	0.00	0.32	0.37	0.32	0.00	0.00
P10	0.06	0.72	0.17	0.06	0.00	0.00

Table A8. Matrix of probabilistic evaluation of actions under “Fairness in its distribution principles” criterion

Fairness in its distribution principles						
	0: Not at all fair	**1**: Very unfair	**2**: Less unfair	**3**: Marginally fair	**4**: Fair	**5**: Very fair
P1	0.05	0.60	0.10	0.10	0.10	0.05
P2	0.00	0.00	0.00	0.11	0.79	0.11
P3	0.00	0.00	0.47	0.26	0.21	0.05
P4	0.00	0.00	0.05	0.30	0.55	0.10
P5	0.00	0.00	0.00	0.05	0.85	0.10
P6	0.00	0.00	0.00	0.00	0.84	0.16
P7	0.00	0.00	0.00	0.06	0.28	0.67
P8	0.00	0.00	0.06	0.00	0.11	0.83

---

[14] For example, incentive provided to invest by P1 is evaluated as: “0: No incentive at all” by 0% of experts, “1: Very low incentive” by 0% of experts, “2: Low incentive” by 0% of experts, “3: Neither high, nor low incentive” by 5% of experts, “4: High incentive” by 25% of experts, “5: Very high incentive” by 70% of experts.

P9	0.00	0.00	0.11	0.11	0.63	0.16
P10	0.00	0.00	0.05	0.11	0.16	0.68

Table A9. Matrix of probabilistic evaluation of actions under “Adaptability to exogenous changes” criterion

Adaptability to exogenous changes					
	0: Not at all flexible	**1**: Little flexibility	**2**: Marginally flexible	**3**: Flexible	**4**: Very flexible
P1	0.05	0.75	0.05	0.15	0.00
P2	0.00	0.05	0.21	0.26	0.47
P3	0.00	0.11	0.11	0.79	0.00
P4	0.00	0.10	0.75	0.15	0.00
P5	0.00	0.30	0.65	0.05	0.00
P6	0.00	0.11	0.68	0.21	0.00
P7	0.00	0.11	0.89	0.00	0.00
P8	0.00	0.00	0.00	0.22	0.78
P9	0.00	0.11	0.11	0.79	0.00
P10	0.00	0.00	0.11	0.11	0.79

Table A10. Matrix of probabilistic evaluation of actions under “Transaction Costs” criterion

Transaction Costs						
	0: Very High transaction costs	**1**: High transaction costs	**2**: Neither high, nor low transaction costs	**3**: Low transaction costs	**4**: Very low transaction costs	**5**: No transaction costs at all
P1	0.05	0.15	0.65	0.05	0.10	0.00
P2	0.00	0.11	0.68	0.11	0.11	0.00
P3	0.00	0.05	0.11	0.74	0.11	0.00
P4	0.00	0.00	0.60	0.30	0.10	0.00
P5	0.00	0.00	0.20	0.75	0.05	0.00
P6	0.00	0.00	0.63	0.21	0.16	0.00
P7	0.00	0.20	0.40	0.20	0.20	0.00
P8	0.00	0.61	0.17	0.17	0.06	0.00
P9	0.05	0.05	0.26	0.00	0.63	0.00
P10	0.00	0.00	0.16	0.79	0.05	0.00

Table A11. Matrix of probabilistic evaluation of actions under “Institutional management & coordination” criterion

Institutional management & coordination					
	0: Not at all	**1**: Limited coordination	**2**: Neither limited nor adequate coordination	**3**: Adequate coordination	**4**: Very Adequate coordination
P1	0.00	0.00	0.26	0.74	0.00
P2	0.28	0.33	0.17	0.22	0.00
P3	0.15	0.23	0.31	0.23	0.08
P4	0.00	0.63	0.32	0.05	0.00
P5	0.00	0.63	0.26	0.11	0.00
P6	0.00	0.50	0.33	0.17	0.00
P7	0.06	0.65	0.24	0.06	0.00

P8	0.00	0.65	0.35	0.00	0.00
P9	0.07	0.43	0.29	0.21	0.00
P10	0.23	0.23	0.38	0.15	0.00

Table A12. Matrix of probabilistic evaluation of actions under “Compatibility with national policy strategy” criterion

Compatibility with national policy strategy					
	0: No compatibility	**1**: Very little compatibility	**2**: Little compatibility	**3**: Compatible	**4**: Very compatible
P1	0.05	0.00	0.10	0.70	0.15
P2	0.00	0.00	0.05	0.74	0.21
P3	0.00	0.05	0.16	0.58	0.21
P4	0.00	0.00	0.00	0.45	0.55
P5	0.00	0.00	0.05	0.50	0.45
P6	0.00	0.00	0.00	0.11	0.89
P7	0.00	0.00	0.56	0.28	0.17
P8	0.00	0.00	0.06	0.78	0.17
P9	0.00	0.00	0.05	0.21	0.74
P10	0.00	0.00	0.00	0.26	0.74

Table A13. Matrix of probabilistic evaluation of actions under “Institutional set-up and capacity” criterion

Institutional set-up and capacity						
	0: No capacity at all	**1**: Very low capacity	**2**: Low capacity	**3:** Neither high, nor low capacity	**4**: High capacity	**5**: Very high capacity
P1	0.05	0.00	0.00	0.16	0.79	0.00
P2	0.00	0.00	0.06	0.17	0.78	0.00
P3	0.00	0.00	0.00	0.22	0.78	0.00
P4	0.00	0.47	0.21	0.21	0.11	0.00
P5	0.00	0.42	0.37	0.16	0.05	0.00
P6	0.00	0.00	0.56	0.33	0.06	0.06
P7	0.00	0.76	0.06	0.18	0.00	0.00
P8	0.00	0.06	0.76	0.12	0.06	0.00
P9	0.00	0.00	0.67	0.22	0.11	0.00
P10	0.00	0.22	0.06	0.39	0.33	0.00

Table A14. Matrix of probabilistic evaluation of actions under “Monitoring & control” criterion

Monitoring & control					
	0: No monitoring & control at all	**1**: Very limited monitoring & control	**2**: Little monitoring & control	**3**: Marginally adequate monitoring & control	**4**: Adequate monitoring & control
P1	0.40	0.15	0.10	0.20	0.15
P2	0.00	0.00	0.16	0.68	0.16
P3	0.00	0.00	0.05	0.16	0.79
P4	0.00	0.70	0.05	0.20	0.05
P5	0.00	0.05	0.15	0.70	0.10
P6	0.00	0.05	0.63	0.26	0.05
P7	0.00	0.78	0.00	0.17	0.06

P8	0.11	0.00	0.67	0.06	0.17
P9	0.00	0.53	0.26	0.11	0.11
P10	0.00	0.16	0.16	0.05	0.63

Table A15. Matrix of probabilistic evaluation of actions under “Financial viability” criterion

	Financial viability					
	0: No financial viability	**1**: Very low financial viability	**2**: Low financial viability	**3**: Neither high, nor low financial viability	**4**: High financial viability	**5**: Very high financial viability
P1	0.00	0.60	0.15	0.15	0.10	0.00
P2	0.00	0.05	0.53	0.21	0.16	0.05
P3	0.00	0.00	0.00	0.63	0.32	0.05
P4	0.00	0.05	0.05	0.15	0.75	0.00
P5	0.00	0.00	0.05	0.05	0.90	0.00
P6	0.00	0.00	0.05	0.00	0.89	0.05
P7	0.00	0.00	0.00	0.78	0.17	0.06
P8	0.00	0.00	0.00	0.06	0.78	0.17
P9	0.00	0.00	0.00	0.79	0.21	0.00
P10	0.00	0.00	0.00	0.21	0.79	0.00

Table A16. Final ranking matrix for weighting priorities - Strategy A

	Strategy A									
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**
P1	I	P^{-}	P^{-}	P	P^{-}	P^{-}	P	R	P^{-}	P^{-}
P2	P	I	P	P	P	P	P	P	P	P
P3	P	P^{-}	I	P	P	I	P	P	P	I
P4	P^{-}	P^{-}	P^{-}	I	P^{-}	P^{-}	P	R	P^{-}	P^{-}
P5	P	P^{-}	P^{-}	P	I	P^{-}	P	R	I	P^{-}
P6	P	P^{-}	I	P	P	I	P	P	P	I
P7	P^{-}	P^{-}	P^{-}	P^{-}	P^{-}	P^{-}	I	R	P^{-}	P^{-}
P8	R	P^{-}	P^{-}	R	R	P^{-}	R	I	R	P^{-}
P9	P	P^{-}	P^{-}	P	I	P^{-}	P	R	I	P^{-}
P10	P	P^{-}	I	P	P	I	P	P	P	I

Table A17. Final ranking matrix for weighting priorities - Strategy B

	Strategy B									
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**
P1	I	P^{-}	P^{-}	P	P^{-}	P^{-}	P	P^{-}	P^{-}	P^{-}
P2	P	I	P^{-}	P	P^{-}	P^{-}	P	P^{-}	P	P^{-}
P3	P	P	I	P	I	I	P	I	P	P^{-}
P4	P^{-}	P^{-}	P^{-}	I	P^{-}	P^{-}	P	P^{-}	P^{-}	P^{-}
P5	P	P	I	P	I	I	P	I	P	P^{-}
P6	P	P	I	P	I	I	P	I	P	P^{-}
P7	P^{-}	P^{-}	P^{-}	P^{-}	P^{-}	P^{-}	I	P^{-}	P^{-}	P^{-}
P8	P	P	I	P	I	I	P	I	P	P^{-}

P9	P	P^{-}	P^{-}	P	P^{-}	P^{-}	P	P^{-}	I	P^{-}
P10	P	P	P	P	P	P	P	P	P	I

Table A18. Final ranking matrix for weighting priorities - Strategy C

Strategy C										
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**
P1	I	P^{-}	P^{-}	P	P^{-}	P^{-}	P	R	P^{-}	P^{-}
P2	P	I	P^{-}	P	P	P	P	P	P	P
P3	P	P	I	P	P	P	P	P	P	P
P4	P^{-}	P^{-}	P^{-}	I	P^{-}	P^{-}	I	P^{-}	P^{-}	P^{-}
P5	P	P^{-}	P^{-}	P	I	I	P	P	I	I
P6	P	P^{-}	P^{-}	P	I	I	P	P	I	I
P7	P^{-}	P^{-}	P^{-}	I	P^{-}	P^{-}	I	P^{-}	P^{-}	P^{-}
P8	R	P^{-}	P^{-}	P	P^{-}	P^{-}	P	I	P^{-}	P^{-}
P9	P	P^{-}	P^{-}	P	I	I	P	P	I	I
P10	P	P^{-}	P^{-}	P	I	I	P	P	I	I

For each pair (*a*, *b*), the following interpretations may be done:
P if a is better than *b* in one of the pre-orders and at least as well ranked in the other pre-order.
I if a is equivalent to *b*.
P^{-} if *a* is ranked worse than *b* in one of the pre-orders and at least as well ranked in the other pre-order.
R if a is incomparable to *b*.

References

Antunes, C.H., Henriques, C.O., 2014. Multi-Objective Optimization and Multi- Criteria Decision Analysis in the Energy Sector (part II – MCDA). Newsletter of the European Working Group "Multicriteria Decision Aiding" 01/2014.
Belton, V., Stewart, T., 2002. Multiple Criteria Decision Analysis: An Integrated Approach. Kluwer Academic Publishers, Boston, MA.
Bertoldi, P., Boza-Kiss, B., Panev, S., Labanca, N., 2014. ESCO Market Report 2013. Joint Research Centre and Policy Reports, European Commission. doi:10.2790/24203
Browne, D., O'Regan, B., Moles, R., 2010. Use of multi-criteria decision analysis to explore alternative domestic energy and electricity policy scenarios in an Irish city-region. Energy 35, 518–528. doi:10.1016/j.energy.2009.10.020
Capano, G., Lippi, A., 2013. Enlightening policy mix complexity : a typology of actors' choices. Paper presented at the 1st ICPP Conference, Grenoble.
Crabbé, A., Leroy, P., 2008. The Handbook of Environmental Policy Evaluation. Earthscan, London.
CRES, 2014. Operative Plan for Energy Efficiency Public Procurements (EEPP). Prepared in the framework of EFFECT project. (in Greek) <http://www.effectproject.eu/>.
D'Avignon, G.R., Vincke, P., 1988. An outranking method under uncertainty. European Journal of Operational Research 36, 311–321. doi:10.1016/0377-2217(88)90123-3
de Melo, C.A., Jannuzzi, G.D.M., Ferreira Tripodi, A., 2013. Evaluating public policy mechanisms for climate change mitigation in Brazilian buildings sector. Energy Policy 61, 1200–1211. doi:10.1016/j.enpol.2013.06.056
Diakoulaki, D., Karangelis, F., 2007. Multi-criteria decision analysis and cost-benefit analysis of alternative scenarios for the power generation sector in Greece. Renewable and Sustainable Energy Reviews 11, 716–727. doi:10.1016/j.rser.2005.06.007
Douvara, S., Zervakakhs, M., Alexopoulos, A., 2013. Energy Consulting and Energy Service Companies (ESCOs) and Their Perspective in the Greek Market. Course paper. Aegaleo, Greece and Edinborough, UK.
EC, 2014. GPP National Action Plans. http://ec.europa.eu/environment/gpp/pdf/national_gpp_strategies_en.pdf
EC, 2013. Financial support for energy efficiency in buildings. Report from the Commission to the European Parliament and the Council, Brussels.
Energypress, 2014. Greenpeace προς ΥΠΕΚΑ: Χρειάζονται πράσινες ενεργειακές λύσεις στα νησιά. http://energypress.gr/news/greenpeace-pros-ypeka-hreiazontai-prasines-energeiakes-lyseis-sta-nisia (accessed 5.20.15).
Eurostat. General government gross debt - annual data. http://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&pcode=teina225&plugin=1 (accessed 6.1.15).
Field, A., 2005. Discovering Statistics using SPSS, Second. ed. SAGE publications, London.
Figueira, J., Mousseau, V., Roy, B., 2005. ELECTRE Methods, in: Figueira, J., Greco, S., Ehrgott, M. (Eds.), Multiple Criteria Decision Analysis, State of the Art Surveys. Springer Science, New York, pp. 133–153.
Gamper, C.D., Thöni, M., Weck-Hannemann, H., 2006. A conceptual approach to the use of Cost Benefit and Multi Criteria Analysis in natural hazard management. Natural Hazards and Earth System Science 6, 293–302. doi:10.5194/nhess-6-293-2006
Gamper, C.D., Turcanu, C., 2007. On the governmental use of multi-criteria analysis. Ecological Economics 62, 298–307. doi:10.1016/j.ecolecon.2007.01.010
Goulder, L., Parry, I., 2008. Instrument Choice in Environmental Policy. RFF Discussion Paper No. 08-07. doi:10.1177/0010836702037002982
Grafakos, S., Flamos, A., Ensenado, E.–M., 2015. Preferences Matter: A Constructive Approach of Incorporating Local Stakeholders' Preferences in the Sustainability Evaluation of Energy Technologies. Sustainability 7. 10922-10960.
Grafakos, S., Flamos, A., Oikonomou, V., Zevgolis, D., 2010. Multi-criteria analysis weighting methodology to incorporate stakeholders' preferences in energy and climate policy interactions. International Journal of Energy Sector Management 4, 434–461. doi:10.1108/17506221011073851
Gysen, J., Bruyninckx, H., Bachus, K., 2006. The Modus Narrandi: A Methodology for Evaluating Effects of Environmental Policy. Evaluation 12, 95–118.
Haydt, G., Leal, V., Dias, L., 2014. A multi-objective approach for developing national energy efficiency plans. Energy Policy 67, 16–27. doi:10.1016/j.enpol.2013.06.133
Hollanders, H., Derbyshire, J., Lewney, R., Tijssen, R., Tarantola, S., Rivera Leon, L., 2012. Regional Innovation Scoreboard 2012 - Methodology report. Brussels: European Commission, DG Enterprise.
Hood, C., Margetts, H., 2007. The Tools of Government in the Digital Age. Palgrave Macmillan, London.
IEA (International Energy Agency), 2011. Policy Pathway, Joint Public-Private Approaches for energy efficiency finance, Policies to scale-up private sector investment.
IEA-RETD (International Energy Agency - Renewable Energy Technology Deployment), 2013. Business models for Renewable Energy in the Built Environment. Routledge, New York.
Javid, R., Nejat, A., Hayhoe, K., 2014. Selection of CO2 mitigation strategies for road transportation in the United States using a multi-criteria approach. Renewable and Sustainable Energy Reviews 38, 960–972. doi:10.1016/j.rser.2014.07.005
Kaldellis, J.K., Anestis, A., Koronaki, I., 2013. Strategic planning in the electricity generation sector through the development of an integrated Delphi-based multi-criteria evaluation model. Fuel 106, 212–218. doi:10.1016/j.fuel.2012.11.073
Kaya, T., Kahraman, C., 2011. Multicriteria decision making in energy planning using a modified fuzzy TOPSIS methodology. Expert Systems with Applications 38, 6577–6585. doi:10.1016/j.eswa.2010.11.081
Kaya, T., Kahraman, C., 2010. Multicriteria renewable energy planning using an integrated fuzzy VIKOR & AHP methodology: The case of Istanbul. Energy 35, 2517–2527. doi:10.1016/j.energy.2010.02.051
Kelly, 1955. The Psychology of Personal Constructs. New York.
Konidari, P., Mavrakis, D., 2007. A multi-criteria evaluation method for climate change mitigation policy instruments. Energy Policy 35, 6235–6257. doi:10.1016/j.enpol.2007.07.007
Kosonen, K., Nicodeme, G., 2009. The role of fiscal instruments in environmental policy, Working Paper No. 19.2009. European Union.
Kowalski, K., Stagl, S., Madlener, R., Omann, I., 2009. Sustainable energy futures: Methodological challenges in combining scenarios and participatory multi-criteria analysis. European Journal of Operational Research 197, 1063–1074. doi:10.1016/j.ejor.2007.12.049
Løken, E., Botterud, A., Holen, A.T., 2009. Use of the equivalent attribute technique in multi-criteria planning of local energy systems. European Journal of Operational Research 197, 1075–1083. doi:10.1016/j.ejor.2007.12.050
Martel, J., d' Avignon, G., 1982. Projects ordering with multicriteria analysis. European Journal of Operational Research 10, 56–69.
McKinsey, 2012. Greenhouse gas abatement potential in Greece, Summary Report. Athens.
MEECC, 2014a. Third National Energy Efficiency Action Plan for Greece. Athens.

MEECC, 2014b. Corollary A ’phase of the Working Group established by the decision of the Secretary of Energy and Climate Change No. YAPE / F1 / 3490 / oik.23982 / 12/30/2013.

MEECC, 2012. Αναπτυξιακός Προγραμματισμός Τομέα Ενέργειας Περιοδος 2014-2020. (in Greek)

MEECC, 2011. Second National Energy Efficiency Action Plan for Greece. Athens.

Mourmouris, J.C., Potolias, C., 2013. A multi-criteria methodology for energy planning and developing renewable energy sources at a regional level: A case study Thassos, Greece. Energy Policy 52, 522–530. doi:10.1016/j.enpol.2012.09.074

Mundaca, L., 2007. Transaction Costs of Energy Efficiency Policy Instruments, in: ECEEE 2007 Summer Study-Saving Energy-Just Do It!

Mundaca, L., Mansoz, M., Neij, L., Timilsina, G.R., 2013. Transaction costs analysis of low-carbon technologies. Climate Policy 13, 490–513. doi:10.1080/14693062.2013.781452

MURE Database. http://www.measures-odyssee-mure.eu/ (accessed 6.5.15).

Nilsson, M., Zamparutti, T., Petersen, J.E., Nykvist, B., Rudberg, P., Mcguinn, J., 2012. Understanding Policy Coherence: Analytical Framework and Examples of Sector-Environment Policy Interactions in the EU. Environmental Policy and Governance 22, 395–423. doi:10.1002/eet.1589

ODYSSEE-MURE Database, 2012. Key indicators. http://www.indicators.odyssee-mure.eu/onlineindicators.html (accessed 6.3.15).

Oikonomou, V., Flamos, A., Grafakos, S., 2014. Combination of energy policy instruments: creation of added value or overlapping?. International scientific Journal: Energy Sources, Part B: Economics, Planning and Policy 9, pp.46-56.

Oikonomou, V., Flamos, A., Zeugolis, D., Grafakos, S., 2012. A Qualitative Assessment of EU Energy Policy Interactions. International scientific Journal: Energy Sources, Part B: Economics, Planning and Policy 7, pp. 177-187.

Oikonomou, V., Flamos, A., Gargiulo, M., Giannakidis, G., Kanudia, A., Spijker, E., Grafakos, S., 2011. Linking least-cost energy system costs models with MCA: An assessment of the EU Renewable Energy targets and supporting policies. Energy Policy 39, pp. 2786-2799.

Ribeiro, F., Ferreira, P., Araújo, M., 2013. Evaluating future scenarios for the power generation sector using a Multi-Criteria Decision Analysis (MCDA) tool: The Portuguese case. Energy 52, 126–136. doi:10.1016/j.energy.2012.12.036

Rogers, M., Bruen, M., 1998. A new system for weighting environmental criteria for use within ELECTRE III. European Journal of Operational Research 107, 552–563. doi:10.1016/S0377-2217(97)00154-9

Rogers, M.G., Bruen, M., Maystre, L.-Y., 2000. Electre and Decision Support Methods and Applications in Engineering and Infrastructure Investment. Springer Science+Business Media.

Rogge, K.S., Reichardt, K., 2013. Towards a more comprehensive policy mix conceptualization for environmental technological change: a literature synthesis, Working paper Sustainability and Innovation S3/2013. Fraunhofer ISI, Karlsruhe.

Roy, B., 1978. ELECTRE III : Un algorithme de classements fondé sur une représentation floue des préférences en présence de critères multiples. Cahiers du Centre d’Etudes de Recherche Opérationnelle (Belgique) 20, 3–24.

Roy, B., Bouyssou, D., 1991. Decision-aid: An elementary introduction with emphasis on multiple criteria. Journal of Information Science and Technology 2, 109–123.

San Cristóbal, J.R., 2011. Multi-criteria decision-making in the selection of a renewable energy project in spain: The Vikor method. Renewable Energy 36, 498–502. doi:10.1016/j.renene.2010.07.031

Schwarz, 2009. Promoting Energy Efficiency in Buildings : Lessons Learned from InternationaL Experience, Environment and Energy. New York, USA.

SEIA (Solar Energy Industries Association), 2015. Issues & Policies. Net Metering. http://www.seia.org/policy/distributed-solar/net-metering

Sirouni, K., 2015. Energy Performance Certificates (property ownership in Greece). Neos Kosmos.

Siskos, Y., 2008. Decision Models. New Technologies Publications, Athens. (in Greek)

Sliogeriene, J., Turskis, Z., Streimikiene, D., 2013. Analysis and choice of energy generation technologies: The multiple criteria assessment on the case study of Lithuania. Energy Procedia 32, 11–20. doi:10.1016/j.egypro.2013.05.003

Spyridaki, N.-A., Flamos, A., 2014. A paper trail of evaluation approaches to energy and climate policy interactions. Renewable and Sustainable Energy Reviews 40, 1090–1107. doi:10.1016/j.rser.2014.08.001

Spyridaki, N.-A., Ioannou, A., Flamos, A., 2015a. How can the context affect policy decision-making: The case of national climate change policies in the Greek building sector. Mitigation and Adaptation Strategies for Global Change (In press).

Spyridaki, N.-A., Ioannou, A., Flamos, A., 2014. Expanding the policy theory behind the climate and energy package in Greece, in: International Energy Policies & Programmes Evaluation Conference (IEPPEC). Berlin.

Spyridaki, N.-A., Ioannou, A., Flamos, A., Oikonomou, V., 2015b. An ex-post assessment of the Regulation on the Energy Performance of Buildings in Greece & the Netherlands - A cross country comparison. Energy Efficiency, 1-19. doi:10.1007/s12053-015-9363-1.

Stagl, S., 2006. Multicriteria evaluation and public participation: The case of UK energy policy. Land Use Policy 23, 53–62. doi:10.1016/j.landusepol.2004.08.007

Streimikiene, D., Balezentis, T., 2013. Multi-objective ranking of climate change mitigation policies and measures in Lithuania. Renewable and Sustainable Energy Reviews 18, 144–153. doi:10.1016/j.rser.2012.09.040

Tervonen, T., Figueira, J., Lahdelma, R., Salminen, P., 2004. An inverse approach for Electre III. Research Report 20, The Institute of Systems Engineering and Computers (INESC Coimbra), Coimbra, Portugal.

Tholen, L., Kiyar, D., Venjakob, M., Xia, C., Thomas, S., Aydin, V., 2013. What makes a good policy ? Guidance for assessing and implementing energy efficiency policies, in: ECEEE 2013 Summer Study: Rethink, Renew, Restart.

Thomas, G.E., Walker, I., Verplanken, B., 2014. Exploring Mental Representations of Home Energy Practices and Habitual Energy Consumption, in: Behavior and Energy Efficiency Conference (BEHAVE2014). Oxford, United Kingdom.

Troldborg, M., Heslop, S., Hough, R.L., 2014. Assessing the sustainability of renewable energy technologies using multi-criteria analysis: Suitability of approach for national-scale assessments and associated uncertainties. Renewable and Sustainable Energy Reviews 39, 1173–1184. doi:10.1016/j.rser.2014.07.160

Tsoutsos, T., Drandaki, M., Frantzeskaki, N., Iosifidis, E., Kiosses, I., 2009. Sustainable energy planning by using multi-criteria analysis application in the island of Crete. Energy Policy 37, 1587–1600. doi:10.1016/j.enpol.2008.12.011

Tuerk, A., Fruhman, C., Frieden, D. et al, 2014. Understanding the Efficacy of Environmental Policy Instruments: the APRAISE 3E Method, in: International Energy Policies & Programmes Evaluation Conference (IEPPEC). Berlin.

van der Gaast, W., Lehtonen, M., 2015. Evaluation of Unintended Effects of Environmental Policies: lessons from APRAISE and suggestions for improving the 3E Method. Submitted in Mitigation and Adaptation Strategies on Climate Change. Special Issue APRAISE.

4. Chapter 4: An ex-post evaluation of the effect of EE financial subsidies

Abstract

This article explores technology ownership patterns to reveal adoption trends for EEMs in the Greek residential sector. To do so, we couple revealed preference survey data with discrete choice modeling. Household preferences are revealed through EE measures (EEMs) owned by Greek householders, after having been questioned for a variety of end-use measures and details about their specification. Our results confirm prior evidence on traditional determinants of technology adoption, and extend those by validating that households familiar with synchronous and advanced technologies are more likely to own EEMs with smart features. We were also able to highlight the positive influence of participation in subsidy as well as other support programmes for vulnerable consumers in households' ownership of EEMs. Our results are then used to simulate the change in technology ownership rates due to participation in a subsidy programme and for three distinct income levels. These suggest that the probability for technology ownership is greater for higher income households benefitting from a subsidy and for almost all EEMs. Nevertheless, the change in the probability of technology ownership due to the subsidy is larger for lower-income households participating in the programme, further encouraging thus support for financial policies targeting lower income households.

4.1 Introduction

Governmental efforts to curb climate change and reduce energy dependency from constantly depleting fossil fuel sources have been continuous. The EE Directive (EED) has established a common framework of measures to increase Member States (MS) efforts to use energy more efficiently and has set a 20% energy savings target by 2020 (Filippini et al., 2014), which has since been upgraded to 30% by 2030 (Forouli et al., 2019). One of the main courses of actions proposed relates to energy upgrade of existing households through the diffusion of EE Measures (EEMs) (Pettifor et al., 2015). Towards achieving this goal, governments across MS countries have devised a variety of policy support programmes to foster the uptake of energy efficient (EE) technologies by householders, including regulation (e.g. minimum energy performance requirements, etc.), financial support programmes (e.g. subsidies, tax-rebates for replacing old, less efficient equipment, etc.), and information programmes (e.g. Energy Labelling, etc.), as well as behavioural programmes (e.g. nudging, etc.) (Spyridaki and Flamos, 2014). Most policy interventions have thus focused on technological innovations to reduce the energy consumption of energy services provided in households and improve their EE. Therefore, the adoption of EEMs by residential end-users plays a key role in improving energy utilization and achieving the goal of going below 2°C dictated by the Paris Agreement.

The need of understanding and predicting technology-relevant behavior of residential end-users, including aspects relevant to technology ownership and adoption, holds significant implications for assessing the CE of policy interventions (Boudet et al., 2016; Li and Just, 2018). This becomes even more urgent in light of the eminent transition in the European building sector from a centralized, fossil fuel-based and highly-energy-consuming system towards one that is more efficient, decentralized, and consumer-focused through the use of smart-home solutions (Shannon Bouton et al., 2010; Siano, 2014; Stragier et al., 2010). To this end, a marketing strategy promoting the adoption of new technologies should target the segments of consumers who will be more inclined to invest and use these technologies (Dua et al., 2016). From a policy perspective, policies and practices promoting new technologies risk of being ineffective or unsustainable, if they do not consider the relative characteristics of potential adopters in the market, along with their needs and preferences (Nikas et al., 2018; Papadelis et al., 2016).

Typically, adoption of EEMs in the residential sector is influenced by different categories and types of contextual factors, which differentiate across EU countries. Some studies categorize such factors as characteristics of the dwellings, socio-economic characteristics of households, households' attitudes and behavior, and households' knowledge about their energy spending and use (Ameli and Brandt, 2015; Gelegenis et al., 2014; Nair et al., 2010; Sardianou, 2007; Trotta, 2017). Other studies supplement such a categorization with the notion of locational context and climate zone, as different locations have varied climates, weather conditions and energy prices that are likely to influence which technological solutions are optimal in each context (Andrews and Krogmann, 2009; Michelsen and Madlener, 2012; Mills and Schleich, 2012).

Regarding households' socioeconomic characteristics (e.g. education, income, age, etc.), there is already a literature consensus acknowledging their vital role in explaining adoption trends of EEMs (Ameli and Brandt, 2015; Heiskanen and Matschoss, 2017; McNeil and Letschert, 2010; Michelsen and Madlener, 2012; Mills and

Schleich, 2014, 2012; Sasaki et al., 2015), with studies highlighting a positive correlation between income and adoption, and noting that different technologies are adopted at different levels of income (Ameli and Brandt, 2015; Leicester and Stoye, 2017; McNeil and Letschert, 2010; Mills and Schleich, 2014; Sasaki et al., 2015). Especially for the case of lower income households, literature acknowledges that they are in general less likely to purchase more energy efficient (EE) technologies due to high-upfront capital costs as well as credit constraints (Schleich, 2019). To this end, a number of government subsidy programmes have been introduced during the past years to support the adoption of EEMs from lower income households. Other studies have nevertheless questioned the role of subsidy programmes targeting low income households in driving EE investments (Fowlie et al., 2018), while others have shown that there is a significant difference between anticipated and observed efficiency gains achieved by subsidies supporting EE upgrades for low-income households (Zivin and Novan, 2016). On the other hand empirical evidence on EE technology adoption by residential end-users suggest that credit constraints exist for certain technologies, whereas for others, public subsidies may have played a role in overcoming credit constraints (Ameli and Brandt, 2015).

Furthermore, according to relevant literature, technology ownership constitutes one of the key determinants of technology-related behavior that has been found to positively correlate with technology readiness and acceptance (Godoe and Johansen, 2012). Therefore, to promote the diffusion of EE technologies, policymakers as well as utility programme implementers, require a better understanding of the drivers behind the uptake of such measures by residential end-users. In other words, who are the current adopters (i.e. technology owners), what are the reasons for their ownership as well as the who will be the future owners (i.e. adopters) and what factors will encourage them to adopt (Dua et al., 2016). As a result, it is of paramount importance to understand the key determinants of ownership of different EEMs, from the more mature ones (e.g. thermal insulation, etc.) to the less (e.g. room thermostats, etc.).

Considering the above, objective of this article is to investigate factors that explain ownership of EEMs in the residential sector in Greece and how such factors may differ across a variety of EEMs compared with dwelling, behavioural or demographic characteristics. Of primary interest was also whether participation in the "Energy Savings at Home (ESH)" subsidy programme had a differential effect on technology ownership of such measures for different income-levels. The "ESH" programme, introduced in early 2011, was the largest house EE retrofit subsidy programme in Greece with a clear focus on supporting low income households (Center of Renewable Energy Sources and Odyssee-Mure, 2015; Droutsa et al., 2016; Gelegenis et al., 2014). It becomes interesting, thus, to examine: (i) whether such incentives can drive lower income households in adopting EE technologies, (ii) and although it is often challenging to determine their incremental effect owing to lack of exogenous variation in the observations of households' behavior (Drivas et al., 2018; Spyridaki et al., 2016b).

In particular, our study used nationally representative data for Greek households from the "Survey on the Energy Consumption in Households (SECH), 2011-2012" to **a)** analyze technology ownership rates for a range of low-to- higher cost residential EEMs, **b)** examine whether the "ESH" support programme has impacted observed technology ownership rates for different technologies, and **c)** investigate how the ESH programme might influence technology ownership when targeting particular income groups. To do so, we coupled revealed preference (RP) data with discrete choice modelling techniques. Our work builds on the approach presented by Ameli and Brandt, (2015) (Ameli and Brandt, 2015), yet it differs, as it is based on the premise that current patterns of technology ownership could provide insights on future trends and preferences for technology adoption. Additionally, it includes a technology-richer set of variables, which allows to draw more insights on the characteristics of owners of EEMs, whether these are technology-specific or not and whether ownership may inform future adoption trends.

Studies so far in literature have addressed the issue of identifying adoption determinants of EEMs in the Greek residential sector. Sardianou, (2007) focused on estimating energy conservation behavioral patterns based on an extensive survey of 586 Greek households (Sardianou, 2007). Other studies have tackled the topic of EEMs in the Greek residential sector, although they mainly use data from the Energy Performance Certificates (EPCs) issued right after the launch of the Energy Performance Buildings Directive (EPBD) (Balaras et al., 2016; Dascalaki et al., 2016, 2012; Droutsa et al., 2016; Gelegenis et al., 2014; Papada and Kaliampakos, 2016) through audits. Finally, Mills and Schleich, (2012) analysed the adoption of EEMs at a European level, including Greece, although their scope was more generic and did not include specific technologies (Mills and Schleich, 2012). To the best of our knowledge this is the first time that the "SECH 2011-2012" data are coupled with a discrete choice model to analyze the key determinants of the technology-relevant behavior of households and the ownership patterns of several EEMs in the residential sector in Greece.

Another point of differentiation is that our study uses RP survey data regarding households' technology ownership for EEMs. Stated-preference surveys are usually applied to provide relevant insights on the characteristics of technology adopters. However consumers have a tendency to respond differently in real market conditions than they would have under hypothetical choice experiments (Godoe and Johansen, 2012), while the literature examining technology relevant behavior for EE improvements using RP data is more narrow. Furthermore, in addition to more commonly investigated factors by relevant studies, such as demographic, socio-economic and dwelling characteristics, the wide range of the variables included in the data under study, allows us also to account for households energy conservation behavior, their readiness for the uptake of smart EE features, as well as the role of subsidy programmes and support schemes in the uptake of EEMs, especially in the case of vulnerable consumer groups.

With regards to the latter, our data allowed us to include explanatory variables relevant to households participation in the “ESH” subsidy programme and the Social Tariff support scheme. Building on previous studies (Ameli and Brandt, 2015; Mills and Schleich, 2012), our work is also extended to examine the additional (i.e. marginal) effect of exogenous policy intervention on observed technology ownership rates. Drivas, et al., (2018) offer casual evidence on the effect that an increase in subsidy rate of the “ESH” programme had on lower-income households’ investment behaviour, yet without capturing the incremental effect that can be attributed to the programme (Drivas et al., 2018). Sleich, (2019) also evaluates whether existing support policies have been effective in terms of targeting particular income groups without yet examining, policy effectiveness in terms of change in technology ownership (Schleich, 2019). Our discrete choice model was then used to simulate technology ownership rates for three distinct income levels, according to the three income-categories specified in the “ESH” programme and under several scenarios, to estimate the potential impact of the programme on particular income groups and for a variety of low to higher cost EEMs. Findings shed light in whether participation in such actions, both targeting lower income households, might be effective in driving higher technology ownership rates. Our work, therefore, contributes to scientific literature by considering lower- income households’ observed behaviour (i.e. technology ownership) and in relation to their participation in available subsidy programmes.

The remainder of this paper is organized as follows. Section 4.2 presents and analyses the survey data used in our work; Section 4.3 describes the discrete choice model used, along with the other statistical methods used to interpret and analyze the relevant data; Section 4.4 presents and discusses the results of the econometric estimations; Section 4.5 presents and discusses further simulation results on the effectiveness of the “ESH” subsidy programme in encouraging ownership of EEMs in Greece, particularly for different income-level households; and, finally, Section 4.6 provides conclusions of our work, along with relevant implications for end-users in the field of policy and practice, and shapes directions for future research.

4.2 Data description

All MS of the European Union participate in community statistical programmes, part of which is the "Development of detailed statistics on Energy consumption in Households." The SECH survey aimed at collecting data and valuable information on the household energy consumption, on the type of final energy (e.g. heating/cooling, lighting, cooking, etc.) and on the sources of energy (e.g. liquid/solid fuels, electricity, etc.) used from the households, compared with demographic and economic characteristics. In Greece this survey was conducted upon the decision of Ministry of Economy and on the basis of the contract with the joint endorsement of Commission (EUROSTAT) and the Hellenic Statistical Authority (ELSTAT). The survey covered a sample of 3.643 private households within the country, regardless of their size or any other financial or social traits. From the total of 3.643 households, 256 were not interviewed, owing to reasons as, limitations in interviewers and staff, ineligibility to provide data, refusal, temporary absence, etc. As a result, the data used in this work concern 3.387 Greek private households.

The survey was conducted during October 2011 and September 2012, in representative samples from all four Greek First-level Nomenclature of Territorial Units for Statistics (NUTS) regions (EL3: Attiki, EL4: Aegean islands and Crete, EL5: Northern Greece and EL6: Central Greece). The primary mode of data collection was face-to-face interviews with paper assistance (PAPI) and use of questionnaires. To the best of our knowledge, this survey is the most recent one performed by ELSTAT for the residential sector in Greece. Note that the microdata file consists of individual survey responses stripped of identifiers and was handed to us upon request. More details on the questionnaire design, respondent targeting and quota sampling are provided in the respective report (Hellenic Statistical Authority, 2013).

A number of other EEMs were also addressed, including building energy management and other automation systems. However, those two fields remained blank, and as a result were excluded from our analysis as missing values. The issue of missing values is very common in this type of studies, especially when it comes to survey data. Missing values typically represent respondents who **(a)** refused to answer, **(b)** answered that they don't know, **(c)** had a valid skip, or **(d)** were skipped owing to an error made by the interviewer. As a result, missing values were not imputed and were excluded from the sample under study. To do so, we performed a Missing Value Analysis (MVA) and we concluded to 1588 complete cases. Comparing to the 3387 initial cases, the final sample is still considered adequate to extract valuable econometric estimations. Results from MVA can be made available upon request. Descriptive statistics of our data are presented in Table 4.1 below.

Table 4.1 Descriptive statistics

Variable	**Obs.**	**Mean**	**Std. Dev.**	**Min.**	**Max.**
Dependent variables: Ownership (1 = owned, 0 = not owned)					
"AC"	1588	0.640	0.480	0	1
"Shad"	1588	0.952	0.212	0	1
"Fans"	1588	0.210	0.409	0	1
"Room"	1588	0.656	0.477	0	1
"Solar"	1588	0.449	0.497	0	1
"Ins"	1588	0.480	0.499	0	1
"EEW"	1588	0.572	0.495	0	1
"Light"	1588	0.369	0.482	0	1
Independent variables					
Dwelling characteristics					
"Owner" (1 = owner, 0 = renter)	1588	0.89	0.316	0	1
"House" (1 = detached/semi-detached, 0 = apartment)	1588	0.37	0.483	0	1
"Tenure" (1 = whole year, 0 = few months)	1588	0.96	0.201	0	1
"Urban" (1 = urban, 0 = rural)	1588	0.86	0.342	0	1
"EL3" (1 = Attica Region)	1588	0.47	0.499	0	1
"EL4" (1 = Aegean Island and Crete)	1588	0.05	0.224	0	1
"EL5" (1 = Northern Greece)	1588	0.31	0.460	0	1
"EL6" (1 = Central Greece)	1588	0.17	0.376	0	1
Socio-economic characteristics/demographics of households					
"HH_age" (years)	1588	58.26	15.91	19	99
"Size" (m^2)	1588	88.99	33.96	20	450
"Income" (€)	1588	1518.48	981.20	100	8000
"one_Minor" (1 = Yes, 0 = No)	1588	0.18	0.39	0	1
"one_Elderly" (1 = Yes, 0 = No)	1588	0.41	0.49	0	1
Households' environmental behavioural patterns, knowledge about energy spending and smart readiness (1 = Yes, 0 = No)					
"Enrg_Spend_Index"	1588	0.78	0.42	0	1
"Enrg_Behav_Index"	1588	0.83	0.38	0	1
"Oil_heat"	1588	0.68	0.47	0	1
"Natgas_heat"	1588	0.10	0.30	0	1

“Smart_Read_Index”	1588	0.49	0.50	0	1
Subsidy programmes and social tariff system *(1 = Yes, 0 = No)*					
“Policy”	1588	0.005	0.07	0	1
“Soc_tariff”	1588	0.06	0.24	0	1

4.2.1 Dependent Variables

The participants were asked, if to their knowledge, their dwelling included an EEM of interest, as well as additional details with regards to its specification (i.e. age of the intervention, efficiency class, year undertaken, etc.). The questionnaire also included a separate section dedicated to ownership of energy end-use technologies as well as a section dedicated to the diffusion of EEMs. The dependent variables for the discrete choice modeling were thus constructed from participants' responses to both sections with care being taken for the characterization of a measure as EE while accounting for the availability of responses for each EEM under assessment.

Our work builds on the premise that ownership of the EEMs under study was most likely the result of the respondents' initiative. Given that in our data sources there was no way of controlling for non-adopters (i.e. tenants that live in a dwelling where a EEM of interest pre-existed), this may bring some bias into our results as regards technology ownership patterns. Nevertheless, the fact that respondents were aware of and provided details on the characteristics (e.g. energy class, age, etc.) of the EEMs under study imply that ownership was most likely result of their initiative. In addition when inspecting descriptive statistics, it is evident that the majority of the respondents is the primary owners of their residence. Such an interpretation thus provides a good starting point to explain ownership patterns across different household characteristics. The final set of dependent variables selected -along with their shorthand- are:

- Heating-ventilating-air-conditioning (HVAC) efficiency features: air conditioning (AC) split units of efficient energy class ('A' rated or better) with inverter (shorthand: **'AC'**), shading systems (i.e. awnings, pergola, shutters, other, shorthand: **'Shad'**), and ceiling/floor fans (shorthand: **'Fans'**);
- HVAC control features: room thermostats (shorthand: **'Room'**), solar thermosiphon system (shorthand: **'Solar'**), and thermal insulation of walls and roof (shorthand: **'Ins'**);
- Energy efficient window systems, with aluminium or Polyvinylchloride (PVC) frames and double or triple glazing (shorthand: **'EEW'**);
- Efficient lighting features: compact fluorescent and LED bulbs (shorthand: **'Light'**).

Each dependent variable takes a value of 1, if households own the respective technology, else it takes a value of 0. Exception to this are the variables 'AC' and 'Light", which are composite variables that we created to synthesize the available information into one final variable. For the case of 'AC', the variable takes the value of 1, if at least half of the households' AC split units are maximum five years of age, inverter-equipped and 'A' class rated or better, else it takes the value of 0. For the case of 'Light', we considered EE households those whose at least half of the lighting bulbs are compact fluorescent or LED.

Among the EEMs considered, shading systems were particularly owned from almost all the households (95%), since these systems are fairly affordable and easily adjustable to the existing building stock. EE window systems were relatively frequently owned from more than half of the households (57%), while almost half of the households stated that they were equipped with thermal insulation (48%) and solar thermosiphon (45%). Results regarding thermal insulation are line with the fact that the Greek legislation on EE buildings was first introduced in 1979, which however did not introduce measures on buildings constructed before 1980, which account for about 45% of the national building stock (Ministry of Energy and Climate Change, 2015). Similarly, our results regarding solar thermosiphon are comparable to statistical data available (Odyssee-Mure, 2015). Finally, low-energy light bulbs and ceiling/floor fans exhibited lower ownership rates (37% and 21% respectively). On the other hand, concerning the case of smart features, results show a high ownership rate of room thermostats (65%). In addition to that, almost 64% of the households are energy efficient in terms of AC. Most of these units have been retrofitted to the existing stock after 2000 as a cheaper alternative to the oil-based heating systems and as a solution to the warmer summers of the last decade.

4.2.2 Explanatory variables

The selection of explanatory variables was based on relevant literature findings and insights from previous studies in the field. Our study groups factors considered to primarily relate to consumers' heterogeneity and could determine ownership of EEMs in four different categories: i. Dwelling characteristics, ii. Socio-economic characteristics/demographics of households, iii. Households' environmental behavioural patterns, knowledge about energy spending and smart-readiness, and iv. Subsidy programmes and support schemes. Note that such a layout was also considered to fit our survey data.

4.2.2.1 Dwelling characteristics

Dwelling characteristics available in the dataset include home-ownership versus rental (shorthand: Owner), dwelling type (detached/semi-detached or apartment - shorthand: House), living the whole year or a few months per year in the dwelling (shorthand: Tenure), year of construction (shorthand: Year), whether households live in a rural or an urban area (Urbanization Degree - shorthand: Urban) and finally in which NUTS region each household belongs (shorthand: EL3 - Attica Region, EL4 - Aegean Island and Crete, EL5 - Northern Greece and EL6 - Central Greece). In the context of our study, all these variables were operationalized as dummy, except from the variable "Year", which was operationalized as categorical with the categories according to the survey questionnaire presented in Table 4.2.

The majority of the respondents (89%) own their residence, while less than the half households (37%) live in a detached/semi-detached single-family house in a block of adjoining buildings. Furthermore, almost all of the respondents (96%) stated that they live the whole year in the dwelling. When it comes to the year of construction of the dwellings, the majority of them have been constructed during 1961-1980. This is also validated by relative literature on the field (Balaras et al., 2016; Dascalaki et al., 2016; Droutsa et al., 2016; Papada and Kaliampakos, 2016; Spyridaki et al., 2016c). Additionally, the majority of the households (86%) live in an urban area. Finally, considering the geographical factor, almost half of the households (47%) live in the Attica Region, which includes the city of Athens, capital of Greece (EL3), 31% of the households live in the area of Northern Greece (EL5), 17% of the households live in the area of Central Greece (EL6), while only 5% of the households live in the area of Aegean Islands and Crete (EL4).

Table 4.2 Characteristics of the dwellings - Year of construction

Year of construction	**Dwellings** (%)
1 (-1945)	3.96
2 (1946-1960)	10.22
3 (1961-1980)	45.30
4 (1981-1990)	15.53
5 (1991-1995)	6.39
6 (1996-2000)	7.99
7 (2001-2005)	6.07
8 (2006-2010)	4.54
9 (2011-)	0.00

4.2.2.2 Socio-economic characteristics/demographics of households

The survey includes, also, demographics of households, such as the age of the household head (shorthand: **HH_age**), the household's size (shorthand: **Size**), and the total net monthly income (exact amount, measured in €1,000/year - shorthand: **Income**). Note that, according to the survey, household head is a "household member who has the primary responsibility to make important decisions regarding the household. In most cases, where households consist of parents with children, the term is referred to the father, while in households consisting of persons related or not, it is referred to the oldest working member or the most senior member." The first two variables were operationalized as categorical with the categories according to the survey questionnaire presented in Table 4.3 below, while the third one was operationalized as continuous. There are, also, three dummy variables informing on whether at least one minor member lives in the household (younger than 13 years old - shorthand: **one_Minor**), and whether an elderly member lives in the household (older than 65 years old - shorthand: **one_Elderly**). Households' average total net monthly family income is approximately €1,500, while the average surface of the dwellings is 90 m^2. The average age of the household head is almost 59 years old, while the vast majority of the household heads are older than 30 years old. Furthermore, only almost 20% of the households include a minor member at their realm, while the double (40%) include an elderly member.

Table 4.3 Socio-economic characteristics/demographics of households – Age of the household head and total household's size

HH_age	**Frequency** (%)	**Size** (m^2)	**Frequency** (%)
1. (-30)	3.26	1. (-50)	8.95
2. (31 - 50)	30.48	2. (51 - 70)	20.26

3. (51 - 65)	29.84	3. (71 - 100)	44.86
4. (66-)	36.42	4. (100-)	25.94

5.2.2.3 Households' environmental behavioural patterns, knowledge about energy spending and smart readiness

Regarding environmental behavioural patterns, the 'Energy Bahaviour Index' (shorthand: **Enrg_Behav_Index**) variable captures whether respondents perform certain energy conservation actions regularly, such as: adjusting the heating thermostat during the winter or the summer period, using room thermostat's auto-mode function for the cooling system, regularly performing maintenance of heating/cooling/AC systems, consulting energy label when buying a new electrical appliance, and setting TV on standby mode when not used. The data suggest that more than 80% of the households perform quite regularly at least half of these energy conservation actions.

Regarding energy spending and use, the 'Energy Spending Index' (shorthand: **Enrg_Spend_Index**) variable captures whether respondents were able to provide information about their household's spending and energy consumption. Typically, literature acknowledges that it is not very common for households to be informed about their energy bills and use (Ameli and Brandt, 2015). This is also the case in Greece, since, according to the survey data, only 30% of the respondents were informed about the daily tariffs of their electricity bill, while less than 8% were informed about the nighty tariffs. On the other hand, results show that more than half of the households (65% and 69%) were aware of their average charges of electricity consumed over a four-month period and their charges on the heating oil purchased in winter period for space heating. However, when it comes to average charges for natural gas purchased in winter period for space heating, only 11% of the respondents were informed. Overall, the 'Energy Spending Index' indicates that almost 80% of the respondents were aware about at least one of these charges.

Furthermore, concerning the primary energy source for main space heating system, almost 70% of the households prefer heating oil (shorthand: **Oil_heat)**, while only a 10% of the households' natural gas (shorthand: **Natgas_heat**). All the variables in this category were operationalized as dummy. Finally, given the availability of the existing data, we introduce an index of how ready a household is to accept smart EE features, an aspect that, to the best of our knowledge, previous studies in the field have not yet included. Research on home automation indicates that consumers are the most interested in using automated systems for safety and security, followed by entertainment and lighting. Wireless technology is the most common form of connectivity and is likely to grow with the increasing availability of products and appliances equipped with wi-fi (Balta-Ozkan et al., 2013). Thus, one indication of how ready a household is to adopt smart EEMs is to examine its familiarization with synchronous, advanced technologies, as personal computers (i.e. desktops or laptops) or internet devices (modems or rooters). The 'Smart Readiness Index' (shorthand: **Smart_Read_Index**) indicates that almost half of the households (49%) are familiar with all these technologies. That could mean that those households are more likely to own, and therefore, adopt smart EE features in the future.

5.2.2.4 Subsidy programmes and support schemes

Regarding the effectiveness of support programmes in encouraging technology ownership, the independent variables was derived from homeowners' responses to the question whether they have benefitted from support policies (i.e. "ESH" subsidy programme and social tariff system). Results show that a very limited number of the investigated households have joined the "ESH" programme receiving financial support for EE retrofits. This is mainly because the programme was launched in 2011; the majority of households might have been less aware of its existence at the time the survey was undertaken. Nevertheless, the variable was included to explore the results of the "ESH" programme during its phasing-in period and was operationalized as dummy. Additionally, the survey data included information on whether households have joined the Social Tariff system (shorthand: Soc_tariff). The Social Tariff was established in 2010 by the Greek government for the protection of vulnerable groups, including lower income, multi-child consumers, and consumers with disabilities or long-term unemployed. These consumer groups were entitled to a 20% reduction in their retail electricity costs up to a limit of 800 KWh energy consumption. Results show that only a small percentage of the households (6%) are part of the Social Tariff system. This is mainly attributed to the fact that the respective scheme has been introduced during the period that this particular survey was conducted.

4.3 Methods

4.3.1 Logistic regression

Our study focuses on modeling the probability of households to own an EEM using discrete choice modeling. For each choice, the probability of each households ’i to own a technology is modeled as:

$$P(\mathrm{y_i} = 1) = \Lambda(\beta \cdot \mathrm{x_i})$$

where:

- $\mathrm{y_i}$ is the dependent variable describing if a household i owns the technology or not;
- $\mathrm{x_i}$ is the vector of independent/explanatory variables for household i;
- β is the parameter vector to be estimated; and
- Λ is the logistic distribution.

The logistic cumulative distribution function is defined as:

$$\mathrm{P}(\mathrm{y_i} = 1|\mathrm{x_i}) = \Lambda(\beta \cdot \mathrm{x_i}) = \frac{\mathrm{e}^{\beta \cdot \mathrm{x_i}}}{1 + \mathrm{e}^{\beta \cdot \mathrm{x_i}}}$$

where P is the probability of y occurring.

The maximum likelihood (ML) estimation method is used to estimate the parameter vector β. All regression parameter estimates are evaluated using quasi standard errors, which are robust for heteroskedastic error terms and misspecifications.

4.3.2 Marginal effects

Since our focus is set on the incremental effect of key determinants for technology ownership, we calculate the average marginal effects of the explanatory variables. Marginal effects can be an informative mean for summarizing how change in a response is related to change in a covariate (Dendramis et al., 2019). For continuous variables, the marginal effects measure the change in the predicted probability of observing that a household owns (y = 1) with infinitesimally small changes in the explanatory variable $\mathrm{x_i}$. For continuous variables marginal effects are computed as:

$$\frac{\partial P(y = 1|x)}{\partial x_k} = \Lambda(\beta \cdot x) \cdot [1 - \Lambda(\beta \cdot x)] \cdot \beta_k$$

Marginal effects are evaluated at the sample median of the variables. For dummy variables, the marginal effect expresses how the predicted probability of observing that a household owns (y = 1), changes when the explanatory variable changes from 0 to 1. In this case marginal effects are calculated as the difference between the predicted probability to invest in a technology with the explanatory dummy variable taking the value of 1 and of 0, while all other explanatory variables are evaluated at the sample median, if continuous, or take the value that is most frequently observed in the sample, if dummy.

4.4 Results and discussion

In this section we present and discuss the respective results (Table 4.4, Table 4.5 and Table 4.6) of the discrete choice model as specified in Table 4.1. These are complemented with descriptive statistics of household technology ownership. The results of the empirical model are then used to simulate technology ownership across different income levels (see section 4.5).

Table 4.4 Logistic regressions I - Dependent variables: EE AC split units, shading systems and ceiling/floor fans.

Explanatory Variables		**EE AC splits units – ‘AC’**		**Shading systems - 'Shad'**		**Ceiling/floor fans - Fans'**	
Category	**Name**	**Coefficients**	**Marginal effects**	**Coefficients**	**Marginal effects**	**Coefficients**	**Marginal effects**
Dwelling characteristics	**‘Owner’**	-0.133 (0.106)	-0.03 (0.042)	1.265*** (0.089)	0.082** (0.04)	-0.125 (0.178)	-0.016 (0.028)
	‘House’	0.442*** (0.077)	0.101*** (0.034)	0.072 (0.064)	0.005 (0.021)	0.134 (0.131)	0.018 (0.02)
	‘Tenure’	0.308* (0.178)	0.07 (0.06)	-1.11*** (0.129)	-0.072 (0.077)	0.676** (0.312)	0.089* (0.051)
	‘Year’	0.21*** (0.02)	0.048*** (0.011)	0.063*** (0.017)	0.004 (0.006)	-0.077** (0.039)	-0.01 (0.007)
	‘Urban’	-0.152 (0.104)	-0.035 (0.046)	0.417*** (0.091)	0.027 (0.023)	-0.495** (0.2)	-0.065** (0.03)
	‘EL3’	-0.577*** (0.141)	-0.132** (0.057)	1.678*** (0.128)	0.109 (0.072)	0.824*** (0.287)	0.109*** (0.024)
	‘EL5’	-0.337** (0.141)	-0.077 (0.062)	0.904*** (0.129)	0.059 (0.05)	-0.446 (0.299)	-0.059 (0.056)
	'EL6’	-0.381*** (0.145)	-0.087 (0.063)	-0.067 (0.133)	-0.004 (0.026)	-0.176 (0.301)	-0.023 (0.048)
Socio-economic characteristics /demographics	**‘HH_age’**	-0.303*** (0.062)	-0.069** (0.027)	0.101* (0.053)	0.007 (0.015)	0.181 (0.117)	0.024 (0.019)
	‘Size’	-0.063 (0.04)	-0.014 (0.015)	0.056* (0.032)	0.004 (0.009)	0.129* (0.068)	0.017 (0.011)
	‘Income’	0.005 (0.057)	0.001 (0.023)	-0.169*** (0.048)	-0.011 (0.015)	-0.133 (0.1)	-0.018 (0.016)
	‘one_Minor’	0.013 (0.089)	0.003 (0.039)	0.117 (0.077)	0.008 (0.025)	-0.277 (0.178)	-0.036 (0.029)
	‘one_Elderly’	0.28*** (0.106)	0.064 (0.045)	-0.236*** (0.088)	-0.015 (0.024)	-0.044 (0.19)	-0.006 (0.029)
Environmental behavioural patterns, knowledge about energy spending	**‘Enrg_Spend_Index’**	0.191 (0.122)	0.044 (0.048)	0.3*** (0.101)	0.019 (0.029)	-0.031 (0.209)	-0.004 (0.032)
	‘Enrg_Behav_Index’	0.537*** (0.097)	0.123*** (0.034)	0.985*** (0.074)	0.064** (0.031)	0.084 (0.149)	0.011 (0.023)
	‘Oil_heat’	-0.06 (0.123)	-0.014 (0.05)	-0.046 (0.103)	-0.003 (0.029)	0.23 (0.218)	0.03 (0.034)
	‘Natgas_heat’	-0.188 (0.162)	-0.043 (0.063)	-0.488*** (0.132)	-0.032 (0.041)	-0.055 (0.303)	-0.007 (0.046)
Households’ ‘smart’ readiness	**‘Smart_Read_Index’**	0.195** (0.081)	0.045 (0.033)	0.437*** (0.067)	0.028 (0.026)	0.308** (0.142)	0.041* (0.022)
Subsidy programmes and support schemes	**‘Policy’**	-0.068 (0.45)	-0.016 (0.169)	0.809** (0.358)	0.053 (0.212)	-0.732 (1.006)	-0.097 (0.148)
	‘Soc_tariff’	0.316** (0.13)	0.072 (0.055)	-1.024*** (0.114)	-0.066* (0.036)	0.317 (0.207)	0.042 (0.034)
Constant		0.352 (0.458)		1.316*** (0.379)		-1.779** (0.823)	
Pseudo R^2 (McFadden)		0.822		0.722		0.815	
Observations		1588		1588		1588	

Table 4.5 Logistic regressions II - Dependent variables: room thermostat, solar thermosiphon system and thermal insulation of walls

Explanatory Variables		**Room thermostat - ‘Room’**		**Solar thermosiphon system - ‘Solar’**		**Thermal insulation of walls - ‘Ins’**	
Category	**Name**	**Coefficients**	**Marginal effects**	**Coefficients**	**Marginal effects**	**Coefficients**	**Marginal effects**
Dwelling characteristics	**‘Owner’**	0.366*** (0.116)	0.049 (0.03)	1.21*** (0.183)	0.291*** (0.055)	0.221 (0.135)	0.045 (0.049)
	‘House’	1.263*** (0.075)	0.171*** (0.053)	0.59*** (0.089)	0.142*** (0.035)	0.875*** (0.089)	0.177*** (0.041)
	‘Tenure’	1.446*** (0.223)	0.195*** (0.065)	0.013 (0.202)	0.003 (0.068)	0.756*** (0.251)	0.153** (0.078)
	‘Year’	0.457*** (0.02)	0.062*** (0.019)	0.205*** (0.024)	0.049*** (0.01)	1.322*** (0.023)	0.267*** (0.044)
	‘Urban’	0.835*** (0.105)	0.113*** (0.038)	-0.471*** (0.119)	-0.113** (0.047)	0.258** (0.126)	0.052 (0.049)
	‘EL3’	-1.715*** (0.135)	-0.232*** (0.027)	-0.86*** (0.149)	-0.207*** (0.059)	-0.078 (0.157)	-0.016 (0.076)
	‘EL5’	-1.052*** (0.135)	-0.142*** (0.025)	-1.366*** (0.151)	-0.328*** (0.055)	-0.105 (0.157)	-0.021 (0.077)
	'EL6’	-1.284*** (0.14)	-0.173*** (0.029)	-1.236*** (0.155)	-0.297*** (0.059)	-0.279* (0.163)	-0.056 (0.084)
Socio-economic characteristics /demographics	**‘HH_age’**	-0.084 (0.064)	-0.011 (0.017)	-0.117 (0.077)	-0.028 (0.028)	0.066 (0.077)	0.013 (0.029)
	‘Size’	0.087** (0.04)	0.012 (0.01)	0.395*** (0.05)	0.095*** (0.017)	0.242*** (0.049)	0.049*** (0.019)
	‘Income’	0.23*** (0.058)	0.031* (0.017)	0.113 (0.069)	0.027 (0.025)	0.129* (0.067)	0.026 (0.026)
	‘one_Minor’	-0.271*** (0.09)	-0.037 (0.027)	-0.041 (0.107)	-0.01 (0.04)	-0.049 (0.098)	-0.01 (0.044)
	‘one_Elderly’	0.125 (0.106)	0.017 (0.029)	0.134 (0.126)	0.032 (0.046)	-0.104 (0.129)	-0.021 (0.047)
Environmental behavioural patterns, knowledge about energy spending	**‘Enrg_Spend_Index’**	-0.259** (0.123)	-0.035 (0.034)	0.123 (0.145)	0.03 (0.052)	0.157 (0.139)	0.032 (0.055)
	‘Enrg_Behav_Index’	0.667*** (0.101)	0.09*** (0.031)	0.167 (0.118)	0.04 (0.038)	0.623*** (0.132)	0.126*** (0.046)
	‘Oil_heat’	1.158*** (0.129)	0.156*** (0.052)	0.121 (0.146)	0.029 (0.053)	0.074 (0.141)	0.015 (0.055)
	‘Natgas_heat’	1.514*** (0.162)	0.205*** (0.07)	-0.213 (0.203)	-0.051 (0.068)	-0.793*** (0.197)	-0.16** (0.079)
Households’ ‘smart’ readiness	**‘Smart_Read_Index’**	0.391*** (0.081)	0.053** (0.027)	0.348*** (0.099)	0.084** (0.036)	0.509*** (0.096)	0.103*** (0.037)
Subsidy programmes and support schemes	**‘Policy’**	0.815** (0.381)	0.11 (0.151)	0.719 (0.452)	0.173 (0.195)	1.275*** (0.452)	0.258 (0.174)
	‘Soc_tariff’	0.076 (0.135)	0.01 (0.035)	0.195 (0.154)	0.047 (0.057)	-0.197 (0.167)	-0.04 (0.061)
Constant		-5.569*** (0.496)		-3.011*** (0.57)		-8.832*** (0.583)	
Pseudo R^2 (McFadden)		0.822		0.722		0.815	
Observations		1588		1588		1588	

Table 4.6 Logistic regressions III - Dependent variables: energy efficient windows systems and efficient lighting Bulbs

Explanatory Variables		Energy efficient window systems - ‘EEW’		Efficient lighting types - ‘Light’	
Category	**Name**	**Coefficients**	**Marginal effects**	**Coefficients**	**Marginal effects**
Dwelling characteristics	**‘Owner’**	0.971*** (0.133)	0.238*** (0.051)	-0.04 (0.134)	-0.005 (0.021)
	‘House’	0.329*** (0.082)	0.081** (0.035)	0.405*** (0.101)	0.048*** (0.017)
	‘Tenure’	1.082*** (0.224)	0.265*** (0.075)	0.599** (0.237)	0.071* (0.038)
	‘Year’	0.572*** (0.02)	0.14*** (0.012)	0.027 (0.027)	0.003 (0.004)
	‘Urban’	0.259** (0.119)	0.063 (0.049)	0.043 (0.16)	0.005 (0.023)
	‘EL3’	0.24 (0.158)	0.059 (0.071)	1.307*** (0.258)	0.154*** (0.018)
	‘EL5’	0.815*** (0.157)	0.2*** (0.066)	0.817*** (0.261)	0.096*** (0.02)
	'EL6’	-0.203 (0.167)	-0.05 (0.076)	0.379 (0.273)	0.045 (0.03)
Socio-economic characteristics /demographics	**‘HH_age’**	0.017 (0.069)	0.004 (0.029)	-0.003 (0.084)	0 (0.013)
	‘Size’	0.17*** (0.043)	0.042** (0.018)	-0.089* (0.052)	-0.01 (0.008)
	‘Income’	0.353*** (0.062)	0.086*** (0.027)	0.242*** (0.078)	0.029** (0.013)
	‘one_Minor’	0.081 (0.093)	0.02 (0.046)	0.386*** (0.115)	0.046** (0.02)
	‘one_Elderly’	-0.3*** (0.114)	-0.073 (0.049)	-0.213 (0.143)	-0.025 (0.024)
Environmental behavioural patterns, knowledge about energy spending	**‘Enrg_Spend_Index’**	-0.075 (0.13)	-0.018 (0.056)	-0.014 (0.162)	-0.002 (0.025)
	‘Enrg_Behav_Index’	0.161 (0.107)	0.039 (0.039)	-0.126 (0.117)	-0.015 (0.018)
	‘Oil_heat’	0.267** (0.132)	0.065 (0.057)	0.158 (0.167)	0.019 (0.026)
	‘Natgas_heat’	0.469*** (0.166)	0.115 (0.074)	0.476** (0.208)	0.056* (0.034)
Households’ ‘smart’ readiness	**‘Smart_Read_Index’**	0.229*** (0.087)	0.056 (0.036)	0.242** (0.109)	0.029* (0.017)
Subsidy programmes and support schemes	**‘Policy’**	3.575*** (0.361)	0.535 (0.632)	0.444 (0.505)	0.052 (0.087)
	‘Soc_tariff’	0.508*** (0.137)	0.124** (0.061)	0.479*** (0.161)	0.057** (0.029)
Constant		-7.73*** (0.538)		-3.978*** (0.649)	
Pseudo R^2 (McFadden)		0.822		0.722	
Observations		1588		1588	

Standard errors are reported in parentheses.
*** $p < 0.01$.
** $p < 0.05$.
* $p<0.1$.

4.4.1 The importance of dwelling characteristics

There is already a clear evidence in literature about the owner-effect in adopting EEMs (Ameli and Brandt, 2015; Davis, 2010; Gillingham et al., 2012; Heiskanen and Matschoss, 2017; Mills and Schleich, 2012). Our results support these findings showing a statistically positive correlation between house-ownership and ownership of almost all the EEMs under study, except from shading systems, where a significant negative correlation is highlighted and solar thermosiphon systems, where no significant correlation is acknowledged. These results are in line with literature findings (Ameli and Brandt, 2015; OECD, 2013) acknowledging a stronger incentive of owners to invest in relatively immobile and permanent measures (i.e. window systems, thermal insulation) in contrast to renters who present a higher probability to invest in more mobile affordable technologies, with a shorter life-cycle, as shading systems (i.e. shutters or awnings).

In addition, our results suggest that households characterized as detached/semi-detached, which can also be perceived as an indicator of space availability (Ameli and Brandt, 2015), present a statistically significant positive correlation with owning shading systems, room thermostats, solar thermosiphon systems and EE window systems. These findings are also validated by the studies presented in (Ameli and Brandt, 2015; Gelegenis et al., 2014). This might be explained by the fact that semi-detached or completely detached households, owing to larger surface exposed to weather conditions, prioritize measures to prevent heating losses over others. Such findings validate literature insights acknowledging a “difficult consensus” between such measures and multi-family houses (Gelegenis et al., 2014). A positive statistical significance between the year of construction and the probability to own shading systems, ceiling/floor fans, room thermostat, solar thermosiphon systems, thermal insulation and EE window systems is observed. These findings are also validated by relevant literature (Balaras et al., 2016; Dascalaki et al., 2016; Droutsa et al., 2016; Gelegenis et al., 2014; Sardianou and Genoudi, 2013). A positive association of ownership of such measures and household age is expected, as newer buildings, built after 1980, were required to be built according to higher energy performance requirements. Finally, literature findings on technology adoption determinants have also well acknowledged that location context (e.g. rural areas) and climate zones affect people’s choice to adopt EEMs (Ameli and Brandt, 2015; Michelsen and Madlener, 2012). Our results on technology ownership for such technologies confirm such evidence, as they indicate that living in rural environments increases the probability of owning ceiling/floor fans, room thermostats, solar thermosiphon systems, thermal insulation, EE window systems and EE lighting bulbs.

On the influence of different climatic zones or regional location of a household on the ownership of different EEMs our results are rather inconclusive. For instance, living in the EL3 region decreases the probability of owning EEMs, such as EE AC split units, room thermostats, solar thermosiphon systems, thermal insulation and EE lighting bulbs. On the other hand, our findings indicate that living in the EL5 region, including the city of Thessaloniki, the second largest city of Greece, increases the probability of owning EEMs, as shading systems, room thermostats, thermal insulation and EE window systems, while decreases the probability of owning ceiling/floor fans and solar thermosiphon systems. These findings are in line with prior knowledge, suggesting that the replacement of window systems and the addition of thermal insulation are two of the most frequently appeared recommendation in the EPCs for this region (Gelegenis et al., 2014). Nevertheless, surprising remains the fact that for all the three climatic zones under study our estimations suggest a significant negative statistical correlation with owning solar thermosiphon systems, while previous results acknowledge no correlation, mainly owing to the great popularity of the measure in Greece (Gelegenis et al., 2014). In any case, updated survey data are required to shed light on the effect of climatic zones on ownership.

4.4.2 The ambiguity in the influence of demographics

Our econometric estimations demonstrate that the age of the household head correlates positively with the ownership of EE AC split units, shading systems, room thermostats, solar thermosiphon systems, thermal insulation and EE window systems, while correlate negatively with owning ceiling/floor fans. These findings validate our initial speculations that age should correlate with the ownership of certain smart, more automated, EE features, and validate literature findings suggesting that middle-aged people have a greater propensity to adopt EEMs (Ameli and Brandt, 2015; Heiskanen and Matschoss, 2017). The latter is visualized in Figure 4.1 below, where it is apparent that middle-aged people (40 - 70 years old) are more likely to own EE AC split units in Greece. Additionally, other socio-economic characteristics, such as households with at least one minor (younger than 13 years old) or elderly member, seem to have no statistically significant correlation with the ownership of the EEMs under study. An interesting finding, though, is that households' with at least one elderly member seem to have a significant negative statistical correlation with the probability of owning smart features as room thermostats. Nevertheless, the age factor remains ambiguous across studies, suggesting that age may be technology specific or driven by certain age-groups (Sardianou and Genoudi, 2013; Willis et al., 2011). Additionally, our results indicate a positive relation between households' size and probability to own EE AC split units, room thermostats, solar thermosiphon systems, thermal insulation and EE window systems and lighting bulbs. Especially for the cases of room thermostats, solar thermosiphon systems and thermal insulation the respective marginal effects are quite high.

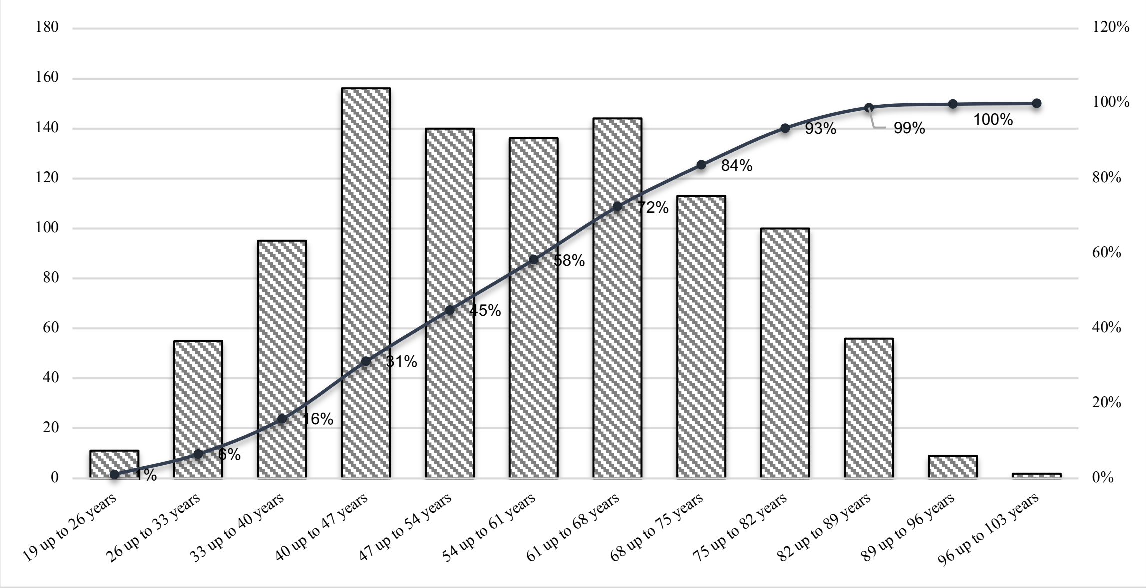


Figure 4.1 Ownership of EE AC split units by age

On the other hand, while the effect of credit constraints regarding the dependency between households' income and the propensity to invest in EEMs has been demonstrated in literature (Long, 1993; Mills and Schleich, 2010a; Sardianou and Genoudi, 2013), other studies have acknowledged this relation as "weak" (Olsen, Marvin, 1981; Sardianou, 2007), suggesting that there is no clear evidence that an increase in household income positively correlates with the adoption of EEMs (Trotta, 2017). Our results on the relationship between income and ownership of EEMs are ambiguous too. Income is positively correlated with the ownership of EE AC split units, which are not typically affordable, while for the case of EE window systems, results show a high statistical significance (at a 1% level) yet with a negative correlation. EE window systems are the most popular EE retrofit measures when it comes to the building stock of Greece, as indicated by the meta-analysis of EPCs. On the latter, literature acknowledges that medium- and high-income households are more likely to invest in high-cost EE retrofit measures (Urban and Sc, 2012). This is also visualized in Figure 4.2 below, where, regardless the type of correlation, it is evident that more than 60% of the window systems are adopted by households of medium-to-high income categories (818-2254€). Finally, regarding other socio-economic characteristics of the households, as education levels, useful indices to enable estimations could not be extracted due to data limitations. Typically, the education effect is well-mentioned in literature studies in the field (Maria et al., 2010; Michelsen and Madlener, 2012; Mills and Schleich, 2012, 2010b, 2009; Sardianou and Genoudi, 2013), and future econometric estimations should explore the effects of education as a key explanatory variable in Greece.

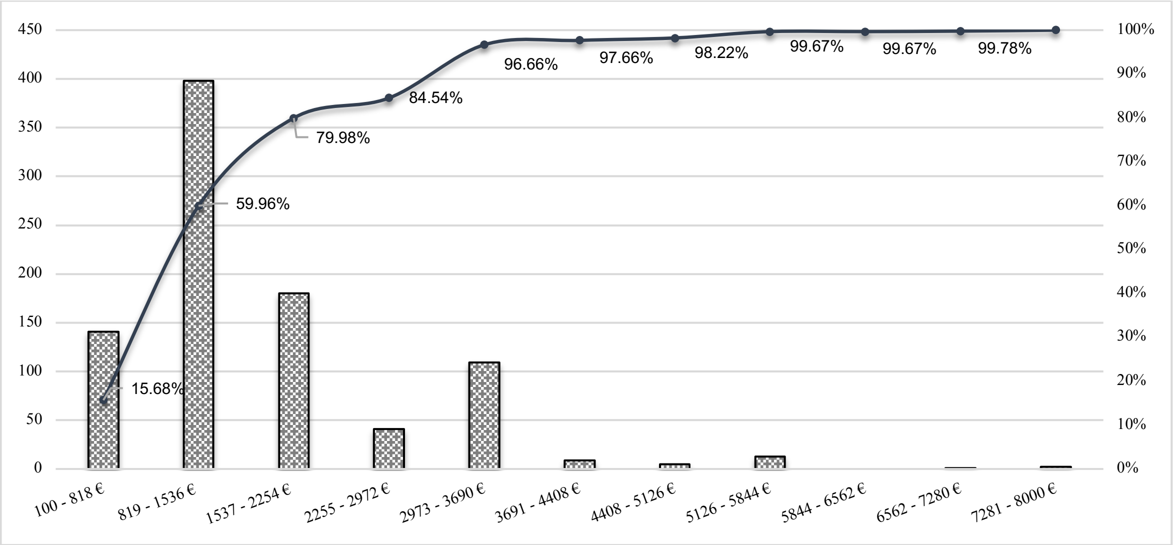


Figure 4.2 Ownership of EE window systems by income

4.4.3 Energy conservation behaviour, heating fuel and smart readiness as indicators for EE technology ownership

Literature acknowledges that there is a causality between households' knowledge on own energy consumption and adoption decisions, and that lack of information can limit the uptake of EEMs (Ameli and Brandt, 2015; Heiskanen and Matschoss, 2017; Mills and Schleich, 2012). Our results support this statement, as the 'Energy Spending Index' variable, capturing whether respondents were able to provide information about their household's energy spending and use, presented a significant correlation with the probability of owning EE AC split units, shading systems, room thermostats and thermal insulation. Furthermore, our findings also show that technology ownership for almost all EEMs is positively associated with households' energy conservation behavior. This is demonstrated through the 'Energy Behavior Index' variable, which captures whether respondents perform certain energy conservation actions regularly, for the cases of EE AC split units, window systems and lighting bulbs. As typically householders that perform regularly conservation actions are considered well informed on the savings of EE products, they are more likely to own EE alternatives, that despite higher upfront costs, are characterized by long lifespan and low energy use, leading to considerable monetary savings.

Households using oil, as the primary energy source for main space heating system, also appear to be more inclined to own namely all EEMs under study. Whereas, households with a preference on natural gas present a positive correlation only for room thermostats. This is reasonable to a certain extent, since households with oil heating systems present higher energy costs than households with alternative heating fuels, and especially during the period the survey was conducted. This may in turn indicate that households with increased energy consumption and higher fuel costs are more likely to own energy conservation measures. Finally, our results don't confirm our original hypothesis that households familiar with synchronous and advanced technologies (i.e. captured under the "Smart Readiness" instrumental variable) are more likely to own smart EE features, as room thermostats. Although a statistical significance is noted the negative association of the Smart readiness index with owning room thermostats comes as a surprise (see Table 4.5).

4.4.4 The role of the "ESH" subsidy programme and the social tariff support scheme

Our results suggest that households receiving financial support in the form of a grant combined with a soft-loan through the "ESH" programme, are more likely to own room thermostats, thermal insulation, EE window systems and lighting bulbs, while are less likely to own shading systems. Especially for the case of EE window systems the corresponding marginal effects indicate about 17 percentage points of more likelihood of technology ownership. This was expected as retrofit windows was one of the main actions eligible under the programme. Surprisingly, households that benefited from the Social Tariff scheme are more likely to own EEMs relevant to heating energy conservation, such as own room thermostats, thermal insulation and EE window systems, while a negative relation is observed for cooling measures. This might be explained by the fact that vulnerable consumer groups under eligible under the scheme have increased energy needs (e.g. people with disabilities or multi-child families). It may also be the case that participants in the Social Tariff scheme have become more aware of energy conservation benefits and are thus more inclined to invest in more permanent EEMs with high upfront costs, but with long lifespans and considerable energy and financial savings.

4.5 Effectiveness of the "ESH" subsidy programme in encouraging ownership of EEMs in Greece, particularly for lower income-level households

Next, we use the empirical model results to run simulations, in order to explore how the implementation of the "ESH" subsidy programme in low-income households may have affected the ownership rates of different EEMs. To do so, we ran 3000 iterations according to the logistic model derived from the full sample of 1588 complete cases. For the simulations, all the control variables are simulated according to their empirical distribution, assuming that a change in the programme participation would not affect other model parameters. Simulations are conducted for three (3) individual scenarios. Scenario 1 predicted technology ownership for the different EEMs under assessment under the observed situation, where 0.5% of households participated in the "ESH" programme. Scenario 2 assumed that "ESH" did not exist and that householders had invested in EEMs at the prevailing market prices. Scenario 3 assumed that all households would have participated in the "ESH" programme receiving financial support for adopting EE retrofit options. Results are presented in Table 4.7 below.

Table 4.7 Simulation results for technology ownership probability based on the discrete choice-logistic regression model

	Predicted probability of owning EEMs [90% confidence interval]			
EEMs	**Scenario 1:** Observed "ESH" participation	**Scenario 2:** No "ESH" participation	**Scenario 3:** With "ESH" participation	**Percentage Change (%)** Scenario 1-2
EE AC split units	64.5 [38.6,85.8]	64.5 [38.6,85.9]	63.1 [37,85]	0.00%
Shading systems	94 [79.1,99.5]	94 [79,99.5]	97.1 [89.4,99.8]	0.00%
Ceiling/floor fans	20.9 [7.8,39.8]	21 [7.8,39.8]	11.7 [3.9,24.1]	-0.48%
Room thermostat	62.7 [11.5,97.4]	62.6 [11.5,97.4]	74.4 [22.6,98.8]	0.16%
Solar thermosiphon systems	45.2 [9.2,81.4]	45.1 [9.2,81.4]	59.1 [17.3,90]	0.22%
Thermal insulation	47.2 [5.5,99.2]	47.1 [5.5,99.2]	66.7 [17.1,99.8]	0.21%
EE window systems	56.9 [20,93.7]	56.7 [20,93.4]	96.8 [89.9,99.8]	0.35%
EE lighting bulbs	37.3 [12.5,70.6]	37.3 [12.5,70.6]	46.4 [18.2,78.9]	0.00%

Simulation results for the observed situation (Scenario 1) are in line with observed ownership rates for EEMs under study: EE AC split units (64%), shading systems (95%), floor/ceiling fans (21%), room thermostats (65%), solar thermosiphon (45%), thermal insulation (47%), EE window systems (57%), and EE lighting bulbs (37%). Likewise, the results under Scenario 2 are analogous to observed adoption rates in the data. Scenario 1 and 2 support the view that the way we generate data (x_i) and simulate adoption rates (i.e. $P(y_i=1)$ is plausible. For Scenario 3, we simulate an extreme, hypothetical scenario to observe how adoption rates would change if all households would participate the subsidy programme in comparison to observed adoption rates.

Results for Scenarios 1 and 2 show the impact of the "ESH" programme participation in technology ownership rates during its first year of implementation. Participation in the "ESH" programme was associated with an considerable increase in technology ownership rates for room thermostats (0.16%), solar thermosiphon systems (0.22%), thermal insulation (0.21%) and EE window systems (0.35%). One has to account for the fact that the scheme had only been one year in effect when the survey was undertaken. In addition our results for ceiling floor fans parallel the results from the logistic regression model (i.e. a negative coefficient of -0.732 is estimated, see Table 4.4). A negative and weak association (i.e. -0.016) is also estimated with ownership rates for EE AC split units, which is also reflected in a zero change in the probability of ownership across Scenario 1 and 2. AC split units were in fact not included in the list of eligible technologies for support under the programme as a parallel support programme targeting the replacement of inefficient AC units was in effect at the time. In tandem, our results suggest that that there is a heterogeneity in the impact of the "ESH" programme in technology ownership rates and that the ownership for EEMs that were primarily prompted by the scheme (i.e. Room, Solar, Ins, EEW) is positively affected. Contrasting simulation results for Scenarios 1 and 3 indicate that public subsidies can potentially help to overcome credit constraints and prompt ownership of EEMs, yet owing to the large variability in our estimates, this conclusion cannot be stated with the appropriate level of statistical confidence.

Separate simulations were performed for households of different income-levels to explore how the predicted probabilities of owning different measures might change owing to the "ESH" programme for the three eligibility categories, as foreseen by it. Results are presented in Table 4.8. As such, during the simulations, for households of high-income level, the FI variable in the adoption model was set to randomly vary between the upper and lower values in the high-income eligibility interval, and accordingly for the rest of the two income categories.

Table 4.8 Simulation results for technology ownership probability based on the discrete choice-logistic regression model for the different income-level decision-makers

EEMs	**Scenario 1:** High Income - No ESH	**Scenario 2:** High Income - With ESH	**Scenario 3:** Medium Income - No ESH	**Scenario 4:** Medium Income - With ESH	**Scenario 5:** Low Income - No ESH	**Scenario 6:** Low Income - With ESH
AC	64 [38.2,85.5]	62.6 [36.6,84.6]	64 [38.1,85.5]	62.5 [36.5,84.6]	63.6 [37.7,85.2]	62.2 [36,84.4]
Shad	93.6 [78.4,99.5]	96.9 [89.1,99.8]	94.1 [79.7,99.5]	97.1 [90,99.8]	96.3 [87.2,99.7]	98.3 [93.7,99.9]
Fans	19.9 [7.6,38.1]	11 [3.8,22.7]	21 [8.2,39.9]	11.7 [4,24.1]	28.7 [11.8,51.8]	16.9 [6,33.7]
Room	64.9 [12.5,98]	76.2 [24.5,99.1]	63 [11.2,97.7]	74.6 [22.2,99]	50.8 [5.6,95.4]	64 [11.9,97.9]
Solar	46.9 [10.4,84.3]	60.8 [19.1,91.6]	45.6 [9.8,83.4]	59.6 [18.4,91.2]	38.5 [7,77.7]	52.4 [13.2,87.6]
Ins	47.7 [5.7,99.3]	67.3 [17.6,99.8]	46.6 [5.3,99.3]	66.2 [16.7,99.8]	40.6 [3.5,98.9]	59.7 [11.5,99.7]
EEW	60.5 [23.8,94.6]	97.4 [91.7,99.8]	56.7 [20.5,93.5]	96.8 [89.9,99.8]	35.3 [6.7,83.5]	90.7 [71.6,99.4]
Light	39.7 [14.3,72]	49 [20.5,80.1]	37 [12.6,69.2]	46.2 [18.3,77.7]	23 [5.6,53.1]	30.5 [8.4,63.2]

Notably, simulation results suggest that the probability of technology ownership in the higher income-eligibility category is greater than the probability for the other two lower income categories and for most of the EEMs under study (i.e. Room, Solar, Ins, EEW and AC). The difference in the technology ownership probability is especially high when comparing simulation results between households of high- and low-income (Scenarios 1 & 5), whereas differences in ownership rates appear to be even higher without the financial support of the "ESH" programme (Scenario 2 & 6). Nevertheless, by comparing simulation results with or without "ESH", and across the three income categories, we observe that the increase in the probability of technology ownership is larger for lower-income households participating in the programme than households of higher income levels receiving a lower grant. This is mainly observed for EEMs with high upfront costs (i.e. room thermostat, solar thermosiphon systems, thermal insulation and EE window systems). The positive change in ownership rates with "ESH" participation is higher for higher income households only for medium to low cost measures (i.e. shading systems, light bulbs).

Owing to data limitations (i.e. limited participation in the "ESH" programme), it was not possible to conduct a similar econometric assessment to explore the exogenous effect of the "ESH" programme in technology ownership across different income levels. Nevertheless, our simulation results are in line with a recent empirical assessment of the "ESH" programme, which concludes that lower-income households in Greece respond to monetary incentives to invest in EEMs, both in terms of participation rates as well as in terms of the investment amount (Drivas et al., 2018). Finally another recent study across countries in Europe finds differences in adoption propensities across income quartiles to exist for medium to low cost measures, suggesting also that these differences would have been higher in the absence of financial support programmes (Schleich, 2019).

4.6 Conclusions and policy implications

One of the key determinants of technology-related behavior is technology ownership, which has been found to significantly and positively correlate with technology readiness and acceptance. To promote the diffusion of EEMs thus, policymakers as well as utility programme implementers, require a better understanding of the drivers behind the uptake of such measures by residential end-users. As a result, it is of paramount importance to understand current ownership patterns for different EEMs, from the more mature ones to the less. The objective of this article was to investigate existing ownership patterns of EEMs in the residential sector in Greece, to reflect on future adoption trends. To do so, we coupled RP data from a rich set of a national households' survey data with discrete choice modeling. In addition to more commonly investigated factors by relevant studies, such as demographic, socio-economic and dwelling characteristics, the wide range of the variables included in our initial data-set, allowed us to account for behavioural features of respondents, such as their energy conservation behavior, the role of subsidy programmes and support for vulnerable consumer groups in the ownership of EEMs, household readiness for the uptake of smart EE features as well as the influence of the heating fuel in the propensity for EE technology onweship.

Our results confirm the positive correlation among technology ownership and household location, size, year of construction and dwelling types for a variety of EEMs in the Greek households sector. The choice of heating fuel and thus associated energy costs also appear detrimental in the propensity for technology ownership and thus future adoption of EE measures. Whereas for features such as climatic zone, income and age we corroborate earlier findings from literature in investments and adoption of EE improvements, indicating that the influence of the latter is rather inconclusive or technology specific. The empirical model also extends prior knowledge on EE technology adoption by providing evidence that households familiar with synchronous and advanced technologies are more likely to own smart EE features, whereas households with elderly tenants were found to negative correlate with owning a room thermostat. These findings should be considered especially in view of the eminent recast of the EPBD entailing increased attention on the smart performance of the Greek building sector. Government planning should thus consider that technology ownership, and therefore potential adoption of EEMs, is differentiated with regards to such consumers' socio-economic and demographic characteristics. Since there is a limit in the public budget available for financial support, policy makers may thus need to prioritize the types of houses that are both more energy-intensive, as well as more inclined to invest in EEMs. From a utilities perspective, hybrid marketing campaigns targeting segments of householders with different needs and aspects of lifestyle should also be introduced. Financial as well as other types of incentives should target beyond the obvious promising market segment of middle-class owner-occupied single-family households, and new solutions may need to be found in, for example, owner-occupied and rented multifamily buildings. The renter's split-incentive dilemma remains unsolved and need also to be accounted for, as our results acknowledge that renters are less likely to adopt EEMs, and when they do, they focus on easy-to-install, mobile options, with limited energy saving potential.

We were also able to highlight the positive influence of participation in subsidy as well as other support programmes for vulnerable consumers in households' ownership of EEMs. Our results are then used to simulate the change in technology ownership rates due to participation in a subsidy programme and for three distinct income levels. Simulation results indicated that the "ESH" programme in Greece affected positively the adoption of more mature EEMs, even during its phasing-in period, and that public subsidies can potentially help to overcome credit constraints and prompt ownership for EE retrofit measures even for lower income households. Financial incentives should thus continue to target primarily lower income households, although these may also take other forms than grant schemes such as on-bill financing or tax-rebates (Anagnostopoulos et al., 2017; Flamos, 2016). For the latter, these should be designed so that lower-income households can indeed benefit from such incentives and that these have a progressive rather than a regressive effect (Schleich, 2019).

Our work dealt with data limitations that prevented the study of empirically estimating the exogenous effect of the "ESH" programme in technology ownership across different income levels. Important factors or types of technologies, such as education profiles or motion detector devices were also not included. A more thorough econometric assessment would thus be required to investigate whether the "ESH" subsidy programme in Greece has indeed had a progressive effect on technology ownership and extend this analysis to technology adoption investment decisions as well as other steps in the investment decision-making process relevant to other consumer characteristics such as social norms and lifestyle features. Accurate high-resolution data, stripped of missing values and interview errors, are of paramount importance to reflect on adoption trends and tailor-made strategies to diffuse successfully EEMs. Organizing more coherent campaigns that collect actual energy use data could be taken in the framework of incentives provided from the side of utilities. The newly launched "EE Obligation" scheme (under Article 7 of the EED), requiring energy providers to reduce their annual energy sales by providing incentives to their customers to become more energy efficient, could be an excellent opportunity to introduce appropriate monitoring requirements. Such a process would accelerate the availability of hard to collect data which could in turn provide valuable empirical evidence on whether financial as well as other types of incentives (e.g. nudging) may influence EE technology adoption and acceptance.

Acknowledgments

This paper is based on research conducted within the EC funded Horizon 2020 Framework Programme for Research and Innovation (EU H2020) Project titled "Coordination and Assessment of Research and Innovation in Support of Climate Mitigation Actions" (CARISMA) - Grant Agreement No. 642242. The authors would like to acknowledge the support from the EC. The content of the paper is the sole responsibility of its authors and does not necessary reflect the views of the EC.

References

Ameli, N., Brandt, N., 2015. Determinants of households' investment in energy efficiency and renewables: Evidence from the OECD survey on household environmental behaviour and attitudes. Environ. Res. Lett. 10. https://doi.org/10.1088/1748-9326/10/4/044015

Anagnostopoulos, P., Spyridaki, N.A., Flamos, A., 2017. A "new-deal" for the development of photovoltaic investments in Greece? A parametric techno-economic assessment. Energies 10. https://doi.org/10.3390/en10081173

Andrews, C.J., Krogmann, U., 2009. Explaining the adoption of energy-efficient technologies in U.S. commercial buildings. Energy Build. 41, 287–294. https://doi.org/10.1016/j.enbuild.2008.09.009

Balaras, C.A., Dascalaki, E.G., Droutsa, K.G., Kontoyiannidis, S., 2016. Empirical assessment of calculated and actual heating energy use in Hellenic residential buildings. Appl. Energy 164, 115–132. https://doi.org/10.1016/j.apenergy.2015.11.027

Balta-Ozkan, N., Davidson, R., Bicket, M., Whitmarsh, L., 2013. Social barriers to the adoption of smart homes. Energy Policy 63, 363–374. https://doi.org/10.1016/j.enpol.2013.08.043

Boudet, H.S., Flora, J.A., Armel, K.C., 2016. Clustering household energy-saving behaviours by behavioural attribute. Energy Policy 92, 444–454. https://doi.org/10.1016/j.enpol.2016.02.033

Center of Renewable Energy Sources, C., Odyssee-Mure, 2015. Energy Efficiency Trends and Policies in Greece.

Dascalaki, E.G., Balaras, C.A., Gaglia, A.G., Droutsa, K.G., Kontoyiannidis, S., 2012. Energy performance of buildings-EPBD in Greece. Energy Policy 45, 469–477. https://doi.org/10.1016/j.enpol.2012.02.058

Dascalaki, E.G., Balaras, C.A., Kontoyiannidis, S., Droutsa, K.G., 2016. Modeling energy refurbishment scenarios for the Hellenic residential building stock towards the 2020 & 2030 targets. Energy Build. 132, 74–90. https://doi.org/10.1016/J.ENBUILD.2016.06.003

Davis, L., 2010. Evaluating the Slow Adoption of Energy Efficient Investments: Are Renters Less Likely to Have Energy Efficient Appliances? https://doi.org/10.3386/w16114

Dendramis, Y., Tzavalis, E., Varthalitis, P., Athanasiou, E., 2019. Predicting Default Risk under Asymmetric Binary Link Functions.

Drivas, K., Rozakis, S., Xesfingi, S., 2018. The Effect of House Energy Efficiency Costs on the Participation Rate and Investment Amount of Lower-Income Households The Effect of House Energy Efficiency Costs on the Participation Rate and Investment Amount of Lower-Income Households.

Droutsa, K.G., Kontoyiannidis, S., Dascalaki, E.G., Balaras, C.A., 2016. Mapping the energy performance of hellenic residential buildings from EPC (energy performance certificate) data. Energy 98, 284–295. https://doi.org/10.1016/j.energy.2015.12.137

Dua, R., White, K., Lindland, R., 2016. Understanding Adoption of Technologies : A Case Study of Battery Electric Vehicle Adoption in the U . S .

Filippini, M., Hunt, L.C., Zorić, J., 2014. Impact of energy policy instruments on the estimated level of underlying energy efficiency in the EU residential sector. Energy Policy 69, 73–81. https://doi.org/10.1016/j.enpol.2014.01.047

Flamos, A., 2016. A sectoral micro-economic approach to scenario selection and development: The case of the greek power sector. Energies 9, 1–12. https://doi.org/10.3390/en9020077

Forouli, A., Gkonis, N., Nikas, A., Siskos, E., Doukas, H., Tourkolias, C., 2019. Energy efficiency promotion in Greece in light of risk: Evaluating policies as portfolio assets. Energy 170, 818–831. https://doi.org/10.1016/J.ENERGY.2018.12.180

Fowlie, M., Greenstone, M., Wolfram, C., 2018. Do Energy Efficiency Investments Deliver? Evidence from the Weatherization Assistance Program. Q. J. Econ. 133, 1597–1644. https://doi.org/https://doi.org/10.1093/qje/qjy005

Gelegenis, J., Diakoulaki, D., Lampropoulou, H., Giannakidis, G., Samarakou, M., Plytas, N., 2014. Perspectives of energy efficient technologies penetration in the Greek domestic sector, through the analysis of Energy Performance Certificates. Energy Policy 67, 56–67. https://doi.org/10.1016/J.ENPOL.2013.09.051

Gillingham, K., Harding, M., Rapson, D., 2012. Split incentives in residential energy consumption. Energy J. 33, 37–62. https://doi.org/10.5547/01956574.33.2.3

Godoe, P., Johansen, T.-S., 2012. Understanding adoption of new technologies: Technology readiness and technology acceptance as an integrated concept. J. Eur. Psychol. Students 3, 38–52. https://doi.org/http://doi.org/10.5334/jeps.aq

Heiskanen, E., Matschoss, K., 2017. Understanding the uneven diffusion of building-scale renewable energy systems: A review of household, local and country level factors in diverse European countries. Renew. Sustain. Energy Rev. 75, 580–591. https://doi.org/10.1016/j.rser.2016.11.027

Hellenic Statistical Authority, E., 2013. Development of detailed statistics on Energy consumption in Households-2011/2012. Quality Report. Hellenic Statistical Authority.

Leicester, A., Stoye, G., 2017. Factors associated with the presence of domestic energy efficiency measures in england. Fisc. Stud. 38, 331–356. https://doi.org/10.1111/1475-5890.12095

Li, J., Just, R.E., 2018. Modeling household energy consumption and adoption of energy efficient technology. Energy Econ. 72, 404–415. https://doi.org/10.1016/j.eneco.2018.04.019

Long, J., 1993. An econometric analysis of residential expenditures on energy conservation and renewable energy sources. Energy Econ. 15, 232–238.

Maria, C. Di, Ferreira, S., Lazarova, E., 2010. Shedding Light on the Light Bulb Puzzle : the Role of Attitudes and Perceptions in the Adoption of. Scott. J. Polit. Econ. 57, 48–67.

McNeil, M.A., Letschert, V.E., 2010. Modeling diffusion of electrical appliances in the residential sector. Energy Build. 42, 783–790. https://doi.org/10.1016/j.enbuild.2009.11.015

Michelsen, C.C., Madlener, R., 2012. Homeowners' preferences for adopting innovative residential heating systems: A discrete choice analysis for Germany. Energy Econ. 34, 1271–1283. https://doi.org/10.1016/j.eneco.2012.06.009

Mills, B., Schleich, J., 2014. Household transitions to energy efficient lighting. Energy Econ. 46, 151–160. https://doi.org/10.1016/j.eneco.2014.08.022

Mills, B., Schleich, J., 2012. Residential energy-efficient technology adoption, energy conservation, knowledge, and attitudes: An analysis of European countries. Energy Policy 49, 616–628. https://doi.org/10.1016/j.enpol.2012.07.008

Mills, B., Schleich, J., 2010a. Why don't households see the light? Explaining the diffusion of compact fluorescent lamps. Resour. Energy Econ. 32, 363–378.

Mills, B., Schleich, J., 2010b. What's driving energy efficient appliance label awareness and purchase propensity? Energy Policy 38, 814–825.

Mills, B., Schleich, J., 2009. Profits or preferences? assessing the adoption of residential solar thermal technologies. Energy Policy 37, 4145–54.

Ministry of Energy and Climate Change, M., 2015. Report on the Long Term Strategy for the Attraction of Investments on the Renovation of the Greek National Building Stock.

Nair, G., Gustavsson, L., Mahapatra, K., 2010. Factors influencing energy efficiency investments in existing Swedish residential buildings. Energy Policy 38, 2956–2963. https://doi.org/10.1016/j.enpol.2010.01.033

Nikas, A., Stavrakas, V., Arsenopoulos, A., Doukas, H., Antosiewicz, M., Witajewski-baltvilks, J., Flamos, A., 2018. Barriers to and consequences of a solar-based energy transition in Greece. Environ. Innov. Soc. Transitions 1–17. https://doi.org/10.1016/j.eist.2018.12.004

Odyssee-Mure, 2015. Diffusion of solar water heaters:percent of dwellings equipped [WWW Document]. Odyssee.

OECD, 2013. Greening Household Behaviour: Overview from the 2011 Survey, OECD Studies on Environmental Policy and Household Behaviour. OECD Publishing, Paris.

Olsen, Marvin, E., 1981. Consumers' attitudes toward energy conservation. J. Soc. Issues 37, 108–131.

Papada, L., Kaliampakos, D., 2016. Measuring energy poverty in Greece. Energy Policy 94, 157–165. https://doi.org/10.1016/j.enpol.2016.04.004

Papadelis, S., Stavrakas, V., Flamos, A., 2016. What do capacity deployment rates tell us about the efficiency of electricity generation from renewable energy sources support measures in Greece? Energies 9. https://doi.org/10.3390/en9010038

Pettifor, H., Wilson, C., Chryssochoidis, G., 2015. The appeal of the green deal : Empirical evidence for the in fl uence of energy ef fi ciency policy on renovating homeowners. Energy Policy 79, 161–176. https://doi.org/10.1016/j.enpol.2015.01.015

Raftery, A.E., 1995. Bayesian Model Selection in Social Research. Sociol. Methodol. 25, 111–163. https://doi.org/10.2307/271063

Sardianou, E., 2007. Estimating energy conservation patterns of Greek households. Energy Policy 35, 3778–3791. https://doi.org/10.1016/j.enpol.2007.01.020

Sardianou, E., Genoudi, P., 2013. Which factors affect the willingness of consumers to adopt renewable energies? Renew. Energy 57, 1–4.

Sasaki, H., Sakata, I., Wangjiraniran, W., Phrakonkham, S., 2015. Appliance diffusion model for energy efficiency standards and labeling evaluation in the capital of lao PDR. J. Sustain. Dev. Energy, Water Environ. Syst. 3, 269–281. https://doi.org/10.13044/j.sdewes.2015.03.0021

Schleich, J., 2019. Energy efficient technology adoption in low-income households in the European Union – What is the evidence? Energy Policy 125, 196–206. https://doi.org/10.1016/j.enpol.2018.10.061

Shannon Bouton, Creyts, J., Kiely, T., Livingston, J., Nauclér, T., 2010. Energy efficiency : A compelling global resource. McKinsey Sustain. Resour. Prod. 1–74.

Siano, P., 2014. Demand response and smart grids - A survey. Renew. Sustain. Energy Rev. 30, 461–478. https://doi.org/10.1016/j.rser.2013.10.022

Spyridaki, N.-A., Banaka, S., Flamos, A., 2016a. Evaluating public policy instruments in the Greek building sector. Energy Policy 88, 528–543. https://doi.org/10.1016/J.ENPOL.2015.11.005

Spyridaki, N.-A., Flamos, A., 2014. A paper trail of evaluation approaches to energy and climate policy interactions. Renew. Sustain. Energy Rev. 40, 1090–1107. https://doi.org/10.1016/J.RSER.2014.08.001

Spyridaki, N.-A., Ioannou, A., Flamos, A., Oikonomou, V., 2016b. An ex-post assessment of the regulation on the energy performance of buildings in Greece and the Netherlands—a cross-country comparison. Energy Effic. 9, 261–279. https://doi.org/10.1007/s12053-015-9363-1

Stragier, J., Hauttekeete, L., Marez, L. De, 2010. Introducing smart grids in residential contexts : Consumers ' Perception of Smart Household Appliances Introducing Smart Grids in Residential Contexts : Consumers ' Perception of Smart Household Appliances 1–8. https://doi.org/10.1109/CITRES.2010.5619864

Trotta, G., 2017. Factors affecting energy-saving behaviours and energy efficiency investments in British households. Energy Policy 114, 529–539. https://doi.org/10.13140/RG.2.2.28357.24807

Urban, J., Sc, M., 2012. Exploring domestic energy-saving : The role of environmental concern and background variables ˇ ˇ asny. Energy Policy 47, 69–80. https://doi.org/10.1016/j.enpol.2012.04.018

Willis, K., Scarpa, R., Gilroy, R., Hamza, N., 2011. Renewable energy adoption in an ageing population: heterogeneity in preferences for micro-generation technology adoption. Energy Policy 39, 6021–9.

Zivin, J.G., Novan, K., 2016. Upgrading efficiency and behavior: Electricity savings from residential weatherization programs. Energy J. 37, 1–23. https://doi.org/10.5547/01956574.37.4.jziv

5. Chapter 5: An ex-ante evaluation of the EE potential for financial subsidies

Abstract

Greece ranks very low in EE across EU countries with the household sector suffering the most from the on-going recession and resulting energy poverty. Governmental efforts have been focused on subsidy programs incentivizing households to invest in EE and the arising question is set on what are the realistic savings potential for these subsidies. To answer this question, we adopt a bottom up economic-engineering approach, which includes a behavioural realism aspect to the estimates of programme savings potential. Our assessment is based on the Savings to Investment ratio calculation and makes use of the strongest evidence available from past evaluations and market data for the Greek residential sector. We conclude that financial subsidies can drive significant EE investments in the Greek household sector, especially when considering ancillary, energy security related benefits. Nevertheless, total programme cost-effectiveness was found to be highly dependent on the rationale for determining the cost-effective potential and the subsequent portfolio of measures. Despite the uncertainty inherent in the variety of inputs required, the proposed assessment framework demonstrates the need for more transparent assessments on the programme savings potential under Article 7 and can be applied in similar country settings with limited data-availability and resource constraints.

5.1 Introduction

Decarbonization efforts by Member States (MS), to achieve the Paris Agreement goals have been ongoing and EE (EE) is gradually being recognized as a significant energy source to meet with these ambitious sustainability goals and future challenges. The European Commission (EC) has suggested that EE should be treated as an independent and competitive energy source (EC, 2015) and in November 2016 proposed further strengthening its role by placing the energy target at 30% across EU MS countries by 2030. The EE Directive (EED), consists the main apparatus towards this goal as it establishes a common framework of measures to increase MS efforts to use energy more efficiently. It requires Member States to report on their calculation methodology and sets firm additionality and materiality requirements for the design and operation of their EE obligation scheme (EEO) and alternative measures (as determined in Article 7 of the EED)[15].Having said that, the EE related budgets available across MS countries are often limited and mismanaged by public authorities, usually targeting more politically rewarding sectors yet with lower value energy savings (Amon and Holmes, 2016). In fact, the Commission has pointed out to the need to better understand the energy savings impact that can be attributed to the use of Member States' government spending under Article 7 (Europe Economics, 2016).

Along with the rest of MS countries, Greece has embarked on this joint pledge to meet with the 20% decrease in primary energy consumption in the EU by 2020. Still, Greece has been in recession and under credit crunch conditions for several years, with high interest rates and high costs of capital further restraining the public budget. At the same Greece ranks very low in EE across EU countries with the household sector suffering the most from the on-going recession and resulting energy poverty levels. Regarding Article 7 commitments, there is a considerable need to acquire additional financial resources and a funding gap estimated around 800 million € to meet the article 7 EED targets for 2020. There is thus an urgent need to hasten the efforts for the effective implementation of EE measures (EEMs) to mitigate any feasibility constraints and lower the risks of non-participation or compliance (MEE, 2017). However, it is often not straightforward to identify let alone materialize, through different policy measures, the achievable EE potential that exists in different sectors of the economy.

Focusing on the Greek household sector, governmental efforts have thus implemented financial support programs incentivizing households with lower income levels to invest in EE and the arising question is set on what are the realistic potential for such subsidies in the Greek household sector in view of the future obligation periods under Article 7 of the EED. This question becomes more complicated when considering the Article 7 EED strict materiality and additionality requirements. An additional consideration lies in the dubious role of financial incentives when it comes to program participation rates and resulting EE investments. In the past, most

---

[15] Under Article 7 eligible (additional) savings can only be considered the ones exceeding existing performance standards and requirements such as the Ecodesign and Labelling directive for products and appliances. For alternative measures energy savings resultant from the effect of standards and norms in effect that target the energy performance of products or services in buildings or other sectors and which are mandatory under Union law, cannot be considered additional and thus be credited. Under the materiality criteria, savings from eligible measures that are the result of autonomous market or technological developments and rolling out of EU legislation are excluded (Labanca and Bertoldi, 2016).

efficiency potential studies for the Greek building sector have thus far provided only some rough estimates on technical savings potential (Dascalaki et al., 2016), (Georgopoulou et al., 2006), or more recently have assessed the cost-effectiveness (Pallis et al., 2019) of EEMs without the consideration of financial incentives. While others have investigated the performance of financial subsidies in relation to other policies (Spyridaki et al., 2016a), (Forouli et al., 2019). A more thorough assessment is required to understand which of this potential can be realized cost-effectively by financial incentives in the Greek household sector and how to develop an EE portfolio of EEM to capture it. Our assessment develops these insights further by offering a more realistic analysis of the programme savings potential in the Greek household sector for alternative EEMs and under varying financial subsidy scenarios.

To infer the achievable programme savings potential there is a need to estimate the change in market shares for different EEMs due to a subsidy. The very limited data available for Greece, did not allow us to estimate these effects with more detailed econometric specifications. The data covers a few years, availability varies per technology and are not sufficient to estimate price elasticities for EEMs so as to approximate the change in market penetration and resultant energy consumption savings on such grounds. To get around this difficulty and on the grounds of previous research in the field (Koomey, 2002), (Markandya et al., 2009), (Mundaca et al., 2010), (Blum et al., 2013), (Popiolek and Thais, 2016) we adopt a simple bottom-up economic-engineering method that builts on evidence from past programme participation rates to determine the impact of financial subsidies on measure-specific product sales. This approach allowed us to include a behavioural realism aspect to our estimates of potential savings for policy induced EEMs which is usually not included in EE potential assessments (Ehrhardt-martinez and Laitner, 2010). We combine the results of this assessment model with engineering estimates and cost-effectiveness (CE) calculations to determine measure-specific savings potential for a financial subsidy (see Figure 5.1). We extend our CE calculations to include ancillary energy security related benefits and compare these benefits to inferred costs at a measure and programme level by using the Savings-to-Investment-Ratio (SIR) index. Finally, we propose a rationale for determining the final portfolio of measures and estimate the total programme costs and benefits for financial subsidies when implemented in the Greek residential sector and until 2030. Our analytical framework relies on much less data and uses more simplified assumptions than the detailed and complex specifications applied in model-based assessments for EE policies and measures, which are often non-available to most national policy makers and practitioners due to budget and resource constraints. It increases transparency behind attributed policy effects in ex-ante policy evaluations and allows its (relatively) easy application in cases where resources and data-availability issues restrain programme implementers' from estimating the realistic EE potential of financial incentives. Despite its limitations, we consider the proposed approach to be directionally reasonable and straightforward enough to allow estimating the effect of financial incentives on the market share for the multitude of measures that are assessed in EE potential assessments. The remainder of this paper is structured as follows. The following two sections (5.2 and 5.3) presents our methodology for estimating the reasonably achievable programme potential for measure-specific financial subsidies in the Greek households sector, while Section 6.4 summarises the data sources and assumptions used. Section 6.5 presents the results of our assessment framework across three financial scenarios and different evaluation perspectives and suggests the potential development of energy and cost savings until 2030. Section 6.6 provides policy recommendations based on our assessment findings while Section 6.7 concludes with weakness in our evaluation framework suggesting areas for future research.

5.2 Determining consumers’ response to financial subsidies

We built upon the approach presented in (Koomey, 2002) that relies on the availability of market data (and their scarcity thereof) to determine the impact of a financial subsidy on the market share for different EEMs (see Figure 5.1). The increase in technologies’ market share due to a financial subsidy is calculated as a function of the SIR[16] of the efficient technology relative to the inefficient technology. A financial incentive offered in the form of a subsidy will reduce the higher costs of the more efficient technology and increases the SIR of hi-efficiency products. With a higher SIR, the product sales of higher efficiency technologies are assumed to increase proportionally to past consumers’ response rate to similar financial incentives offered for investing in EEMs. To estimate the measure-specific consumer response to a financial subsidy, we use information from past programme evaluation studies.

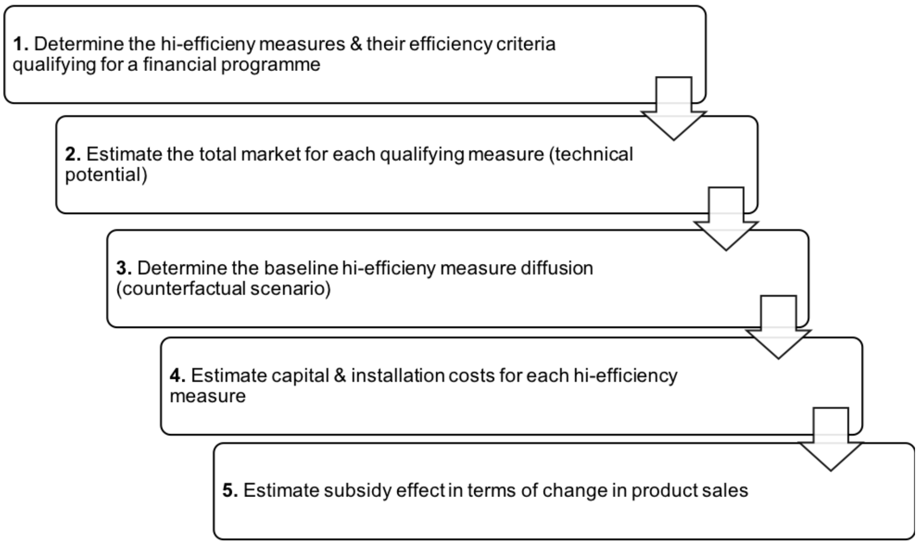


Figure 5.1 Analytical steps followed to determine the consumer response to a financial subsidy

A financial subsidy will then reduce the capital costs by a fixed percentage for a fixed period of time, fostering the purchase of more energy-efficient technologies. The increase in sales due to the subsidy will be accompanied by a simultaneous drop in capital costs due to increased production experience (i.e. energy intervention learning curve*),* making them even more attractive to consumers (Weiss et al., 2010). Therefore, our estimates of equipment related costs under a subsidy scenario consider a simultaneous decline to take place from baseline installed costs due to the “learning curve” effect. We thus assume that under the financial subsidy scenario, production experience is greater than in the baseline (non-policy) case, which bears lower capital costs. The following equations formalize our assessment approach:

$$sales_{i,pol}(t) = sales_{i,lrn}(t) + sales_{i,sub}(t) - \mathrm{sales}_{\mathrm{i,bc}}(\mathrm{t}) \tag{5.1}$$

$$sales_{i,lrn}(t) = \frac{SIRpar_{i,lrn}(t) - SIRpar_{i,bc}(t)}{SIRpar_{i,lrn}(t)} \times resp_i(t) \times tsales_i(t) \tag{5.2}$$

$$sales_{i,sub}(t) = \frac{SIRpar_{i,sub}(t) - SIRpar_{i,lrn}(t)}{SIRpar_{i,sub}(t)} \times resp_i(t) \times tsales_i(t) \tag{5.3}$$

$$sales_{i,bc}(t) = tsales_i(t) \times base_i(t) \tag{5.4}$$

---

[16] A recent financial metric that is used in the EE industry, is the savings to investment ratio (SIR). It is estimated by dividing the total cost savings of an EEM or project over the project’s expected useful life (EUL) by the total investment cost of the project. The advantage of the SIR metric is that it captures the EUL of each measure and considers their benefits throughout their EUL (Tonn and Hendrick, 2011). Most importantly, the SIR provides an easy to understand return on investment measure which also allows for a comprehensive comparison of EEMs and is more useful than the simple payback period as it accounts for the EUL of the equipment as well as the time value of money.

$$resp_i(t) = \frac{pol\_ef_i \times (1-f(t))}{m_i(t)} \times \frac{(t_{last}+1-t_{first})}{total\_years_{pol}} \tag{5.5}$$

where:

$sales_{i,pol}(t)$=sales forecast of $technology_i$ under the policy case scenario in year t (the t^{th} year of the assessment period).
$sales_{i,lrn}(t)$= sales forecast of $technology_i$ due to learning effect in year t
$sales_{i,sub}(t)$= sales forecast of $technology_i$ due to direct price effect of the subsidy in year t
$tsales_i(t)$= total sales forecast of $technology_i$ in year t (represent the total number of household-size units of the $technology_i$ sold in the market)
$SIRpar_{i,lrn}(t)$=participant SIR of $technology_i$ sold in year t due to increased production experience
$SIRpar_{i,sub}(t)$=participant SIR of $technology_i$ sold in year t in the financial subsidy scenario
$SIRpar_{i,bc}(t)$=participant SIR of $technology_i$ sold in year t in the base case scenario
$sales_{i,bc}$ (t) = baseline annual sales for a hi-efficiency $technology_i$ in year t,
$base_i(t)$ = baseline factor expressed as percentage share over total product sales for a $technology_i$ in year t
$resp_i(t)$=consumer response expressed as percentage point increase in marketshare of total market sales for $technology_i$ for the policy case scenario in year t.
f(t)= market diffusion corrrection factor (s.t. $0<f(t)<1$) accounting for free-rider effects.
$pol\_ef_i(t)$=total policy effect at the end of the policy implementation period expressed as a share of total marke potential percentage point increase in the hi-efficiency technology market share of total sales.
t_{first}=first year of the policy implementation period
t_{last}=last year of the policy implementation period
$total\_years_{pol}$=total number of years the PI is implemented.
$m_i(t)$=subsidy level, expressed as a share of installation/equipment costs, offered to consumers for a $technology_i$ in year t.

The baseline rate of hi-efficiency technology turnover due to consumer investments is assumed to be a fixed share over time of the estimated total market to reflect the independent technology diffusion trend irrespective of the policy in effect. Increased production experience due to subsidy is assumed to reduce the installed cost beyond the subsidy level during the subsidy implementation years and beyond the baseline installed cost after the end of the subsidy, according to the progress ratio. The consumer response to the direct subsidy (cost-reduction) effect is applied to determine consumers' response to the decrease in installed cost due to increased production experience. The overall change in product sales due to the subsidy is then estimated as sum of the change due to direct-price effect of the subsidy and the indirect price effect due to the learning effect, minus the baseline diffusion sales. Figure 5.2 provides an overview of the overall methodological framework adopted to determine a portfolio of EEMs comprising the realistic EE potential for a financial subsidy under Article 7 of the EED. Once the additional change in sales due to the subsidy is determined, the results are combined with exogenous data based on engineering and economic analysis. These consist unit-level energy and CO_2 consumption for the base-case and efficient measure, lifetime and survival probability for each measure in a given year of its lifetime, retail capital costs, installation and annual maintenance costs for the base-case and efficient measure and energy price forecasts for the assessment period. Total sales projections for each EEM over the analysis period, feed into the consumer-response estimation module. These serve as an input to calculate the SIR result indicator at a measure and programme level, required to determine the final portfolio of measures and their cost-effective programme potential. The rationale for determining the latter is presented in the section below (section 5.3). Although the assessment model follows a bottom-up approach, a top-down validation of the outputs from each assessment module was conducted with national policy experts from the Greek Ministry of Energy and Environment (MEE) (i.e. through personal communication) as well as with the results of national EE technology and programme evaluation studies (Pallis et al., 2019), (Forouli et al., 2019), (Tsalemis, 2018), (CRES, 2017), (MEE, 2017), (Dascalaki et al., 2016), (MEECC, 2014c), (Georgopoulou et al., 2006) when available, to end up with results being as close to reality as possible.

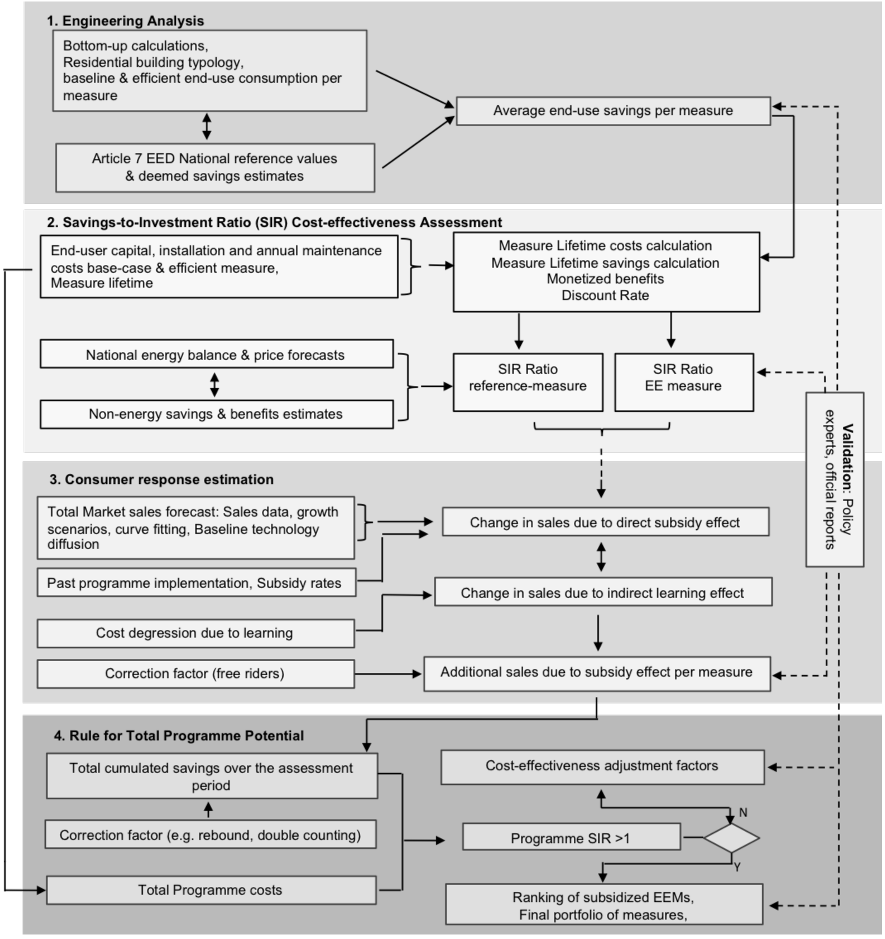


Figure 5.2 Methodological approach to estimate the EE achievable programme potential for a financial subsidy under Article 7 EED.

5.3 Rationale for determining achievable programme potential

Before examining the rationale for determining the final portfolio of EEMs comprising the cost-effective programme potential, one must examine the differences in the SIR calculations across evaluation perspectives. To capture both the cost-effective potential from the side of consumers while also considering total programme CE (Tonn and Hendrick, 2011), CE is examined from different evaluation perspectives and levels as demonstrated in the table below.

Table 5.1 Savings and investments included in the SIR calculations from three evaluation perspectives and across two evaluation levels

	SIR - Participant perspective (PartSIR)	**SIR - Program perspective (PSIR)**	**SIR - Societal perspective (SSIR)**
Measure-level	**Savings:** Unit-level Discounted lifetime energy cost savings. **Investment:** Unit-level Discounted lifetime equipment and installation expenditures (including incentives) as well as other maintenance costs.	**Savings:** Unit-level Discounted lifetime energy cost savings. **Investment:** Same investments as in Part SIR that are extended to include programme administrative and overhead costs along with the equipment and installation expenditures.	**Savings:** Unit-level discounted lifetime savings are extended to include monetary values of lifetime non-energy benefits. **Investment:** same investment costs as in the program perspective.

Programme-level	**Savings:** Total cumulative first-year energy cost savings. **Investment:** Total equipment and installation expenditures (including incentives) as well as other maintenance costs.	**Savings:** Total cumulative first-year energy cost savings **Investment:** Total equipment and installation expenditures (including incentives) and maintenance costs as well as total programme administrative costs.	**Savings:** Total cumulative first-year energy cost savings are extended to monetary values for cumulative first-year fuel non-energy benefits. **Investment:** Total equipment and installation expenditures (including incentives) and maintenance costs as well as total programme administrative costs.

The SIR calculations at a measure and programme level use the same types of savings and investments, yet the measure-level SIR includes a measure's lifetime cost savings and a measure's lifetime costs. At a programme level, SIR CE calculations include, the total cumulative first year cost savings per measure, estimated as the product of annual costs savings and cumulated unit-sales estimated to be sold during the implementation of the subsidy programme and according to the lifetime of each measure. Likewise, investment costs include the product of measure-level capital costs and the sum of units estimated to be sold for each EEM during the programme.

With regards to the three evaluation perspectives, the participant SIR at a measure level (PartSIR-Measure) is calculated as the present value of the lifetime energy cost savings of an EE technology purchased from a beneficiary participant divided by the lifetime measure costs. From a program administrator perspective at the measure level (PSIR - Measure), savings refer to the same savings as in the participant SIR, yet investments are expanded to include management and overhead costs along with installation expenditures (Blasnik et al., 2014). From a social perspective (SSIR-Measure), the savings are extended to include non-energy benefits. Societal SIR also uses a lower (i.e. social) discount rate than the other two perspectives.

To determine the achievable programme potential, we evaluate CE at a programme level. This means that EEMs within a program must pass the CE test collectively, while some measures might not be cost-effective and other measures with higher CE make up for them. Following the rational of recent potential studies (Herndon, 2015), (Navigant, 2017), to conduct the programme-level CE test we rely on measure-level CE and relax the measure level CE thresholds for individual measures. At first, the analysis considers all technically feasible measures that make up the total technical savings potential and estimated the programme-level CE with the full inclusion of all measures. This resulted in a programme SIR below unity which suggested that additional adjustments at a measure-level were required. Adjustments in the applicability of measures included determining minimum measure-level social SIR threshold at 0.3 as well as creating adjustment caps for measures with social SIR between 0.3 and 1.0. The adjustment caps for EEMs under a financial support programme in the residential sector were applied upon the programme potential of each EEM. These were meant to represent a simulation of how programme implementers would prioritize funds to satisfy the market demand for such measures based on their relative economic benefits. Based on this reasoning, cost-effective programme potential consists a sub-set of programme potential and were derived through iterative adjustments to produce a programme-level ratio greater than 1.0. As presented in Table 5.2 below, for measures with a SIR ratio between 0.3 and 0.5 a 5% adjustment factor is applied to their programme potential, for measures with a ratio between 0.5 and 0.8 a 20% is applied upon their total programme potential and for those between 0.8 and 1.0 a 50% adjustment factor is applied to limit their theoretical programme potential to achievable cost-effective savings. The aforementioned process was conducted across all three evaluation perspectives. For the participant, CE screening was applied at a measure level. For the other two we use the extended PSIR and SSIR calculations to screen EEMs and apply the CE test at a programme level by using the adjustment factors presented in Table 5.2 to determine the final portfolio of measures. The results are cross compared and presented for both the strict measure as well as the programme-level CE test highlighting the differences that may result from a strict measure level screening or a more relaxed programme level screening and by taking a broader social perspective.

Table 5.2 Applicability factors for EEMs to derive achievable EE potential of a financial subsidy

Savings-to-Investment Ratio	Adjustment factor
[0 - 0.3)	0%
[0.3 - 0.5)	5%
[0.5 - 0.8)	10%
[0.8 - 1.0)	20%
≥1	100%

5.4 Determining the total market for EE technologies

To overcome the data limitations and serve the scope of our comparative evaluation, our approach for estimating future market potential for the variety of EEMs was tailored to each measure case (and their data scarcity thereof) and is outlined in Table 5.3 below. For building envelope measures that sales data forecasts were not available, their future market potential was estimated based on the number of households using that particular device/technology in year t. The stock of these EEMs is determined using estimated ownership levels by type of insulation (i.e. building envelope measure) in Greek households. In our case this concerns the year of 2011 due to the availability of survey data[17] (ELSTAT, 2013a). Then the stock for these EEMs for the given year in Greek households, is determined by multiplying the ownership levels and number of households in Greece. Future trends were determined based on assumptions on annual modernization rates.

For appliances, future technology diffusion was based on product sales data acquired from the best information available from pulic domain sources for each generic technology type. Data from countries with comparable markets were also adapted in case of data-unavailability for the country under assessment. Future technology sales were based on EU-wide, consolidated scenario analysis assumptions best describing the future trend in these product sales. The following table (Table 5.3) summarizes our efforts to establish the required data-sets to conduct our evaluation and the key assumptions used to estimate the market potential for the multitude of EEMs under assessment. For more details on the assumptions and trend analysis adopted for each technology type, please refer to Table 5.5 below.

Table 5.3 Summary of general assumptions, approaches & data sources used to estimate the market potential for EEMs in the sector under evaluation

Residential-size EE investments (i.e. EEMs)	Type of data & assumptions adopted	Future Market potential estimation approach	Sources
Building Envelope Measures	Household ownership, annual modernization rates (%), population growth trends, household size growth trend.	Assumptions based on national consolidated scenario studies.	(ELSTAT, 2013a),(Dascalaki et al., 2016), (EC, 2016).
Heating, & thermostatic control systems, cooking ovens, dish-washer	Annual sales data, apparent sales data, annual growth rates	Trend analysis and assumptions based on EU-wide and/or national consolidated scenario studies.	(van Holsteijn et al., 2019), (Kemna et al., 2019), (Kemna et al., 2007), (van Elburg et al., 2011)
Solar thermal water heating system, fridge, washing machine, luminaries	Historical time series annual sales data	Autoregressive Model Average (ARIMA) model	(Michel et al., 2016), the ODYSSEY_MURE database, (IEA-4E, 2014)
Air-conditioning	Available future sales projections	-	(Riviere et al., 2009)

In the absence of available future sales projections for the Greek domestic market or consolidated assumptions on the future growth potential for some technology cases, future sales were forecasted using autoregressive moving average models (ARMA). Autoregressive (AR) consists a stochastic process that can be described by a weighted sum of its previous values and a white noise error. Moving average (MA) consists a stochastic process described by a weighted sum of a white noise error and the white noise error from previous periods (Box et al., 1994).

It is well known in the forecasting literature that ARMA(p) models (i.e. of p order) can accommodate parsimoniously a large set of stationary stochastic processes (Christodoulos et al., 2010). From a theoretical perspective, the Wold theorem allow us to approximate any stationary process by a deterministic process and a $MA(\infty)$ stochastic process while under some regularity conditions this $MA(\infty)$ can be approximated by an AR(p) process (Brooks, 2008). Moreover, empirical evidences in the econometric/forecasting (e.g. Ferrara et al., 2015) literature

---

[17] The ELSTAT Household energy consumption survey, consists the most reliable available source on appliance ownership levels in Greek households based on survey results of a large representative population sample undertaken in 2011.

suggest that this type of modelling can provide very accurate forecasts overperforming many computational intensive methods such as factor augmented models or penalized regression methods.

ARMA(p,q) models state that the current value of some series y_t depends linearly on its lagged values plus a combination of current and previous values of a white noise error term. The model could be expressed as:

$$\varphi(L)y_t = \mu + \theta(L)u_t \tag{6.6}$$

Where

$$\varphi(L) = 1 - \varphi_1 L - \varphi_2 L^2 - \cdots - \varphi_p L^p \quad \textit{and} \tag{6.7}$$

$$\theta(L) = 1 - \theta_1 L - \theta_2 L^2 - \cdots - \theta_q L^q \tag{6.8}$$

or

$$y_t = \mu + \varphi_1 y_{t-1} + \varphi_2 y_{t-2} + \cdots + \varphi_p y_{t-p} + \theta_1 u_{t-1} + \theta_2 u_{t-2} + \cdots + \theta_q u_{t-q} + u_t \tag{6.9}$$

with

$$E(u_t) = 0;\ E(u_t^2) = \sigma^2; E(u_t u_s) = 0, t \neq s \tag{6.10}$$

Where

φ_i=the parameters of the autoregressive part of the model,
θ_i =are the parameters of the moving average part and
p=determines the number of autoregressive orders, which means that it specifies which previous values from the data series will be used to predict the current values.
q=defines the order of the moving average orders in the model, in other words how the mean values deviation of the previous time-series are used to predict the current values.
$u_{t,s}$ = a white noise disturbance term

To apply an ARMA model, the dataset needs to be stationary. To make the dataset stationary we transform the time series to stationary, by differencing the log of the data series.

To select the best-fitting ARMA model we use information criteria. These include two factors: a term which is a function of the residual sum of squares (RSS), and a penalty for the loss of degrees of freedom from including additional parameters. Therefore, adding a new variable or an additional lag to the model will have two opposing effects on the information criteria: the residual sum of squares will fall but the penalty factor will rise. The objective is to select the number of the parameters that minimizes the information criteria value. Adding an extra term will decrease the criteria value provided that the decrease in the RSS is sufficient to offset the increase in the penalty term value (Brooks, 2008). There are several different criteria, which vary according to how stringent the penalty term is. Among the most popular information criteria is the Schwarz's (1978) Bayesian information criterion (SBIC), which can be expressed algebraically as:

$$SBIC = \ln(\hat{\sigma}^2) + \frac{k}{T} lnT \tag{6.11}$$

In our forecasting exercise, given the small degrees of freedom (i.e. due to data scarcity), we evaluate AR (1) and AR (2) models, while the BIC criterion suggests the use of AR(1) as a more parsimonious presentation of the data in all cases examined. Therefore, we fit an AR (1) model to forecast recursively until 2030. The results of our forecasting estimates for solar thermal water heating system (SOL_HEAT), refrigerators (FRIDGE), washing machine (WASH) and luminaries (CFL, LED), along with our estimates for the rest of the EEMs under assessment are summarized in the following table (Table 5.4).

Table 5.4 Estimates of sales (1000 residential-size investment units) for hi-efficiency generic technologies

Hi-efficiency technologies (1000 households)	**2010**	**2016**	**2020**	**2025**	**2030**
N_TH_RF	-	0.14	0.12	0.00	0.00
N_TH_PIL	-	0.01	0.01	0.00	0.00
N_TH_EX	-	0.25	0.21	0.00	0.00
N_WIN	-	15.76	16.29	15.09	15.53
COND_BOIL_NG	14.84	16.33	15.69	14.92	14.19
BOIL_EL	0.00	0.00	0.00	0.00	0.00
COND_BOIL_OIL	0.00	5.49	5.88	6.86	7.84
GEO_PUMP	0.05	0.08	0.09	0.10	0.11
AIR_PUMP	3.15	6.06	8.24	12.11	17.79
BIO_PEL	0.86	1.00	2.00	2.05	2.10
THERM_STAT	12.00	17.44	18.00	18.19	18.42
AIRC	76.65	81.19	81.28	82.38	82.62
SOL_HEAT	69.44	92.79	97.98	104.65	111.77
CFL	295.42	302.23	324.56	354.79	387.84
LED	13.38	102.14	237.72	682.91	1961.82
COOK	341.03	362.01	376.71	395.93	416.12
FRIDGE	322.00	259.78	255.48	250.25	245.13
WASH	316.00	290.45	299.97	312.21	324.95
DISH	208.69	187.40	199.91	196.08	200.91

N_TH_RF: installation of household roof thermal-insulation, **N_TH_PIL:** installation of household pilotis thermal-insulation, **N_TH_EX:** installation of household external wall thermal-insulation insulation, **N_WIN:** replacement of old window frames with new efficient ones, **COND_BOIL_NG:** replacement of old oil boiler (central heating) with a more efficient condensing natural gas boiler, **GEO_PUMP:** geothermal heat-pump, AIR_PUMP: aerothermal heat-pump, **BIO_PEL**: pellet burner installation, **THERM_STAT:** central thermostat installation for heating units, **AIRC:** replacing existing air conditioners with new inverter technology, **SOL_HEAT:** replacing an electric water heater with a solar water heater, **CFL:** replacement of incandescent lamps with CFL lamps, **LED:** Replacement of incandescent lamps with LED lamps, **COOK:** Replacing electric kitchen with new energy efficient one, **FRIDGE**: Refrigerator replacement with new efficient one, **WASH:** washing machine replacement with new efficient one, **DISH:** dish-washer replacement with new efficient one.

5.5 Tools, data requirements and assumptions

A spreadsheet tool was developed to determine the programme savings potential a portfolio of EEMs under a subsidy scheme applied from 2018 until 2024 in the Greek household sector. The tool was structured to allow easy updating of the existing (PRIMES) scenario projections as well as other input data outlined in Table 5.5.

The market data required for our EE potential analysis were product sales projections, energy price projections, emission factors and future energy balance projections for the Greek energy sector. In this evaluation, we were seriously hampered by the lack of available data to determine past and future estimates of annual sales for hi-EE technologies, which constituted the basis for our evaluation. During the review, it became apparent that significant studies of appliance household ownership, stock and distribution of sales across different energy classes was unavailable for the variety of EEMs under assessment for the residential sector in Greece. Only pockets of data were available, mostly specific to each appliance/retrofit group or sub-group and more general market research data. To overcome these data limitations, technology diffusion was based on product sales acquired from the best information available from public domain sources for each generic technology type. Data from countries with comparable markets to the Greek one (i.e. Portuguese market) were also adapted in case of data-unavailability for Greece. The following table (Table 5.5) summarizes our efforts to establish the required data-sets to conduct our evaluation and the key assumptions used to operationalize the aforementioned steps in our assessment methodology.

Table 5.5 Summary of general assumptions &data sources

Aspects	Assumptions & main considerations	
End-use measure-level savings for household-size EEMs	Baseline end-use consumption consist the median value of engineering estimates conducted for 6 typical dwelling cases for the Greek household sector. These were specified based on: the type of building (SFH, MFH), climatic zone (A, B, C, D) & construction period (pre-980, 1981-2010, post 2010) according to baseline energy performance standards under Article 7(CRES, 2017), (MEE, 2017). Efficiency: Frozen efficiency according to Article 7 EED requirements & standards (CRES, 2017).	
Technology diffusion	**Envelope measures:** External wall insulation (N_TH_EX), Roof insulation (N_TH_RF), Pilotis insulation (N_TH_PIL), Replacement of window frames and single-gazed windows (N_WIN)	For building enevelope technologies, that sales data were not available, technology diffusion was based on household ownership rates and annual modernization rates. Population growth for Greece based on PRIMES 2016 reference scenario (EC, 2016). The size of Greek households was derived from (EU-SILC). The current state of ownership for insulation was derived from the national survey census data (ELSTAT, 2013b). Modernization rates are based on the ones adopted for the TREND scenario based on (Dascalaki et al., 2016). These involve lower values for annual wall insulation upgrade rate (0.10% per year) and higher values for annual window replacement with double glazing (1.00%).
	Heating, hot-water & thermostatic control systems: Oil condensing boilers (COND_OIL), NG condensing boilers (NG_COND_BOIL), Biomass pellet boilers (BOI_PEL), Geothermal heat pump (GEO_PUMP), Aerothermal heat pumps (AIR_PUMP), Thermostatic Radiator Valves (TRV) systems, Solar heaters (SOL_HEAT)	We used sales data for different heating systems from the review studies of Ecodesign and energy labelling for residential space heating boilers prepared for the EC (Kemna et al., 2007), (Kemna et al., 2019). Sales data for the case of Greece were available until 2014. Non housing end-use boiler sales in Greece are assumed equal to 2% (Kemna et al., 2019). For the projections until 2030, future sales were assumed to develop according to the growth rates adopted in the Business as Usual scenario analysis (van Holsteijn et al., 2019). Accordingly: Non-condensing gas and oil boilers are assumed to disappear from the market from 2016 onwards. Sales of NG_COND_BOIL are assumed to decrease 1% annually until 2030. Sales of electric air-source heat pumps (+8%/a) and ground-source heat pumps (+2%/a) are assumed to increase. For condensing oil boilers sales are assumed to remain relatively constant. For BIO_PEL, observed sales until 2016 and estimates for 2020 for residential burners (i.e. <50KW) for the Greek market were adopted from the European Biomass Association (AEBIOM, 2017). Future sales were assumed to remain relatively constant according to (van Holsteijn et al., 2019). For TRV systems, sales data until 2009 were derived from Apparent consumption (sales) data for the respective years available for Greece (van Elburg et al., 2011) assuming a conservative selling price of €43 per TRV unit. Future sales until 2030 are assumed to follow the trend of total boiler sales in Greece (Kemna et al., 2019). For SOL_HEAT, sales data until 2015 were available from the ODYSSEY_MURE database for residential solar-water heater systems. Future sales were estimated by means of on a 1st order AR model.
	Appliances: Air-conditioning-split units (AIRC), Cooking ovens (COOK), Refrigerators (FRIDGE), Washing machines (WASH), Dish-washers (DISH)	For AIRC, we used sales data projections for the residential sector in Greece available from the EC Preparatory study on the environmental performance of residential room conditioning appliances (airco and ventilation) (Riviere et al., 2009). Intermediate year values were linearly interpolated. For COOK, unit sales available for Greece were adopted for 2007. Due to lack of further data future sales projections were based on the projected growth rate of the EU total product sales until 2030 (Promotion 3E, 2008). For FRIDGE and WASH, product sales for the respective market in Portugal until 2014 (Michel et al., 2016) were adopted. Future sales were estimated by means of a 1st order autoregressive model. Finally, for DISH, product sales for Greece in 2007 were used (Promotion 3E, 2008). Sales projections were assumed to follow the projected growth rate of the EU total product sales until 2030 (JRC, 2017).
	Luminaries: (CFL, LED)	In the absence of sales or stock data for Greece, total sales data available for Portugal for 2008 (IEA-4E, 2014). Sales until 2013 were assumed to evolve according to the observed average EU-growth rates 2008 (IEA-4E, 2014), (Kemna and Lemeire, 2015) for the respective lighting product (i.e. CFL and LEDs). 59% of total light source sales quantities is assumed for residential use (Kemna and Lemeire, 2015). Future sales until 2030 were estimated by means of a 1st order autoregressive model.
	Measure-specific baseline technology diffusion is based on technology ownership rates for each technology type calculated on the grounds of census data (ELSTAT, 2013b) for the year prior to the introduction of the financial support programme.	
Technology learning Rate (LR)	A conservative technology learning rate (i.e. 1%) is assumed to take effect until 2030 reducing capital and installation costs of all EEMs, in agreement with the ministry's assumptions used for developing the long-term strategy for mobilising investment in the renovation of the national stock of residential and commercial buildings (MEECC, 2014c).	

Equipment lifetime	All products within the same technology type have the same lifetime.
Policy response	Policy-response is calculated as the ratio of the number of households applying for participation in the ESH programme over total eligible households, for each EEM and income level. These estimates are based on empirical observations for Energy Performance Certificates (EPC) issued for participating in the ESH programme (Gelegenis et al., 2014), the level of participation for each household income category (Drivas et al., 2018), and census data on the maximum technical potential of EEMs across Greek households (ELSTAT, 2013b). Free-ridership is assumed equal to zero.
Double counting	To account for double counting for the sum of households over the entire assessment period (i.e. out of which some invest in multiple measures and some do not), we use a correction factor approximated at about 25% to lower the total programme savings potential resulting from building envelope measures, upgrading heating and TRV systems. Our assumption was based on similar potential studies (Ehrhardt-martinez and Laitner, 2010) and was validated by the MEE policy officials.
Discount rates	A discount rate equal to 8% was applied for residential consumers (Zachariadis et al., 2018). A social discount rate equal to 5% was applied in the societal SIR calculations to reflect society's relative weight of economic welfare (Steinbach et al., 2015).
Energy security	Domestic energy production and net imports projections until 2030 were based on PRIMES 2016 reference scenario energy balances data.
Emission factors	For long-term emissions until 2030 CO_2 emission factors based on PRIMES 2016 reference scenario were estimated.
Energy prices	Fuel prices and projections until 2030 were based on best available information from pulic domain sources. Cost for oil heating after tax was based on (Kakaras et al., 2016). Price estimates for NG and pellets, as well as fuel escalation rates were based on the ministry's official estimates (MEECC, 2014c). Cost of electricity was based on PPRIMES 2016 average electricity prices after tax for the household sector.
Average import cost savings	Per KWh estimates equal to 0.029 €/KWh for estimating electricity system benefits based on (Rosenow et al., 2018), (Lazar and Colburn, 2013) Per KWh estimates equal to 0.0025 €/KWh for estimating savings in adjustment costs from macroeconomic disruption due to oil imports based on a U.S study (Leiby, 2008).
Administrative costs	Historical and future program spending information from a financial subsidy programme targeting the residential sector in Greece, collected after personal communication with Ministry's policy experts.

Estimates on energy and import cost savings were calculated using PRIMES 2016 reference scenario energy balances for Greece until 2030 (EC, 2016). To factor in our SIR calculations the monetary indirect benefits of EEMs with regard to energy security, and in absence of any relevant study for the case of Greece, we use per KWh estimates for monetizing oil and electricity import savings based on existing studies and as specified in Table 5.5. These are added in the program SIR calculations by assuming no additional cost for their occurrence. Finally, administrative costs were included in our assessment on the grounds of historical program spending from a financial subsidy implemented in Greece (i.e. through personal communication with national policy experts from the Ministry of Environment and Energy - MEEE).

5.6 Specification of EEMs and subsidy options under assessment

The set of EEMs were selected after reviewing the catalogue of standard measures submitted by EU MS countries defining the main types of actions to be considered eligible under Article 7 EED[18]. The final set of EEMs under assessment comprise 26 out of the most commonly applied EEMs in the Greek household sector. The EEMs have been specified to differentiate based on their end-use, fuel usage as well as their efficiency factor. The final selection of measures was also determined on the grounds of feasibility and data-availability issues characterizing the relevant domestic market for the Greek household sector. The main parameters describing the reference dwellings under consideration to represent typical household cases in the Greek residential sector are provided in Appendix A. The assumptions describing the state and energy performance of the reference dwellings were adapted so that our estimates on baseline end-use consumptions approximate the national reference values determining the baseline final energy consumption under Article 7 for households in Greece (CRES, 2017).

Table 5.6 presents the range of our unit savings-estimates and investment costs across the reference dwellings for each EEM. The capital and installation costs are obtained from the two implementation guides for the Energy Savings at Home (ESH)'financial support programme[19] issued from the (MEECC, 2012b),(MEE, 2018). Lifetime of EEMs are consistent with the ones issued under the suppliers' obligation under Article 7 of the EE by the Greek

---

[18] https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficiency-directive/obligation-schemes-and-alternative-measures

[19] The ESH programme essentially consists the first and primary financial support programme for the residential sector introduced in 2011. The programme aims at improving the energy performance of residential buildings through the provision of soft loans and subsidies for the installation of RES plants and energy-saving measures. The percentage funded by a subsidy or an interest-free loan depends on the personal or family income of the applicant. Low income individuals/families are offered more favorable financial support packages from the programme, i.e. higher subsidy, contributing to the moderation in mal-distribution of income and providing incentives to low income individuals/families to increase their residence's EE.

Ministry (MEECC, 2011b). Final energy savings estimates reflect the efficiency gains that can result from the implementation of EEMs on each dwelling-type under assessment in the Greek household sector. These consist approximate engineering estimates of annual end-use energy savings, calculated according to the national guidance note on bottom-up calculations for EEMs under Article 7 of the EED (CRES, 2017) and are assumed to remain constant over time. These were complemented with other official reports, a variety of up-to-date market data and were validated by policy officials implementing Article 7 through personal communication. To estimate the long-term programme potential of alternative EEMs under a financial subsidy scheme and according to Article 7 standards, we used the median values of final energy savings across the reference household cases under consideration to represent the savings and investment costs relevant to EEMs for a typical dwelling in Greece as depicted in Table 5.6 below.

Table 5.6 Estimated final energy savings, fixed and variable costs of household-size investments in EEMs under Article 7 EED and across Greek household types under consideration

EE Measure (EEM)	Specification	Lifetime (years)	Estimated final energy savings (MWh/year)	Fixed investment costs per household (K€)	Variable costs per household (K€)
Envelope measures	U-values equal or higher to the ones foreseen by the Regulation on the Energy Performance of Buildings (REPB) for each element according to climatic zone & year of construction				
N_TH_RF_041	Roof insulation only for SFH- Expanded polystyrene - U-value: 0.41 W/m2k, thickness levels for each climatic zone (A, B:6cm, C, D:8cm)	25	3.9 (0.1-12.8)	5.2 (5.1-5.6)	0.1
N_TH_PIL_041	Pilot insulation only for SFH- Expanded polystyrene - U-value: 0.41 W/m2k, thickness levels for each climatic zone (A, B:6cm, C, D:8cm)	25	2.7 (1.5-12.4)	5.4 (5.2-5.6)	0.1
N_TH_EX_045	External wall insulation - Expanded polystyrene - U-value: 0.41 W/m2k, thickness levels for each climatic zone (A:4cm, B:6cm, C, D:6-8cm)	30	1.6 (0.2-13.2)	4.8 (3.3-6.8)	0.1
N_WIN_2.9	Efficient windows with aluminium frames, low-E double glazing - U-value: 2.9 W/m^{2}k	30	2.3 (0.9-6.5)	4 (2.7-5.4)	0.1
N_TH_RF_016	Roof insulation only for SFH- Expanded polystyrene - U-value: 0.41 W/m2k, thickness levels for each climatic zone (A, B:5cm, C, D:6-7cm)	25	4.8 (0.6-13.7)	6.1 (5.7-6.1)	0.1
N_TH_PIL_016	Pilot insulation only for SFH- Expanded polystyrene - U-value: 0.41 W/m2k, thickness levels for each climatic zone (A, B:6cm, C, D:8cm)	25	3.2 (2.2-13.3)	6.1 (5.7-6.1)	0.1
N_TH_EX_015	External wall insulation - Expanded polystyrene - U-value: 0.41 W/m2k, thickness levels for each climatic zone (A:3cm, B:4cm, C, D:5cm)	30	2.6 (0.6-14.3)	5.5 (3.9-7.4)	0.1
N_WIN_1.1	Efficient windows with aluminium frames, low-E double glazing - U-value: 1.1 W/m^{2}k	30	3.3 (1.3-8.4)	4.9 (3.3-6.4)	0.1
E/M systems	Actual system data on B.A.T specification				
COND_BOIL_NG_88	Condensing boiler natural gas fired- n:88% - Pw=8-12KW (SHF), 20-35KW (MFH) - Seasonal COP - $n_{sh,Eff}$=94%	20	1.5 (0.6-5.2)	3.6 (3.5-3.7)	0.1
COND_BOIL_NG_98	Condensing boiler natural gas fired- n:98% - Pw=8-12KW (SHF), 20-35KW (MFH) - Seasonal COP - $n_{sh,Eff}$=104%	20	3 (1.2-10.4)	3.9 (3.9-4)	0.1
COND_BOIL_OIL	Condensing boiler oil fired - n: 95% - Pw=8-12KW (SHF), 20-35KW (MFH) - Seasonal COP - $n_{sh,Eff}$=94%	20	1.5 (0.6-5)	4.7 (4.6-4.8)	0.1
GEO_PUMP_4.7	Ground source heat pump (35^{0}C) only for SFH - COP 4.7	25	10.4 (4.4-28.6)	14.4	0
GEO_PUMP_6.3	Ground source heat pump (35^{0}C) only for SFH - COP 5.3	25	10.7 (4.5-29.6)	15.6	0
AIR_PUMP_3.05	Air source heat pump (air-to-water 55^{0}C) - COP 3.05	15	8.7 (3.5-29.3)	9.3 (7.4-11.2)	0
AIR_PUMP_3.8	Air source heat pump (air-to-water 55^{0}C) - COP 3.8	15	9.6 (3.9-32.5)	9.9 (7.8-12)	0
BIO_PEL	Biomass (pellet) boiler -n: 95% - Energy class: A+ (Seasonal COP - $n_{sh,Eff}$=112%)	15	4 (1.6-13.8)	5.3 (4.9-5.8)	0.2
THERM_STAT	Installation of automated calometry with: thermostatic valves, heat cost collectors, central meters, differential pressure valve and central weather compensation system.	10	4.6 (1.9-15.8)	2.9 (1.6-2.9)	0.1
SOL_HEAT	Replacement of electric hot water system with solar thermal plants (evacuated tube collectors) for domestic hot water (DHW)	20	1.2 (1-1.4)	2.1 (1.9-2.3)	0
Appliances & Luminaries:	Average energy performance of existing products in the market under the Energy Labelling Regulation				

AIRC_A++	Efficient Air-conditioning 3(SFH)-5(MFH) AC units - (Energy Class A++)	15	0.5 (0.2-0.9)	2.9 (2.2-3.7)	0.1
AIRC_A+++	Efficient Air-conditioning 3(SFH)-5(MFH) AC units - (Energy Class A+++)	15	0.6 (0.2-1.2)	4.9 (3.7-6.2)	0.1
CFL	Replacement of halogen with more efficient lamps 9 (SFH)-18(MFH) units, 16-24 Watt	2.083	0.7 (0.5-0.9)	0.1 (0.1-0.2)	0
LED	Replacement of halogen with more efficient lamps 9 (SFH)-18(MFH) units, 7-11 Watt	10.42	0.9 (0.6-1.2)	0.4 (0.2-0.5)	0
COOK A+++	Replacement of old with more efficient electric kitchen. Built-in electric oven with ceramic hobs, Class: A +, Oven capacity 65-71lt	12	0.40	0.7 (0.5-0.8)	0
FRIDGE_A+++	Replacement of refrigerator with more efficient one. Refrigerator 348-450lt, (Maintenance: 198-302lt / Freezer: 93- 148lt)	15	0.11	0.59 (0.57-0.61)	0
WASH_A+++	Replacement of washing machine with more efficient one. Washing machine 7-8kg, Class A+++	12	0.03	0.42 (0.41-0.43)	0
DISH_A+++	Replacement of dish-washer with more efficient on. Placement: Free, Capacity: 10-13 Serving utensils, Energy Class: A +++	12	0.04	0.62 (0.56-0.69)	0

To better demonstrate the different savings potential of a financial subsidy scheme when implemented in the Greek household sector and assess the sensitivity in our policy response results, we have formulated a set of three alternative subsidy options according to the ESH programme implementation guide (MEECC, 2012b).The financial subsidy options (see Table 5.7) under evaluation are assumed to promote the portfolio of EEMs as specified above. Our estimates for the programme participation of each subsidy option are presented in in Appendix A.

Table 5.7 Financial subsidy options and key policy parameters under assessment

Policy pararameters	**FI1** - 7-year 15% subsidy	**FI2** - 7-year 35% subsidy	**FI2** - 7-year 70% subsidy
Individual income (I.C)	40.000 € < I.C <= 60.00€	12.000 € < I.C <= 40.00€	I.C <= 12.000 €
Financial incentive	15% Grant	35% Grant	70% Grant
Implementation period	2018-2024	2018-2024	2018-2024

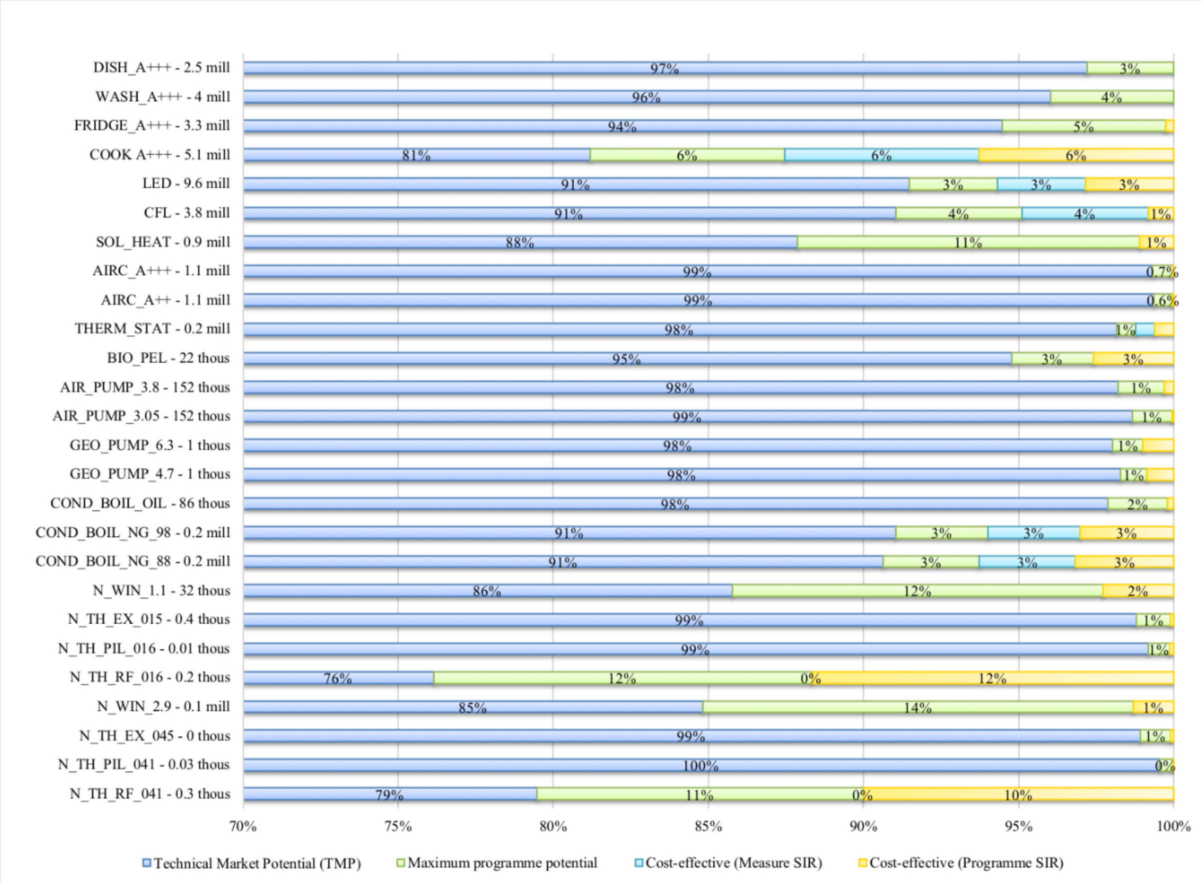
5.7 Results & Discussion

In this section we sum up the results of modelling the programme potential for EEMs when supported through financial subsidies targeting the Greek household sector in the period from 2018 to 2030. First, we show the level of deployment of each measure and compare their associated energy savings potential until 2030 across our subsidy-options and evaluation perspectives. Next, we rank the EEMs according to their cost-effectiveness, expressed through their SIR calculated at a measure and programme level. Finally, we estimate the total costs and benefits for each subsidy-scenario and calculate their overall CE from a programme administrator’s perspective.

5.7.1 Market potential for EEMs in the Greek household sector

Figure 5.3 depicts our estimates of the potential diffusion for a 35% 7-year subsidy programme, expressed as a share of total sales and for each of the EEMs under assessment, in the Greek household sector by 2030. The maximum programme market potential consists the diffusion that would be achievable in the case that all EEMs were eligible for support under a financial support programme for households, thus without considering measure level CE or budget constraints. This is then limited to achievable programme potential by applying the two CE tests. Our estimates on the share of the programme potential are thus presented under a “measure-level” and “programme-level” CE test, along with the remaining share in the market (i.e. Technical market potential).

The graph (figure 3) illustrates that EEMs with the highest market potential correspond to LED and CFL lamps and electrical appliances followed by the installation of solar thermal plants and TRV systems. In fact the latter will likely constitute a significant and growing part of the boiler business (Kemna et al., 2019). According to our model and programme participation estimates, a small share of these sales can be attributed to a 35% financial subsidy. For most EEMs except for windows replacement, roof insulation, COOK+A+ and SOL_HEAT, their maximum programme potential is equal or far less than 5% of their total technical potential. Under the measure-level CE test, the programme potential is lowered to almost 0% for almost all building envelope measures (e.g. N_TH_RF, N_WIN), as well as for BIO_PEL, and SOL_HEAT. When relaxing the CE test by including in the SIR calculations the imported energy monetary benefits and applying the test at a programme level, we observe a change in the programme market potential for only a handful of measures. These are measures for which their PartSIR is below unity and which under the programme-level calculations their SIR is improved. For N_THRF_041,016, and N_WIN_2.9,1.1, their CE programme potential are increased to 2% and up to 19% of their total market potential than under the cost-effective measure level potential, while for BIO_PEL and SOL_HEAT the programme potential is increased from 0% to 3% and 1% of their total market potential. Notably this is not the case for CFL, where only one fifth of the cost-effective measure-level potential, is achieved under the programme-level CE test.



	Technical Market Potential (TMP)	Maximum programme potential	Cost-effective (Measure SIR)	Cost-effective (Programme SIR)
DISH_A+++ - 2.5 mill	97%	3%		
WASH_A+++ - 4 mill	96%	4%		
FRIDGE_A+++ - 3.3 mill	94%	5%		
COOK A+++ - 5.1 mill	81%	6%	6%	6%
LED - 9.6 mill	91%	3%	3%	3%
CFL - 3.8 mill	91%	4%	4%	1%
SOL_HEAT - 0.9 mill	88%	11%		1%
AIRC_A+++ - 1.1 mill	99%			0.7%
AIRC_A++ - 1.1 mill	99%			0.6%
THERM_STAT - 0.2 mill	98%	1%		
BIO_PEL - 22 thous	95%	3%		3%
AIR_PUMP_3.8 - 152 thous	98%	1%		
AIR_PUMP_3.05 - 152 thous	99%	1%		
GEO_PUMP_6.3 - 1 thous	98%	1%		
GEO_PUMP_4.7 - 1 thous	98%	1%		
COND_BOIL_OIL - 86 thous	98%	2%		
COND_BOIL_NG_98 - 0.2 mill	91%	3%	3%	3%
COND_BOIL_NG_88 - 0.2 mill	91%	3%	3%	3%
N_WIN_1.1 - 32 thous	86%	12%		2%
N_TH_EX_015 - 0.4 thous	99%	1%		
N_TH_PIL_016 - 0.01 thous	99%	1%		
N_TH_RF_016 - 0.2 thous	76%	12%	0%	12%
N_WIN_2.9 - 0.1 mill	85%	14%		1%
N_TH_EX_045 - 0 thous	99%	1%		
N_TH_PIL_041 - 0.03 thous	100%			0%
N_TH_RF_041 - 0.3 thous	79%	11%	0%	10%

Figure 5.3 Proportion of the programme market potential in the total market potential (in terms of total sales expressed in thousand or million households) that can be achieved from a 35% 7-year subsidy by 2030.

5.7.2 Energy savings potential for alternative subsidy options

Figure 5.4 below demonstrates the results for the energy savings potential by 2030, expressed as a share of the Greek residential sector's energy consumption in 2016 according to EUROSTAT. These are assumed to be achieved by taking together the mix of EEMs that is determined under each subsidy rate and CE assessment level. When applying the programme level CE test and depending on the subsidy level, the modelling results show, that the energy savings potential that can be achieved by a financial subsidy range from 5% to more than 16% of existing household energy consumption. Notably a large share of these savings is due to the adoption of a single measure, the replacement of inefficient lighting systems with LED lamps. Especially under the two lowest subsidy levels (i.e. 15% and 35%), LED lamps harness almost 50% of the total savings potential. Efficient cooking ovens, condensing natural gas (NG) heating systems and windows replacement also seem to hold a significant share of savings, whereas SOL_HEAT systems present significant savings potential yet only under the highest subsidy level and from a social evaluation perspective (i.e. FI3 – 70% - PROGRAMME).

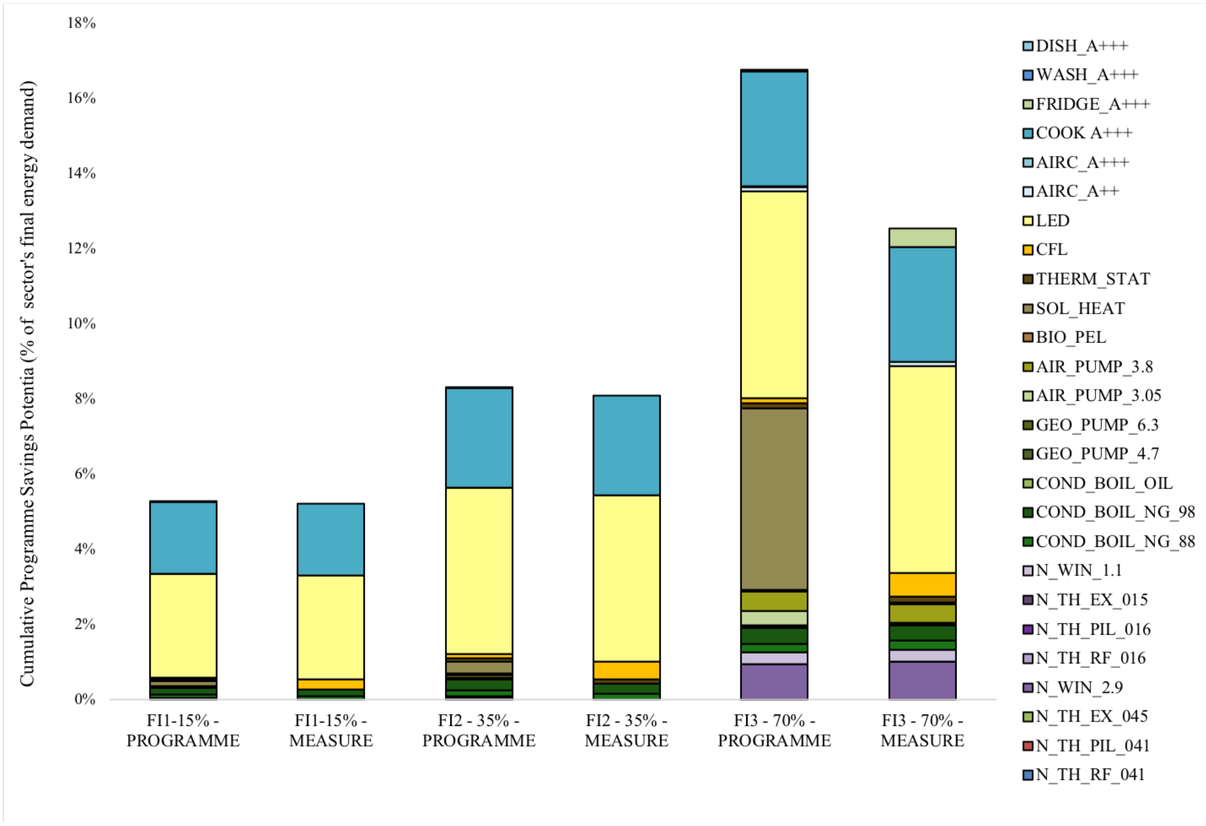


Figure 5.4 Estimated potential for energy savings in the residential sector by 2030 per measure, financial subsidy and under the measure and programme level CE test (i.e. programme SIR and measure SIR as noted on the column labels). Estimates are expressed as a percentage of the sector's final energy consumption in 2016.

When contrasting the savings potential resultant from applying the CE test at a measure and programme level, it becomes evident that considerable differences are observed as the level of the subsidy goes up. Under the 70% subsidy level, and when taking into account the broader import cost savings, 4% more reduction in energy consumption could be achieved, than with a strict measure level CE screening. Under the two lower subsidy levels (i.e. 15% and 35%), the savings potential is only slightly lower under the measure level CE, despite that fact that under the programme-level CE, the mix of EEMs is relaxed to include more measures. This is largely due to the lowering of savings potential of a single measure, namely CFL lambs, under programme level screening that offsets savings from the enriched set of EEMs (e.g. SOL_HEAT, THER_STAT, N_WIN) included in the mix under a more relaxed CE screening. Notably, under the lowest subsidy case and SSIR calculations (i.e. FI1-15%-PROGRAMME), 5% of the market potential of most building fabric improvements are included in the cost-effective programme potential as well as 10 to 20% of market potential of heat-pumps, that are excluded under the strict measure level screening. Electrical appliances with a higher efficiency rating (e.g. WASH_A++, DISH_A++) remain rather unexploited across all subsidy levels, while roof insulation, LED lamps, NG boiler upgrades and TRV systems remain cost-effective and are fully exploited across almost all financial options and CE tests. Nevertheless, the contribution of aerothermal heat pumps (i.e. AIR_PUMP_3.05,3.8) in the programme savings potential becomes larger than other boiler upgrades, when subsidized under the highest subsidy rate (i.e. FI3-70%-PROGRAMME).

5.7.3 Cost-effectiveness considerations at a measure and programme level

Figure 5.5 andFigure 5.6 break down the SIRs by subsidy level, evaluation perspective (i.e. partSIR, PSIR, SSIR) and across the two main evaluation levels, the unit (i.e. measure-level) and programme level.

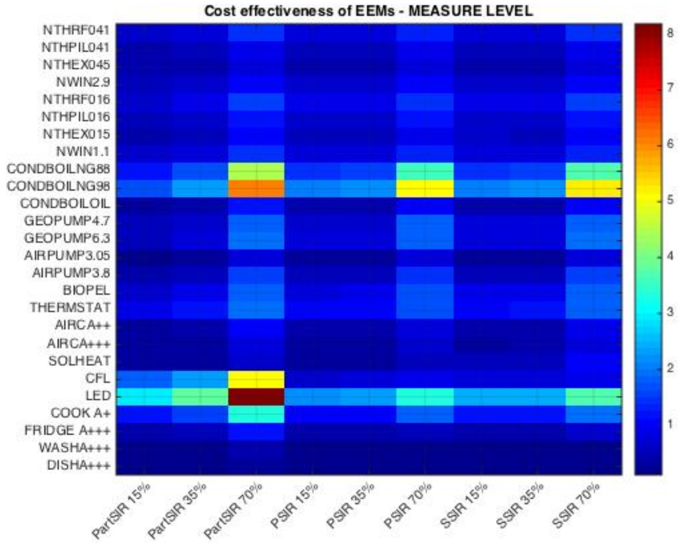


Figure 5.5 Cost effectiveness at a measure by subsidy level and evaluation perspective. The assessment is based on 2018€ and uses an 8% discount rate for PartSIR and a 5% for the SSIR perspective.

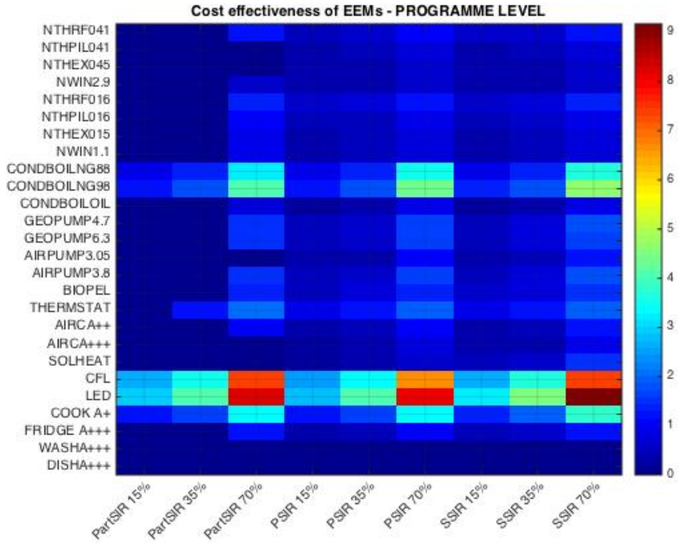


Figure 5.6 Cost effectiveness at a programme level by subsidy level and evaluation perspective. PartSIR results are based on a strict measure level CE test, PSIR and SSIR results are based on a programme level CE test. The assessment is based on 2018€ and uses an 8% discount rate for PartSIR and a 5% for the SSIR perspective.

From a participant perspective (Figure 5.5), for highly-efficient condensing NG boilers, their installation is supported by highly-favourable PartSIR which more than doubles as the subsidy level goes from 35% to 70% of investment costs. Condensing oil and biomass boilers, as well as geothermal and aerothermal heat pumps are cost-effective only under the highest subsidy scenario. Highly-efficient air conditioners (AIRC_A++), SOL_HEAT and almost all electrical appliances except for cooking ovens don't pass the CE test as their partSIR is below unity across all three subsidy levels. Notably the most energy efficient EEMs aren't always the most cost-effective as the case of air conditioning systems, where AIRC_A+++ is less cost-effective than the less efficient types (i.e. AIRC_A++) and with a price differential among them approximating 2 to 3 (the most efficient type of air-conditioning costs 1.75 and 2.98 more than systems lower energy classes – see Table 5.6). This is observed in product classes with higher cost-differences. For heating systems and insulation measures where price differentials are closer to unity, EEMs with highest efficiencies are also supported by higher SIR. Among insulation measures, roof and ground (i.e. pilotis) insulation present the highest CE. Naturally, the SSIR results are lower than the PartSIR estimates, except for fuel switching measures to non-imported fuels (i.e. SOL_HEAT, BOI_PEL and geothermal heat pumps) for which their SSIR estimates are alleviated. Subsequently under a social perspective, the relative profitability of fuel-switching EEMs is improved. Still, most measures with a PartSIR higher than 1 still remain profitable under the program SIR calculations across subsidy levels with the exception of CFL lamps. This is due to the fact the measure's additional electricity import cost savings, are relatively lower and are offset by the additional program administrator costs, accounted for in the PSIR and SSIR calculations (see Figure 5.5).

From a programme implementers' perspective (Figure 5.6) and under a strict measure-level screening (Part SIR), the majority of EEMs are set to zero, except for CFL, LED, COND_NG_BOIL, THERM_STAT and COOK). All building envelope measures, the rest of the heating systems and almost all electric appliances are excluded from the cost-effective programme potential for the first two subsidy levels (i.e. PartSIR/Measure -15% and 35%) and contribute to programme potential only when heavily subsidized (PartSIR/Measure – 70%). When compared to measure level CE (Figure 5.5), we observe that the programme CE of measures is lower for all building envelope measures and almost all EEMs relevant to upgrading heating systems (i.e. except for heat pumps) for which their programme savings potential has been corrected for double counting. In addition, the most cost-effective programme potential can indeed be realized by the most cost-effective set of measures across evaluation perspectives. These consist top-ranked measures also under the PartSIR calculation (Figure 5.5) and include highly-efficient COND_NG_BOIL, LED and CFL lamps, COOK, THERM_STAT, AIR_PUMP as well as BIO_PEL. Notably the relative profitability of EEMs remains the same across evaluation perspectives and subsidy levels. Overall the current results of this CE evaluation should be considered with caution since free-ridership has been assumed equal to zero. Should the data-availability be improved, to account for the free-ridership effect in the CE assessment one would have to consider the gross number of products (i.e. including free-riders) when determining the programme costs entailed with the implementation of a subsidy scheme.

5.7.4 Total programme costs and benefits

Table 5.8 summarizes the total programme results in terms of energy and import saving, their associated costs and accrued monetary benefits for each subsidy-case scenario. These are likely to occur when implementing a financial subsidy in the Greek household sector through the diffusion of the portfolio of EEMs determined to be eligible for each subsidy and CE test. According to our calculations, 191 to 478 ktoe of cumulated first year final energy will be saved in 2030 by applying a 7-year financial subsidy depending on the subsidy rate and according to the strict measure level screening. This translates to a contribution of approximately 3 to 7% depending on the subsidy level, when compared to the national target set under Article 7 for 2030 (i.e. target range of 7.3 Mtoe) (MEE, 2019). When accounting for the additional benefits associated with energy security, final energy savings are uplifted by 1.5% to more than 24% under the highest subsidy-scenario. Imported energy savings is close to final energy savings or even surpasses these under the FI3 - 70% Programme scenario.

Notably under the programme level test, the sum of energy cost savings is lower than under the measure CE test and across all subsidy levels. This is mainly due to the fact that the savings potential for a single measure, CFL with significant market potential, is lowered under the programme level CE test, offsetting the additional savings offered by the enriched portfolio of EEMs yet with lower market potential. However total programme benefits are uplifted through the ancillary benefits due to improved energy security, that are larger under the CE Programme and especially under the higher subsidy rates. This underlines the influence of the inclusion of fuel-switching measures and especially to non-imported fuels (i.e. BIO_PEL, SOL_HEAT and GEO_PUMP) to the portfolio's collective CE.

The present value of total funding costs to materialize these benefits range from 28 M€ 2018 to more than 452 M€ 2018 under the highest subsidy level under the strict CE screening. Notably, these are considerably higher than the Ministry's estimated budget to support such investments through the ESH Programme, which amounted to 379 M€ and 293 M€ for the first (2011-2016) and second implementation period (2017-2023) respectively (i.e. as reported by a MEE policy-maker through personal communication with the authors). Finally, a consistent pattern in the overall CE results can be observed according to which CE is lower, yet still well above unity, under the programme level CE evaluation and improves as the level of the subsidy goes up, since incentives are treated as transfer payments from these evaluation perspectives. In fact, small differences can be observed in the CE across evaluation levels for the lower subsidy rates whereby the final mix of EEMs is only slightly differentiated. Whereas larger differences can be observed under the highest subsidy rates, where we observe that the CE of FI3-70%- Programme scenario is considerably lower than the FI3-70% and the FI2-35% - Measure scenario. This is due to the fact that the portfolio of measures comprising the total programme potential under a programme level and the 70% subsidy rate, is enriched to include a more diverse yet marginally cost-effective set of EEMs, that under lower subsidy rates were not included.

Table 5.8 Summary of total programme costs and benefits as estimated until 2030 for the three alternative financing options under the measure and programme level CE test

	FI1 - 15 %	FI2 - 35%	FI3 - 70%	FI1 - 15 %	FI2 - 35%	FI3 - 70%
	Measure level cost-effectiveness test			Programme level cost-effectiveness test		
Present Value Total Programme Costs	28	103	452	30	113	602
Present Value Total Programme Funding costs (M€ 2018)	28	102	451	29	112	600
Administrative costs	0.4	0.8	1.1	0.4	0.8	1.1
Capital costs						
Net Equipment and Installation costs[1] (M€ 2018)	225	245	280	240	272	360
Savings						
Energy Savings (ktoe)	191	297	478	195	307	629
CO2 savings (Mt CO_2)	1.25	2.01	3.67	1.32	2.20	5.21
Imported Energy Savings (ktoe)	162	254	446	170	279	701
Benefits						
Energy Cost Savings (M€ 2018)	392	599	860	380	582	850
Fuel import cost savings	46	69	94	46	72	171
Total Programme Benefits	438	668	954	427	655	1022
Participant SIR ratio	1.74	2.44	3.07	1.58	2.14	2.37
Programme SIR ratio	1.74	2.43	3.06	1.58	2.14	2.36
Societal SIR ratio	1.94	2.71	3.39	1.77	2.40	2.83

5.8 Policy recommendations

The analysis presented here suggests that financial subsidies can play a significant role in driving residential EE investments in the household sector, especially when considering ancillary benefits such as energy security related ones. Under a more generous 7-year subsidy rate equal to 70% and a societal CE framework, their potential was estimated to contribute by almost 16% of total sectors' demand and by almost 8% of the total savings target for 2030 under Article 7. To achieve this potential, the public budget would have to provide up to 578 million € for incentive payments. The equivalent level of private investments required to materialize these savings were found to be equally high (i.e. 348 million €) yielding a total benefit of 1 billion €, out of which 16% relate to ancillary energy security benefits. Under more conservative rates (i.e. 15% or 35% subsidy rate) 3 to 4% of the total savings target set could be achieved at a much lower cost of approximately 30 to 112 million € accrued to the public budget.

The proposed level of public spending for the 2018–2030 period to yield the estimated energy savings, especially under the highest subsidy rate, consists definitely a challenge both for the public budget as well as private households. Notably, the funding requirements to capture the estimated savings potential under the highest subsidy cases are more ambitious and costly than the budget foreseen by the Ministry for the continuation of the financial support 'ESH' programme. These are estimated to be almost twice as high as the funds allocated for an equivalent 7-year implementation period. Accounting for the aforementioned budget constraints, government support should continue to be pivotal in driving EE investments, yet it needs to target a portfolio comprising measures higher in the CE ranking such as highly efficient condensing boilers, particularly fuel-switching ones to NG as well as heat pumps, LED lamps and TRV systems. These are supported by highly-favourable participant SIR even under the lowest subsidy levels and also present significant programme market potential until 2030. In addition, according to our model and assumptions, higher adoption rates and thus programme potential are also estimated for less cost-effective, yet more mature technologies such as efficient window-frames with double glazing, solar heaters, and roof insulation measures. This may contradict consumer preferences over measures, for which their savings potential and thus CE is considerably lower under the stricter eligibility and materiality requirements of Article 7. The preference over these technology categories has also been recently demonstrated by findings on the frequency of measures across applications during the first months of continuation of the ESH programme under Article 7 of the EED (Tsalemis, 2018). Financial incentives may thus need to take the form of direct subsidies (i.e. grant schemes) for less mature measures while for more mature ones, financial support could be offered in the form of tax-deductions or through on-bill financing. With regard to the latter, focus should be placed on the newly launched EEO scheme for the development of appropriate financing tools as well as for the diversification of the portfolio of measures to include demand-response schemes. Finally, the portfolio of EEMs should be diverse enough to tap harder to reach savings potential and should be formulated to target packages of EEMs which ensure the programme CE collectively.

When it comes to programme CE, all subsidy scenarios considered to promote the portfolio of EEMs were found to be cost-effective within a strict or societal evaluation framework. The most cost-effective subsidy scenario was deemed to be the most generous one, both under a strict or societal CE framework, since higher adoption rates are assumed to be driven by higher subsidy rates that increase the measures' SIR for the participants. Nevertheless, CE may decline from a program-administrator or non-participant perspective. In addition, as the level of the subsidy goes up, larger differences can be observed in the assessed programme SIR. In fact when comparing CE across evaluation perspectives, the more moderate subsidy scenario (i.e. FI2-35% - MEAUSRE) was deemed more cost-effective than the more generous one (i.e. FI3-70% - PROGRAMME). This suggests that total programme CE is highly dependent on the rationale for determining the cost-effective potential and the subsequent types of measures included in the final portfolio eligible for support.

5.9 Conclusions & Discussion

This paper has had two aims: (i) to propose a simple economic-engineering framework for assessing the programme savings potential for a financial subsidy, in a way that enables the inclusion of consumer response and increases transparency and validity in the evaluation results, (ii) to determine the potential for a financial subsidy under Article 7 of the EED in the Greek household sector. The first aim has been fulfilled by combining bottom-up engineering estimates, CE calculations, as well as estimates on consumer response from past programme participation evidence, for different EEMs and varying subsidy levels, under a step-wise SIR approach. Our analytical framework relies on much less data and uses more simplified assumptions than the detailed and complex formulations used in model-based assessments for EE policies and measures, which are often non-available to most national policy makers and practitioners due to budget and resource constraints.

A number of issues yet need to be considered to strengthen the methodological framework presented. First, we have assumed that we can estimate the savings potential of a financial subsidy by considering only the direct price and indirect learning effect as the primary drivers for consumers' decision making and resulting technology adoption due to a financial subsidy. Accounting for additional effects such as, marketing, word of mouth or the influence by social learning, along with the acquisition of new data on end users' actual investment decisions and programme participation, could further help to scrutinize the estimated effect of financial subsidies across different subsidy rates and consumer characteristics. In addition, substitution effects between different products or products of the same technology type yet different in energy class, are also not included in the present assessment as data on the distribution of sales across product classes were non-existent for most of the EEMs under evaluation.

To fulfil the second aim, we have applied the proposed SIR framework on the best available information describing the Greek household sector. Past sales data were used for each EEM category to account for current market saturation, technical feasibility issues as well as future trends based on EU-wide databases, official market reports as well as national data and statistics when available. We then relied on past programme participation evidence to derive estimates on the share of sales that can be credited to the implementation of financial incentives offered to consumers in the Greek household sector. We based our assumptions on information from previous evaluation studies on the largest financial scheme that has been implemented in the Greek household sector (Gelegenis et al., 2014), (Drivas et al., 2018). We also relied on an extensive national survey data, analysing information from the Statistical Service of Greece as regards the ownership rate for different end-use technologies by Greek households, as well as the share of households eligible for support according to income, location and other demographic and technical specifications. Our results should be taken into account for a more elaborated policy evaluation which would be necessary before generalizing the conclusions on policy response from this analysis since a number of behavioural factors, may have contributed to the resultant adoption rates which are not accounted for. Although we account for the baseline technology diffusion of the EEMs under assessment, prior to the introduction of the scheme, free-ridership is not captured in our estimates of policy response. Nevertheless, our findings on the number of eligible households were determined by accounting for pre-existing adoption trends and are thus conservative enough to avoid indicating overambitious response rates. Therefore, we consider our calculation results on policy response to be directionally reasonable when also compared to other results from relevant studies for similar EEMs (Bordigoni et al., 2016), (Alberini and Bigano, 2015), (Blum et al., 2013), (Dietz et al., 2009). We then estimated the SIR CE index from various perspectives and proposed a rationale for determining the portfolio of measures to achieve the cost-effective programme savings potential. The associated incentive payments required to yield programme participation were also estimated along with the monetary energy and import cost savings for different subsidy levels until 2030.

Our methodological framework demonstrates different ways of using the outcomes to produce CE estimates showcasing how CE estimations are sensitive to what benefits and costs are added in the numerator and denominator of the SIR approximations, and how the latter can be uplifted through the careful consideration of energy security related benefits. Scenario analysis was also applied for different subsidy rates to determine the impact of key assumptions used in the SIR calculations. Nevertheless, the savings potential and SIR calculations at measure and programme level would need to be confirmed by a thorough sensitivity analysis considering alternative economic growth rates, variability in energy prices, fuel escalation and discount rates, energy savings estimates, programme participation rates, investments costs and monetary benefits for import savings.

Subsequently, the results of this analysis should be viewed as an approximation of the impacts that would actually be achieved by alternative subsidy scenarios. These can be improved in the future by a more comprehensive data-set to provide a clearer picture of the distribution of market shares between different levels of energy performance and for emerging technologies entering the market. The establishment of a systematic monitoring of sales data at a national level is required to allow for regular analysis based on up-to-date market data towards more effective policy design. In addition, assessing ex-post the effectiveness of financial subsidies for different types of retrofits, from an econometric perspective and through dedicated surveys targeting a representative sample of programme participants examining whether they would have participated in the absence of the programme (i.e. free ridership) or how much they consume after the retrofits (e.g. rebound effect), would be off added value. Such a study has not yet been undertaken in Greece and could provide significant insights in the response of Greek householders to financial incentives and the real CE of such incentives.

The methodological approach presented in this paper has shown that with the appropriate use of information on total market shares for alternative retrofit options, energy performance before and after measure implementation, it becomes possible to determine which measures should be included in financial support programmes and to evaluate their anticipated impacts, funding requirements and associated benefits. On the whole, the portfolio of measures to be promoted by financial incentives should not be determined solely on CE considerations since consumer preferences as well as domestic market conditions should be accounted for to avoid implementing less effective or efficient incentives which would fail to tap their realistic EE potential. Most importantly there is a need to take a broader view on the cost-benefit assessments of EEMs by considering ancillary non-energy benefits such as energy security related ones as well as additional ones (e.g. health and living comfort benefits) to further encourage their diffusion and savings potential.

Overall, our assessment framework consists an approximation of a complex reality and a more comprehensive approach supported by an input-output model, would have been more appropriate to conduct such an assessment. Nevertheless, we consider our study to pave the way towards more transparent assessments on the potential outcomes and impacts of different policy tools that can be applied in similar country settings with limited data-availability and resource constraints. Finally, by applying our framework in the Greek household sector, we demonstrate in practice the challenges that emerge and which could be addressed by establishing direct links between the results of the monitoring and verification stage with their policy evaluation, planning and re-design step in the policy cycle (Schlomann et al., 2015). The outcomes for the Greek household sector can also be insightful on the savings potential, costs and benefits for financial incentives, when provided in the form of subsidies, regardless of their source, public or market-driven.

Acknowledgments

This paper is partly based on research conducted within the EC funded Horizon 2020 Framework Programme for Coordination and Support Action (EU H2020) Project titled “Peer Powered Cities & Regions” (PROSPECT) - Grant Agreement No. 75212 and on research conducted within the EC funded Horizon 2020 Framework Programme for Research and Innovation (EU H2020) Project titled “Transitions pathways and risk analysis for climate change mitigation and adaption strategies” (TRANSrisk) - Grant Agreement No. 642260. The authors would like to acknowledge the support from the EC. The content of the paper is the sole responsibility of its authors and does not necessary reflect the views of the EC.

Appendix A

Table A19. Specification of reference dwellings in the Greek residential building stock

Reference Dwellings	**Single Family House (SFH) dwelling**			**Multi Family House (MFH) apartment dwelling**		
Number of floors	1	1	1	5	5	5
Climatic Zone	A-B-C-D	A-B-C-D	A-B-C-D	A-B-C-D	A-B-C-D	A-B-C-D
House-type	SFH	SFH	SFH	MFH	MFH	MFH
Year of construction	<1980	1981-2010	post 2010	<1980	1981-2010	post 2010
Total building surface (m^2)	285	285	285	492	492	492
Ceiling surface (m^2)	85	85	85	166	166	166
External wall surface (m^2)	104	104	104	58	58	58
Openings surface (m^2)	11	11	11	21	21	21
Heated surface (m^2)	199	199	199	393	393	393
Level of insulation	NONE	MEDIUM	REPB[1]	NONE	MEDIUM	REPB[1]
Number of persons	3	3	3	5	5	5
Cooling system	3 AC units - 9000-12000btu/h - (Energy Class A)			5 AC units - 9000-12000 btu/h - (Energy Class A)		
Heating system[20]	Oil boiler, Pw=16KW, ns=86%	Oil boiler, Pw=16KW, ns=86%	Oil boiler, Pw=16KW, ns=86%	Oil boiler, Pw=32KW, ns=86%	Oil boiler, Pw=32KW, ns=86%	Oil boiler, Pw=32KW, ns=86%
Domestic How Water (DHW) system	Electric water heater	Electric water heater	Electric water heater	Electric water heater	Electric water heater	Electric water heater
Specific fuel consumption (KWh/m2,y)	186.4 / 216.6 / 384.6 / 424.2	101 / 135.6 / 255.2 / 257.2	81.7 / 85 / 180.1 / 199.7	188.3 / 209.2 / 287 / 349.4	102 / 94.5 / 124 / 151	74.8 / 64.2 / 73.2 / 89.1
Specific electricity consumption (KWh/m2,y)	71 / 78.4 / 63 / 62.8	58.6 / 71.1 / 66.2 / 59.4	44.7 / 49.9 / 43.8 / 42.6	87.5 / 94.7 / 92.8 / 85.8	87.5 / 94.7 / 92.8 / 85.8	64 / 69.9 / 65.7 / 56.3
Lighting	9 halogene (40-60W)	9 halogene (40-60W)	18 halogene (40-60W)	18 halogene (40-60W)	18 halogene lamps (40-60W)	18 halogene lamps (40-60W)
Electric Kitchen	Energy class A (Hobs EEI 45-55, Oven EEI 82-107)					
Refrigerator	Energy class A+ (267 KWh/year)					
Clothes-washing	Energy class A+ (185 KWh/year)					
Dish-washer	Energy class A+ (275 KWh/year)					

Table A20. Estimated programme participation rates under the three financial incentive options under assessment expressed as % of total market potential for a 7-year implementation period.

Hi-efficiency technology	**Programme Market Potential[1]**					
	FI1 - 7-year 15% subsidy		**FI2** - 7-year 35% subsidy		**FI3** - 7-year 70% subsidy	
	Maximum Programme Potential	Cost effective (Programme SIR)	Maximum Programme Potential	Cost effective (Programme SIR)	Maximum Programme Potential	Cost effective (Programme SIR)
N_TH_RF_041	6.8%	1.4%	10.0%	10.0%	17.3%	17.3%
N_TH_PIL_041	0.4%	0.0%	0.5%	0.0%	0.8%	0.8%
N_TH_EX_045	0.4%	0.0%	0.8%	0.1%	1.3%	0.3%
N_WIN_2.9	6.5%	0.6%	16.2%	1.6%	26.9%	26.9%
N_TH_RF_016	8.4%	1.7%	12.2%	12.2%	21.1%	21.1%
N_TH_PIL_016	0.6%	0.1%	0.7%	0.1%	1.1%	1.1%
N_TH_EX_015	0.5%	0.0%	1.0%	0.1%	1.6%	1.6%

---

[20] GEO_PUMP and AIR_PUMP are considered to replace heat pump space heaters (55 °C) with a COP 1.1 in accordance to to the national guidance note on bottom-up calculations for EEMs under Article 7 of the EED (CRES, 2017).

N_WIN_1.1	7.9%	1.6%	19.8%	4.0%	32.9%	32.9%
COND_BOIL_NG_88	2.1%	2.1%	4.1%	4.1%	6.4%	6.4%
COND_BOIL_NG_98	1.9%	1.9%	3.7%	3.7%	5.8%	5.8%
COND_BOIL_OIL	1.3%	0.1%	2.8%	0.3%	4.4%	4.4%
GEO_PUMP_4.7	0.6%	0.1%	1.1%	1.1%	1.5%	1.5%
GEO_PUMP_6.3	0.7%	0.1%	1.3%	1.3%	1.7%	1.7%
AIR_PUMP_3.05	1.0%	0.0%	1.8%	0.1%	2.4%	2.4%
AIR_PUMP_3.8	1.1%	0.1%	2.1%	0.4%	2.7%	2.7%
BIO_PEL	3.1%	0.6%	3.9%	3.9%	6.1%	6.1%
THERM_STAT	0.6%	0.6%	1.2%	1.2%	1.8%	1.8%
AIRC_A++	0.4%	0.0%	0.8%	0.1%	1.3%	1.3%
AIRC_A+++	0.4%	0.0%	0.9%	0.0%	1.5%	0.3%
SOL_HEAT	4.8%	0.5%	12.8%	1.3%	20.5%	20.5%
CFL	3.4%	0.3%	6.3%	1.3%	8.4%	1.7%
LED	4.9%	4.9%	9.1%	9.1%	12.2%	12.2%
COOK A+++	4.1%	4.1%	7.8%	7.8%	10.3%	10.3%
FRIDGE_A+++	3.7%	0.2%	6.8%	0.3%	9.1%	0.9%
WASH_A+++	3.0%	0.0%	5.7%	0.0%	7.5%	0.0%
DISH_A+++	2.2%	0.0%	4.1%	0.0%	5.5%	0.0%

Appendix B

Bottom-up engineering analysis of the savings potential of EEMs

- Estimating the energy savings potential for an EEM

To calculate the technical savings potential for each hi-efficiency technology intervention under each scenario (e.g. baseline or efficient/policy scenario) we conducted engineering estimates which are summarized in the following generic bottom up equations.

$$TES_i = \sum_{\tau=2018}^{2030} sales_{i,pol}(\tau) \times \sum_{t=\tau}^{2030}\left(UES_i \times psurv_i(L_i, t-\tau+1)\right) \tag{6.1.1}$$

$$LES_i = UES_i \times \sum_{j=1,LFi}\left(psurv_i(LF_i, j)\right) \tag{6.1.2}$$

$$UES_i = \sum_f \left(UEC_{ref,i,f} - UEC_{Eff,i,f} \right) \tag{6.1.3}$$

$$UEC_{i,f} = (UF_{i,f} \times A_{\frac{hf}{cf}})/EF_i \tag{6.1.4}$$

$$UF_{i,f} = P_{i,f} \times h_{i,f} \tag{6.1.5}$$

$$psurv_i(LF_i, v) = \begin{cases} 1, & v < 2/3L \\ 2 - \frac{3v}{2L}, & \frac{2}{3L} \leq v \leq 4/3L \\ 0, & v > 4/3L \end{cases} \tag{6.1.6}$$

Where:

TES_i= total (cumulative) final energy savings for all units represented by hi-efficiency technology i sold across all years due to a policy from the first year of application t until the last year of assessment.

LES_i = lifetime final energy savings for a hi-efficiency technology unit t in kilo watt hour (KWh).

UES_i = unit final energy savings across fuels f, for a hi-efficiency technology unit t in kilo watt hour (KWh).

$UEC_{i,f}$ = unit (i.e. household) annual final energy consumption of each hi-efficiency technology i, for fuel f

$psurv_i(LF_i,v)$= survival probability of technology i with a lifetime L_i on its v^{th} year of operation.

$tsales_i(t)$ =the total number of a $technology_i$ sold in year t,

$sales_{i,pol}(t)$ = annual sales for a hi-efficiency $technology_i$ through time sold due to a policy.

EF_i = the efficiency factor of each device i

$UF_{i,f}(t)$ = useful energy demand of each unit (i.e. household) for each fuel f and technology i. The calculation of useful energy demand is based on assumptions on the power required by the technology and h is the hours of technology use annually.

- Estimating the CO2 emissions savings potential for an EEM

We extend our calculations to estimate savings potential in terms of emissions for each individual EEM and support policy/programme under assessment using the equations below. The amount of CO2 emitted by the operation of the hi-efficiency technologies applied in the sector (i.e. households) under consideration is calculated by multiplying the amount of energy (thermal or electrical) consumed by the various systems with a CO_2 emission factor.

$$TER_i = \sum_{\tau=2018}^{2030} sales_{i,pol}(t) \times \sum_{t=\tau}^{2030}\left(UER_i(j) \times psurv_i(LF_i, t-\tau+1)\right) \tag{6.1.7}$$

$$LER_i = \sum_{j=1,LFi}\left(UER_i(j) \times psurv_i(LF_i, j)\right) \tag{6.1.8}$$

$$UER_i(t) = \sum_f \left(UEM_{ref,i,f}(t) - UEM_{Eff,i,f}(t) \right) \tag{6.1.9}$$

$$UEM_{i,f}(t) = UEC_{i,f} \times \ CO_2F_{i,f}(t) \tag{6.1.10}$$

Where:

TER_i= cumulative CO_2 emission reductions for all units represented by hi-efficiency technology i sold across all years from the first-year τ until the last year of projection.
LER_i (t)= lifetime emissions reduction of operation of a hi-efficiency technology unit i in year t, in in tCO_2.
UER_i = unit CO_2 emissions reduction savings across fuels f, for a hi-efficiency technology unit t in in tCO_2
UEM_i (t)= unit emissions of operation of a hi-efficiency technology unit i in year t, in in tCO_2.
$CO_2F_{i,f}$ (t)= CO_2 emissions factor for energy carrier f in year t of operation of a unit represented by a hi-efficiency technology i in tCO_2/MWh.

- Estimating the imported energy savings potential for an EEM

In addition, EEMs and supporting policies have a multitude of benefits in addition to energy and greenhouse gas emission savings as has been recognized and considered in the Fifth Assessment Period (Pachauri et al., 2014) as well in the 2014 IEA report on "Capturing the Multiple Benefits of EE"(IEA, 2014b). Among them, the importance of national security benefits of reduced fuel consumption and imports has been recognized by a number of efficiency potential and impact assessment studies (Leiby, 2008), (Tonn and Hendrick, 2011). By reducing energy demand, EE contributes to reducing a country's dependence on imported energy and increases its energy security. Following the approach of (Haydt et al., 2014) and (Löschel, Moslener and Rübbelke 2010) the proposed quantification of the imported energy savings is expressed in equations below:

$$TIES_i = \sum_{\tau=2018}^{2030} sales_{i,pol}(t) \times \sum_{t=\tau}^{2030}\big(UIES_i(j) \times psurv_i(LF_i, t-\tau+1)\big) \quad (6.1.11)$$

$$LIES_i = \sum_{j=1,LFi}\big(UIES_i(j) \times psurv_i(LF_i, j)\big) \quad (6.1.12)$$

$$UIES_i(t) = \sum_f (UIEC_{ref,i,f}(t) - UIEC_{Eff,i,f}(t)) \quad (6.1.13)$$

$$UIEC_{i,f}(t) = UEC_{i,f}(t) \times np_{i,f} \times ni_{i,f}(t) \quad (6.1.14)$$

Where:

$TIES_i$= cumulative energy import savings for all units represented by hi-efficiency technology i sold across all years from the first year t until the last year of projection.
$LIES_i$ (t)= lifetime imported energy savings of a hi-efficiency technology unit t in year t, in kilo watt hour (KWh).
$UIES_i$ (t)= unit imported energy savings of operation of a hi-efficiency technology unit i in year t, in kilo watt hour (KWh).
$UIEC_{i,f}$ (t)= unit imported energy consumption of a hi-efficiency technology unit t in year t, in kilo watt hour (KWh).
$np_{i,f}$ = final to primary energy factor for energy carrier f in year t of operation of a unit represented by a hi-efficiency technology i.
$ni_{i,f}$ (t)= imported energy factor for energy carrier f in year t of operation of a unit represented by a hi-efficiency technology i.

The final to primary energy factor reflects how much primary energy is used for each unit of final energy consumed and refers only to the energy carriers for which the transformation process from the primary energy to final is performed domestically inside the country. Considering that if fuels such as oil or gas are imported from other countries but are acquired in their final and exploitable form after processing takes place in the domestic market under assessment (i.e. Greece), conversion factors will be used for primary energy (domestic process). In all other cases, it is assumed as one.

The imported energy factor $n_{i,f}$ factor for energy carriers comprise the percentage of the energy carrier imported from other countries and were calculated on the basis of projections for energy balances data from PRIMES 2016 reference scenario (E. C. EC 2016). The imported energy factor related to electricity was calculated separately as the annual weighted sum of the imported energy factors from all energy carriers that contribute to the domestic electricity conversion process. More specifically the following factors must be taken into account: the different energy carriers involved in the electricity mix, their annual share in the electricity mix, the conversion factor $np_{i,f}$ for each energy carrier separately, as well as the conversion factor of the energy carrier into electricity. The following equation formalizes these calculations:

$$ni_{i,el}(t) = \sum_{f=1}^{n} \frac{np_{i,f} \times ni\_el_{i,f}(t) \times yearly\_share_f(t)}{n_f} \tag{6.1.15}$$

Where:

$ni_{i,el}(t)$= imported energy factor for electricity in year t,
n_f= average efficiency from the conversion process of energy carrier f to electricity
$ni\_ef_{i,f}(t)$= percentage of utilized energy carrier f, as a component of the electricity mix, coming from import rather than from domestic production,
$np_{i,f}$= final to primary energy factor for energy carrier f,
n=total number of energy carriers imported to produce electricity domestically,
$yearly\_share_{if}(t)$= annual contribution share for the electricity converted from energy carrier f.

- Savings-to-Investment-Ratio (SIR) CE assessment of EEMs

For any EE investment, whether the investment utilizes public grants and other incentives or not, financial metrics are essential to evaluate them. A recent financial metric that is used in the EE industry, is the savings to investment ratio (SIR). It is estimated by dividing the total savings of an EEM or project over the project's expected useful life (EUL) by the total investment cost of the project. The advantage of the SIR metric is that it captures the EUL of each measure and considers their benefits throughout their EUL (Tonn and Hendrick, 2011). Most importantly, the SIR provides an easy to understand return on investment measure which also allows for a comprehensive comparison of EEMs and is more useful than the simple payback period as it accounts for the EUL of the equipment as well as the time value of money.

To capture both the cost-effective potential from the side of consumers while also considering total programme CE and following recent evaluation practices of front-runner programmes for EE (Tonn and Hendrick, 2011), CE is examined from three perspectives:

- **participant perspective**: savings include and are limited to all fuel energy savings occurring throughout the project's EUL while investments are narrowed down to net investment costs (i.e. equipment and installation expenditures account for incentives or potential rebates) as well as other maintenance costs expected to occur through the EUL of the EEMs.
- **program perspective:** savings include energy savings as in the participant SIR. Investments are extended to include programme administrative and overhead costs along with the equipment and installation expenditures.
- **societal perspective:** compares society's costs of EE to resource savings while including non-cash benefits and costs. Savings include energy savings and are extended to include monetary values of non-energy benefits and investments include the same investment costs as in the program perspective. Societal SIR also uses a lower (i.e. social) discount rate than the other two perspectives. Participant, program and social SIR for each EEM supported by a financial policy scheme were estimated based on the following equations:

$$SIRpar_{i,pol}(t) = \frac{enBfit_{i,bc}(t)}{qcost_{i,bc}(t) - m_{i,pol}(t)} \quad . \tag{6.1.16}$$

$$SIRprog_{i,pol}(t) = \frac{lenBfit_{i,bc}(t)}{qcost_{i,bc}(t) - m_{i,pol}(t) + adm_{i,pol}(t)} \tag{6.1.17}$$

$$SIRsocial_{i,pol}(t) = \frac{lenBfit_{i,bc}(t) + limpBfit_{i,bc}(t)}{qcost_{i,bc}(t) - m_{i,pol}(t) + adm_{i,pol}(t)} \tag{6.1.18}$$

$$SIRpar_{i,bc}(t) = \frac{lenBfit_{i,bc}(t)}{qcost_{i,bc}(t)} \tag{6.1.19}$$

$$enBfit_{i,bc}(t) = enCost_{i,ref}(t) - enCost_{i,Eff}(t) \tag{6.1.20}$$

$$impBfit_{i,bc}(t) = impCost_{i,ref}(t) - impCost_{i,Eff}(t) \tag{6.1.21}$$

$$enCost_i(t) = \sum_f (UEC_{i,f}(t) \times fprice_{i,f}(t)) \tag{6.1.22}$$

$$impCost_i(t) = \sum_f (UIEC_{i,f}(t) \times fprice_{i,f}(t)) \tag{6.1.23}$$

$$lenBfit_i(t) = lenCost_{i,ref}(t) - lenCost_{i,Eff}(t) \tag{6.1.24}$$

$$limpBfit_{i,bc}(t) = limpCost_{i,ref}(t) - limpCost_{i,Eff}(t) \tag{6.1.25}$$

$$lenCost_i(t) = \sum_f \sum_{j=1}^{iLF}(UEC_{i,f}(j) \times psurv_i(j) \times fprice_{i,f}(t+j-1) \times (1+dRate)^{(1-j)}) \tag{6.1.26}$$

$$limpCost_i(t) = \sum_f \sum_{j=1}^{iLF}(UIEC_{i,f}(j) \times psurv_i(j) \times impc_{i,f}(t+j-1) \times (1+dRate)^{(1-j)}) \tag{6.1.27}$$

$$qCost_{i,bc}(t) = TC_{i,bc}(t) + inst_{i,bc}(t) + \sum_{j=1}^{LFi}(mnt_{i,bc}(j) \times (1+dRate)^{(1-j)}) \tag{6.1.28}$$

where:
$SIRpar_{i,pol}(t)$=savings to investment ratio of technology$_i$ from a participant perspective, sold in year t
$SIRprog_{i,pol}(t)$=savings to investment ratio of technology$_i$ from a programme perspective, sold in year t
$SIRsocial_{i,pol}(t)$=savings to investment ratio of technology$_i$ from a social perspective, sold in year t
$SIRpar_{i,bc}(t)$= savings to investment ratio of technology$_i$ sold in year t in the base case scenario,
$enCost_i(t)$= annual energy costs of technology$_i$ sold in year t expressed in €
$impCost_i(t)$= annual energy import costs of technology$_i$ sold in year t
$lenCost_i(t)$= present value in year t of lifetime energy costs of technology$_i$ sold in year t
$limpCost_i(t)$= present value in year t of lifetime energy import costs of a technology$_i$ in year t
$enBfit_i(t)$=annual energy benefits of technology$_i$ sold in year t expressed in €
$impBfit_i(t)$=annual energy import benefits of technology$_i$ sold in year t expressed in €
$lenBfit_i(t)$= present value in year t of lifetime energy cost savings of a technology$_i$ in year t
$limpBfit_i(t)$= present value in year t of lifetime imported energy cost savings of a technology$_i$ in year t
$qcosts_{i,bc}(t)$= present value in year t of lifetime technology equipment costs of technology$_i$ sold in year t in the base case scenario,
$TC_{i,bc}(t)$= technology unit costs of technologyi sold in year t in the baseline (non-policy) scenario
$inst_{i,bc}(t)$= technology installation costs of technologyi sold in year t in the base case scenario
$mnt_{i,bc}(t)$= annual maintenance and repair costs of technology$_i$ sold in year t in the base case scenario,
$adm_{i,pol}(t)$= annual administrative and overhead costs for the program implementer including installation expenditures that might be eligible.
fprice(t)= energy price in year t, expressed in €/KWh
$importc_{i,f}(t)$=energy import cost factor (beyond the energy price) in year t, expressed in €/KWh
dRate= social discount rate,
$m_{i,pol}(t)$=financial incentive offered to consumers investing in hi-efficiency technologies$_i$ eligible under the policy scenario and sold in year t, expressed as a percentage share of equipment costs.

- Consumer response estimation for each policy scenario

A financial subsidy will reduce the capital costs by a fixed percentage for a fixed period of time, fostering the purchase of more energy-efficient technologies. The increase in sales due to the subsidy will be accompanied by a simultaneous drop in capital costs due to increased production experience (i.e. energy intervention learning curve), making them even more attractive to consumers (Weiss et al., 2010). The following equations formalize our assessment approach.

$$sales_{i,pol}(t) = sales_{i,lrn}(t) + sales_{i,sub}(t) - \mathrm{sales_{i,bc}(t)} \tag{6.1.29}$$

$$sales_{i,lrn}(t) = \frac{SIRpar_{i,lrn}(t) - SIRpar_{i,bc}(t)}{SIRpar_{i,lrn}(t)} \times resp_i(t) \times tsales_i(t) \tag{6.1.30}$$

$$sales_{i,sub}(t) = \frac{SIRpar_{i,pol}(t) - SIRpar_{i,lrn}(t)}{SIRpar_{i,pol}(t)} \times resp_i(t) \times tsales_i(t) \tag{6.1.31}$$

$$sales_{i,bc}(t) = tsales_i(t)\ \times base_i(t) \tag{6.1.32}$$

$$resp_i(t) = \frac{pol\_ef_i \times (1-f(t))}{m_i(t)} \times \frac{(t_{last}+1-t_{first})}{total\_years_{pol}} \tag{6.1.33}$$

$$\mathrm{TC_{i,lrn}(t)} = \mathrm{TC_{0,i}(t_O)} \times \mathrm{PR_i}^{\frac{\ln\,(\mathrm{CSales_{i,pol}(t)/CSales_{i,pol}(t_O)})}{\ln 2}} \tag{6.1.34}$$

$$\mathrm{PR_i} = 1 - \mathrm{LR_i} = 2^{-\mathrm{b_i}} \tag{6.1.35}$$

where:

sales$_{i,pol}$(t)=sales forecast of technology$_i$ under the policy case scenario in year t (the tth year of the assessment period).
sales$_{i,lrn}$(t)= sales forecast of technology$_i$ due to learning effect in year t
sales$_{i,sub}$(t)= sales forecast of technology$_i$ due to direct price effect of the subsidy in year t
tsales$_i$ (t)= total sales forecast of technology$_i$ in year t (represent the total number of household-size units of the technology$_i$ sold in the market)
SIRpar$_{i,lrn}$(t)=participant SIR of technology$_i$ sold in year t due to increased production experience
SIRpar$_{i,sub}$(t)=participant SIR of technology$_i$ sold in year t in the financial subsidy scenario
SIRpar$_{i,bc}$(t)=participant SIR of technology$_i$ sold in year t in the base case scenario
sales$_{i,bc}$ (t) = baseline annual sales for a hi-efficiency technology$_i$ in year t,
base$_i$(t) = baseline factor expressed as percentage share over total product sales for a technology$_i$ in year t
resp$_i$(t)= consumer response expressed as percentage point increase in marketshare of total market sales for technology$_i$ for the policy case scenario in year t.
f(t)= market diffusion correction factor (s.t. $0<f(t)<1$) accounting for free-rider effects.
pol_ef$_i$(t)=total policy effect at the end of the policy implementation period expressed as a market penetration increase in the share of the hi-efficiency technology market share of total sales.
t$_{first}$=first year of the policy implementation period
t$_{last}$=last year of the policy implementation period
total_years$_{pol}$=total number of years the PI is implemented.
m$_i$(t)=subsidy level, expressed as a share of installation/equipment costs, offered to consumers for a technology$_i$ in year t.
PR$_i$= progress ratio (%) for an energy-efficient technology$_i$,
LR$_i$= learning rate (%) for an energy-efficient technology$_i$,
TC$_{i,lrn}$(t$_o$) = technology$_i$ unit costs due to increase production experience under the policy scenario in year t,
TC$_{0,i}$(t$_o$) = technology$_i$ unit costs for the first unit produced in the first year t$_o$ of the assessment period,
csales$_{i,pol}$(t$_o$)=cumulative sales of technology$_i$ in the policy scenario in first year of the assessment period,
csales$_{i,pol}$(t)=cumulative sales of technology$_i$ in the policy scenario in year t.

- Result Metrics for total savings potential & implementation costs for a subsidy programme

The total cumulative energy, emissions and imported energy savings of all units for all eligible EE technology measures sold in a given year of the assessment period under a policy measure scenario are formalized in the equations below.

$$PES = \sum_i TES_i \times s_i \tag{6.1.36}$$

$$PER = \sum_i TER_i \times s_i \tag{6.1.37}$$

$$PIES = \sum_i TIES_i \times s_i \tag{6.1.38}$$

The monetization of the energy and imported energy benefits as well as the total programme costs are estimated through the following metrics:

$$PenBfit = \sum_i \left(\sum_{t=2018}^{2030} \left(sales_{i,pol}(t) \times \sum_{j=1}^{t-2018+1} \left(enBfit_i(t) \times psurv_i(LF_i, j) \times (1 + dRate)^{(1-j)}\right)\right) \times s_i\right) \tag{6.1.39}$$

$$PimBfit = \sum_i \left(\sum_{t=2018}^{2030} \left(sales_{i,pol}(t) \times \sum_{j=1}^{t-2018+1} \left(impBfit_i(t) \times psurv_i(LF_i, j) \times (1 + dRate)^{(1-j)}\right)\right) \times s_i\right) \tag{6.1.40}$$

$$PCosts = \sum_{\mathrm{i}} \left(\sum_{t=2018}^{2030} \left(sales_{i,pol}(t) \times \left(\left(TC_i(t) + inst_i(t)\right) \times \left(1 - m_{i,pol}(t)\right)\right) \times (1 + dRate)^{(1-t)}\right) \times s_i\right) \tag{6.1.41}$$

$$AdmCosts = \sum_{\mathrm{i}} \left(\sum_{t=2018}^{2030} sales_{i,pol}(t) \times \left(\mathrm{adm}_{\mathrm{i,pol}}(\mathrm{t}) \times (1 + dRate)^{(1-t)}\right) \times s_i\right) \tag{6.1.42}$$

$$FCosts = \sum_{\mathrm{i}} \left(\sum_{t=2018}^{2030} \left(sales_{i,pol}(t) \times \left(\left(TC_i(t) + inst_i(t)\right) \times m_{i,pol}(t) + \mathrm{adm}_{\mathrm{i,pol}}(\mathrm{t})\right) \times (1 + dRate)^{(1-t)}\right) \times s_i\right)$$

(6.1.44)

$$PSIRpar = \frac{PenBfit}{PCosts} \tag{6.1.43}$$

$$PSIRprog = \frac{enBfit_{i,bc}(t)}{PCosts+AdmCosts} \tag{6.1.44}$$

$$PSIRsocial = \frac{enBfit_{i,bc}(t)+PimBfit}{PCosts+AdmCosts} \tag{6.1.45}$$

$$s_i = \begin{cases} 0\%, & 0 \leq SIR < 0.3 \\ 5\%, & 0.3 \leq SIR < 0.5 \\ 10\%, & 0.5 \leq SIR < 0.8 \\ 20\%, & 0.8 \leq SIR < 1 \\ 100\%, & SIR > 1 \end{cases} \tag{6.1.46}$$

where:

si= adjustment factor applied to each measure i market potential according to each technology's SIR.
PES= cumulative programme final energy savings for a policy measure across all years during the assessment period
PER= cumulative programme CO2 emission reductions/savings for all units for all hi-efficiency technologies sold under a policy measure across all years during the assessment period
PIES= cumulative programme imported energy savings for all units for all hi-efficiency technologies sold under a policy measure across all years during the assessment period.
PenBfit=cumulative energy cost savings for all units for all hi-efficiency sold due to a policy measure across all years during the assessment period.
PimpBfit=cumulative imported energy cost savings for all units for all hi-efficiency technologies sold due to a policy measure across all years during the assessment period.
PCosts=total programme costs for all units for all hi-efficiency technologies sold due to a policy measure across all years during the assessment period.
FCosts=total programme funding and overhead (i.e. administrative) costs for all units for all hi-efficiency technologies funded by policy measure across all years during the assessment period.
AdmCosts=total programme management and overhead (i.e. administrative) costs for all units for all hi-efficiency technologies funded by policy measure across all years during the assessment period.
PSIRpar= savings to investment ratio from a participant perspective estimated at a programme level
PSIRprog= savings to investment ratio from a programme perspective estimated at a programme level
PSIRprog= savings to investment ratio from a social perspective estimated at a programme level

References

AEBIOM, 2017. PELLET MARKET OVERVIEW. European Biomass Association. Brussels.

Alberini, A., Bigano, A., 2015. How effective are energy-efficiency incentive programs? Evidence from Italian homeowners. Energy Econ. 52, S76–S85. https://doi.org/10.1016/J.ENECO.2015.08.021

Amon, A.D.A., Holmes, I., 2016. Energy Efficiency as Infrastructure: Leaping the Investment Gap.

Blasnik, M., Dalhoff, G., Pigg, S., Mendyk, A., Carroll, D., Ucar, F., 2014. National Weatherization Assistance Program Impact Evaluation: Energy Impacts for Single Family Homes.

Blum, H., Atkinson, B., Lekov, A.B., 2013. A methodological framework for comparative assessments of equipment energy efficiency policy measures. Energy Effic. 6, 65–90. https://doi.org/10.1007/s12053-012-9162-x

Bordigoni, M., Berthou, M., Frechard, M., Ngaboyamahina, E., 2016. Forecasting white certificate flows with system dynamics.

Box, G.E.P., Jenkins, G.M., Reinsel, G.C., Ljung, G.M., 1994. Time series analysis : forecasting and control.

Brooks, C., 2008. Introductory Econometrics for Finance. Cambridge University Press, Cambridge.

Christodoulos, C., Michalakelis, C., Varoutas, D., 2010. Forecasting with limited data: Combining ARIMA and diffusion models. Technol. Forecast. Soc. Change 77, 558–565. https://doi.org/10.1016/J.TECHFORE.2010.01.009

CRES, 2017. ΠΡΟΣΔΙΟΡΙΣΜΟΣ ΤΗΣ ΕΞΟΙΚΟΝΟΜΗΣΗΣ ΕΝΕΡΓΕΙΑΣ ΑΠΟ ΜΕΤΡΑ ΒΕΛΤΙΩΣΗΣ ΤΗΣ ΕΝΕΡΓΕΙΑΚΗΣ ΑΠΟΔΟΣΗΣ ΣΤΟ ΠΛΑΙΣΙΟ ΤΟΥ ΚΑΘΕΣΤΩΤΟΣ ΕΠΙΒΟΛΗΣ ΤΗΣ ΥΠΟΧΡΕΩΣΗΣ ΕΝΕΡΓΕΙΑΚΗΣ ΑΠΟΔΟΣΗ. Centre for Renewable Energy Studies. Athens.

Dascalaki, E.G., Balaras, C.A., Kontoyiannidis, S., Droutsa, K.G., 2016. Modeling energy refurbishment scenarios for the Hellenic residential building stock towards the 2020 & 2030 targets. Energy Build. 132, 74–90. https://doi.org/10.1016/J.ENBUILD.2016.06.003

Dietz, T., Gardner, G.T., Gilligan, J., Stern, P.C., Vandenbergh, M.P., 2009. Household actions can provide a behavioral wedge to rapidly reduce US carbon emissions. Proc. Natl. Acad. Sci. 106, 18452–18456. https://doi.org/10.1073/PNAS.0908738106

Drivas, K., Rozakis, S., Xesfingi, S., 2018. The Effect of House Energy Efficiency Costs on the Participation Rate and Investment Amount of Lower-Income Households The Effect of House Energy Efficiency Costs on the Participation Rate and Investment Amount of Lower-Income Households.

EC, 2016. EU Reference Scenario 2016, European Comission. https://doi.org/10.2833/9127

EC, 2015. Energy Union Package - A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy, COM(2015) 80 final. Brussels. https://doi.org/10.1017/CBO9781107415324.004

Ehrhardt-martinez, K., Laitner, J.A. “Skip,” 2010. People-Centered Initiatives for Increasing Energy Savings. Am. Counc. an Energy Effic. Econ. 202–507.

ELSTAT, 2013a. SURVEY ON ENERGY CONSUMPTION IN HOUSEHOLDS, 2011-2012. Hellenic Statistical Authority. Athens.

ELSTAT, 2013b. SURVEY ON ENERGY CONSUMPTION IN HOUSEHOLDS, 2011-2012.

Europe Economics, 2016. Evaluation of Fiscal Measures in the National Policies and Methodologies to Implement Article 7 of the Energy Efficiency Directive Final report.

Ferrara, L., Marcellino, M., Mogliani, M., 2015. Macroeconomic forecasting during the Great Recession: The return of non-linearity? Int. J. Forecast. 31, 664–679. https://doi.org/10.1016/J.IJFORECAST.2014.11.005

Forouli, A., Gkonis, N., Nikas, A., Siskos, E., Doukas, H., Tourkolias, C., 2019. Energy efficiency promotion in Greece in light of risk: Evaluating policies as portfolio assets. Energy 170, 818–831. https://doi.org/10.1016/J.ENERGY.2018.12.180

Gelegenis, J., Diakoulaki, D., Lampropoulou, H., Giannakidis, G., Samarakou, M., Plytas, N., 2014. Perspectives of energy efficient technologies penetration in the Greek domestic sector, through the analysis of Energy Performance Certificates. Energy Policy 67, 56–67. https://doi.org/10.1016/J.ENPOL.2013.09.051

Georgopoulou, E., Sarafidis, Y., Mirasgedis, S., Balaras, C.A., Gaglia, A., Lalas, D.P., 2006. Evaluating the need for economic support policies in promoting greenhouse gas emission reduction measures in the building sector: The case of Greece. Energy Policy 34, 2012–2031. https://doi.org/10.1016/J.ENPOL.2005.02.002

Herndon, J., 2015. Potential Studies – Aligning achievable potential with local market conditions and policy or planning objectives through an innovative approach to economic screening.

IEA-4E, 2014. Mapping Document - Domestic Lighting. IEA.

JRC, 2017. Follow-up of the preparatory study for Ecodesign and Energy Label for Household Dishwashers Final report. Joint Research Center - European Comission. Brussels. https://doi.org/10.2760/0768

Kakaras, E., Karellas, S., Vourliotis, V., Gramellis, P., Pallis, P., Karabinis, E., 2016. Σύγκριση κόστους θέρμανσης από διάφορες τεχνολογίες. 1-11. National Technical University of Athens.

Kemna, R., Lemeire, C., 2015. Preparatory Study on Light Sources for Ecodesign and/or Energy Labelling Requirements. Final report - Task 2 Markets 1–116.

Kemna, R., van Elburg, M., Corso, A., 2019. Review Study Task 2 Market Analysis DRAFT FINAL REPORT (Energy Label) Space and combination heaters Ecodesign and Energy Labelling.

Kemna, R., van Elburg, M., Li, W., van Holsteijn, R., 2007. Eco-design of Boilers - Preparatory Study on Eco-design of Boilers. European Commission, DG TREN. Delft (NL).

Koomey, J.G., 2002. FROM MY PERSPECTIVE: Avoiding “The Big Mistake” in forecasting technology adoption. Technol. Forecast. Soc. Change 69, 511–518. https://doi.org/10.1016/S0040-1625(01)00153-6

Labanca, N., Bertoldi, P., 2016. Title: Energy Savings Calculation Methods under Article 7 of the Energy Efficiency Directive. https://doi.org/10.2790/855880

Lazar, J., Colburn, K., 2013. Recognizing the Full Value of Energy Efficiency.

Leiby, P.N., 2008. Estimating the Energy Security Benefits of Reduced U.S. Oil Imports. Oak Ridge Natl. Lab. Rep. ORNL TM-20, 1–67.

Markandya, A., Ortiz, R.A., Mudgal, S., Tinetti, B., 2009. Analysis of tax incentives for energy-efficient durables in the EU. Energy Policy 37, 5662–5674. https://doi.org/10.1016/J.ENPOL.2009.08.031

MEE, 2019. NATIONAL ENERGY AND CLIMATE PLAN. MInistry of Environment & Energy. Athens.

MEE, 2018. ΟΔΗΓΟΣ ΕΦΑΡΜΟΓΗΣ ΠΡΟΓΡΑΜΜΑΤΟΣ «ΕΞΟΙΚΟΝΟΜΗΣΗ ΚΑΤ’ ΟΙΚΟΝ ΙΙ». Ministry of Environment & Energy. Athens.

MEE, 2017. 4ο Εθνικό Σχέδιο Δράσης Ενεργειακής Απόδοσης Της Ελλάδας. Ministry of Environment & Energy. Athens.

MEECC, 2014. Report on the long-term strategy for mobilizing investment to renovate residential and commercial buildings, public and private, of the national building stock (Article 4, Directive 27/2012/EU) 1–164.

MEECC, 2012. ΟΔΗΓΟΣ ΕΦΑΡΜΟΓΗΣ ΠΡΟΓΡΑΜΜΑΤΟΣ «ΕΞΟΙΚΟΝΟΜΗΣΗ ΚΑΤ’ ΟΙΚΟΝ». Ministry of Energy Environment & Climate Change. Athens.

MEECC, 2011. Πλαίσιο μεθοδολογίας μέτρησης και επαλήθευσης της εξοικονομούμενης ενέργειας για την επίτευξη του ενδεικτικού εθνικού στόχου εξοικονόμησης ενέργειας στη τελική χρήση. Ministry of Energy, Environment & Climate Change. Athens.

Michel, A., Attali, S., Bush, E., 2016. Energy efficiency of White Goods in Europe : monitoring the market with sales data – Final report 72.

Mundaca, L., Neij, L., Worrell, E., Mcneil, M., 2010. Evaluating Energy Efficiency Policies with Energy-Economy Models ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY, LBNL NUMBER TIMES NEW ROMAN.

Navigant, 2017. Energy Efficiency Potential and Goals Study for 2018 and Beyond Final Public Report.

Pallis, P., Gkonis, N., Varvagiannis, E., Braimakis, K., Karellas, S., Katsaros, M., Vourliotis, P., 2019. Cost effectiveness assessment and beyond: A study on energy efficiency interventions in Greek residential building stock. Energy Build. 182, 1–18. https://doi.org/10.1016/J.ENBUILD.2018.10.024

Popiolek, N., Thais, F., 2016. Multi-criteria analysis of innovation policies in favour of solar mobility in France by 2030. Energy Policy 97, 202–219. https://doi.org/10.1016/J.ENPOL.2016.07.036

Promotion 3E, 2008. Promotion3e - Promotion of Energy-efficient Appliances in Europe Publishable result-oriented report. European Comision IEE project. Brussels.

Riviere, P., ADNOT, J., Grignon-masse, L., Marchio, D., Riviere Armines, P., Philippe ANDRE, Detroux, L., Lebrun, J., Teodorose, V., Luis ALEXANDRE, J., Benke, G., Bogner, T., Conroy, A., Hitchin, R., Pout, C., Thorpe Bre, W., 2009. Preparatory study on the environmental performance of residential room conditioning appliances (airco and ventilation) Study on residential ventilation-Final report after SH comments.

Rosenow, J., Guertler, P., Sorrell, S., Eyre, N., 2018. The remaining potential for energy savings in UK households. Energy Policy 121, 542–552. https://doi.org/10.1016/J.ENPOL.2018.06.033

Schlomann, B., Rohde, C., Plötz, P., 2015. Dimensions of energy efficiency in a political context. Energy Effic. 8, 97–115. https://doi.org/10.1007/s12053-014-9280-8

Spyridaki, N.-A., Banaka, S., Flamos, A., 2016. Evaluating public policy instruments in the Greek building sector. Energy Policy 88, 528–543. https://doi.org/10.1016/J.ENPOL.2015.11.005

Steinbach, J., Isi, F., Staniaszek, D., 2015. Discount rates in energy system analysis Discussion Paper.

Tonn, B., Hendrick, T., 2011. Evaluation of the National Weatherization Assistance Program during Program Years 2009-2011 (American Reinvestment and Recovery Act Period).

Tsalemis, D., 2018. « Energy Savings at Home Programme II », in: Financing Energy Efficiency in Greece and Cyprus. Ministry of Environment and Energy, Athens.

van Elburg, M., van den Boorn, R., Kemna, R., 2011. Development of European Ecolabel and Green Public Procurement Criteria for Hydronic Central Heating Systems Draft Report: Product definition and scope Economic and market analysis Technical analysis.

van Holsteijn, R., Kemna, R., van Elburg, M., Wierda, L., 2019. Space and combination heaters Ecodesign and Energy Labelling - Task 7 Scenarios.

Weiss, M., Patel, M.K., Junginger, M., Blok, K., 2010. Analyzing price and efficiency dynamics of large appliances with the experience curve approach. Energy Policy 38, 770–783. https://doi.org/10.1016/J.ENPOL.2009.10.022

Zachariadis, T., Michopoulos, A., Vougiouklakis, Y., Piripitsi, K., Ellinopoulos, C., Struss, B., 2018. Determination of cost-effective energy efficiency measures in buildings with the aid of multiple indices. Energies 11, 1–20. https://doi.org/10.3390/en11010191

6. Chapter 6: Summary and conclusions

6.1 Introduction

Through this thesis we have identified the need for a more pragmatic design and effective implementation of EE PIs to meet with the ever-increasing energy savings targets as well as the stricter monitoring and evaluation pre-requisites. The objective of this thesis was therefore set to develop improved, evidence-based, evaluation methodologies to support policy decision-makers as well as programme implementers towards the formulation of more effective EE PIs. Our objective was met by developing a set of successive research-chapters that enhance existing evaluation practices in different ways and support the decision-making process at different stages of the policy cycle of EE PIs. These relate to:

Chapter 1: Emphasis of the problem of evaluating EE PIs at a national level and the parameters that affect it.

Chapter 2: Analysis of the literature, the major research efforts at European level on national energy policy evaluations, and the most widespread evaluation approaches and practices to support decision-making in the policy planning and design of energy PIs and their mixes.

Chapter 3: Development of a qualitative process evaluation approach of EE PIs and application in the mix of national EE PIs targeting the building sector in Greece.

Chapter 4: Development of an ex-post evaluation model assessing the effect of EE PIs and application for the real-case of financial subsidies targeting the household sector in Greece.

Chapter 5: Development of an ex-ante evaluation approach of the EE potential and application for the case of financial subsidies targeting the household sector in Greece

Taken as a whole, the aforementioned research chapters, constitute stand-alone yet successive evaluation steps of an integrated methodological evaluation framework as presented in Chapter 1, that evaluates EE PIs at different stages in their policy cycle (i.e. during, ex-post and ex-ante) and explicitly accounts for social and behavioural barriers when estimating their future energy savings potential. The methodological framework ultimately supports the decision-making process of planning and (re-)designing more effective EE PIs by: (i) providing a comparative evaluation and ranking of EE PI based on evidence on their functionality and ease of implementation, (ii) quantifying the additional effect of the highly-ranked PI while accounting for social and behavioural determinants of EE investment decisions, (iii) estimating the achievable EE potential for the selected PI by including a behavioural and social realism aspect in those estimates.

This chapter presents the summary of results, and general conclusions of this PhD thesis as well as the prospects for further research activities on the problem under consideration.

6.2 Summary of the results

This section presents and discusses the main findings and the contributions with regard to the sub- questions and to the central research question of this thesis. This thesis is focused on how to improve existing evaluation practices to support policy planning and design for a more effective implementation of EE PIs in national energy and climate policy. The central research question for this thesis was:

- How can the policy planning and design of effective EE PIs be improved by evidence-based methodological evaluation frameworks and practices?

In order to answer this overall research question, the following sub questions were determined:

1. How to evaluate energy PIs or PI mixes at different stages in their policy cycle?

2. How can the perspective of different actors and target groups be considered in the policy evaluation process to support the policy planning and decision-making?

3. Which key factors should be taken into account when designing effective EE PIs?

4. How to assess and quantify the effects that can be attributed to EE PIs, while accounting for non policy determinants and consumer heterogeneity?

5. What are the net effects that can be attributed to financial subsidies and how can these support the process of policy planning & (re-)design?

With these sub questions in mind, we aimed to determine the key aspects and factors that should be accounted for in the evaluation of EE policies to support and improve their effective (re-)design and implementation. The sub questions have been analysed in one or more of the previous chapters 2 to 5 of this thesis (you may refer to section 1.4 to read about the link between the sub questions and the different chapters these are discussed).

1. How to evaluate energy PIs or PI mixes at different stages in their policy cycle?

In **chapter 2**, we review the variety of methodologies that have been developed for the appraisal of energy and climate policy mixes. In particular we refer to the evaluation approaches, the different evaluation means (i.e. methods), their impact focus and explanatory factors pertaining the policy impact of energy and climate policy mixes, where we still find a considerable lack of clarifications despite previous work and studies in the field. Qualitative design approaches contribute to the assessment of the diversity and complexity of energy policies and their combinations thereof, allowing the impacts of PIs to be assessed in relative terms. Qualitative approaches usually provide descriptive explanatory analysis of often non quantifiable policy processes and help to explain contextual differences and cause impact effects. They tend to focus more on the role of the implementation context and design characteristics in the effects of energy PIs and can more easily integrate participatory analysis allowing for a better understanding of assumptions and key structural relations.

On the other hand, modelling (i.e. quantitative) approaches provide absolute numbers and economic trends that influence policy effects and are based on a numerical data-base to estimate the extent of policy impacts. This strand of evaluation approaches tends to focus more on the long-term effects of policies, cam accommodate more easily sufficient market and technology details, representing supply and demand equilibriums and may offer enhanced support for effectiveness and efficiency evaluation judgments in energy policies and their combinations.

We also find the focus of energy policy evaluations to be largely organized around substantial concerns rather than methodologically oriented assemblies. In fact, the impacts of policy combinations upon societal welfare, technology costs and innovation have attracted considerably less attention in the policy evaluation literature and social and technology impacts integration should be strengthened in future analytical frameworks. These findings also indicate that the majority of past research in energy policy evaluation has been focused on assessing the potential or observed outcomes and impacts that can result from policy interventions, and very few of them have turn their focus on earlier stages in the policy life-cycle. We conclude that evaluation frameworks should combine qualitative and quantitative information based on empirical observations and incorporate both ex-ante and ex-post viewpoints. Such frameworks would then be able to generate a more reliable measure of the magnitude of impacts and outcomes of policies as well as a greater depth of understanding of how and why a (set of) PI(s) was or can be effective and how it might be reconfigured to make it more cost effective in the future.

In **Chapter 3**, we apply this consideration to evaluate the main EE PIs applied in the Greek building sector (e.g. Financial support measures, Voluntary Agreements, Building Codes, Energy Performance Certificates, Energy Performance Contracting etc.) by focusing on their implementation stage of their policy cycle. To do so we apply multi-criteria analysis (MCA) to evaluate public policy mechanisms that foster EE and RES technologies in the Greek building sector, based on stakeholders' understanding and perceptions of the functionality of PIs. We found that the majority of multi-criteria policy evaluation studies adopt a rational view on policy, implying an ex-ante estimation of the possibility that desired policy impacts will be achieved. They assess PIs by estimating their impacts and congruently their effectiveness as a result of their implementation. In fact, most multi-criteria evaluations tend to focus primarily on the assessment of policy impacts. More frequently the evaluations carried out use criteria, which concentrate largely on policy effects and to a lesser extent on policy processes and implementation. This dissertation underlines that each phase in the policy cycle, such as the implementation one, should be evaluated in its own right, especially when one's aim is to shed light on the so-called "implementation deficit", which may clarify the differences between policy in paper and tangible policy effects (Crabbé and Leroy, 2008). The policy implementation process is thus deemed of fundamental importance in determining a PI's effectiveness (Rogge and Reichardt, 2013) and may impinge on policy's success (Crabbé and Leroy, 2008).

The first component in the proposed evaluation framework therefore does not focus on comparing goals with achieved effects. It rather consists an assessment of policy products and processes produced throughout the implementation phase of the policy cycle. This is depicted onto the selected criteria set describing the functionality of PIs through indicators related to factors such as implementation hurdles, compatibility issues and coherence featuring coordination processes among pertinent authorities. The objective is to shed light on the implementation of currently employed policy mechanisms that aim to achieve the 2020 energy savings targets and beyond, providing useful information to policy makers for future policy (re-) formulations.

The MCA results showed that Greece is still missing significant energy saving opportunities that could be reached through more streamlined implementation practices and political support. Within the frame of prolonged recession, the Greek government should also revitalize the implementation of alternative funding mechanisms and support policy alternatives such as green public procurement, voluntary agreements, and energy performance contracting. Despite the recessionary environment, actors with implementation and feasibility priorities ranked financial support programs supporting EE installations in public and residential buildings on top of the list, as quite functional. Interviews with several representatives from the Energy Agency and MEECC, responsible for the overview of such schemes, revealed that EE subsidies operating with tight budgets, have been carefully designed, closely administered and monitored. This also relates to the fact that subsidy mechanisms implemented thus far in Greece by way of soft loans and grants have been primarily financed from EU funds as well as from the state budget (MEECC, 2012a). Their high evaluation may also reflect their deemed necessity to drive demand for such investment from building owners and municipalities to market and policy actors, especially under an unfavorable investment climate. Reportedly, their high overall evaluation relates also to non-financial factors such as the inclusion of local actors (i.e. cooperating banks and municipalities) fostering trust and capacity while also sharing some of the administrative burden. However, as suggested by MEECCs' officials, Greece still faces significant budgetary constraints due to the prolonged negative economic conditions and limited additional financing is expected to come from the public purse. Financial incentives should preferably be provided in the form of soft loans, guarantees or smaller grants for measures with a shorter payback time so as to relieve the pressure put on the already drained national budget (EC, 2013), while decision-support frameworks should support the planning procedures for the allocation and cost-effective exploitation of the available funds to promote such investments. Alternative ways of financing EE actions, such as on-bill financing (OBF) or the set-up of an EE revolving fund, could work towards overcoming significant budgetary constraints also in the longer run (EC, 2013; IEA , 2011).

2. How can the perspective of different actors and target groups be considered in the policy evaluation process to support the policy planning and decision-making?

The perspectives of stakeholders, market actors as well as target groups consists a central element affecting the policy planning and design of energy PIs and much required to address existing obstacles to EE policy and technology diffusion (please refer to Section 1.5). We have demonstrated the significance of different actors' perspectives and ways in which these could be considered into concrete policy planning and design procedures in all **evaluation components** of our methodological framework. In **Chapter 3**, a MCA framework for assessing and selecting EE PIs is presented which incorporates actual preferences of decision-makers in the analysis. MCA provides a transparent tool to consider the multiple aspects of the decision problem (Gamper et al., 2006; Grafakos et al., 2010) allowing the inclusion of multiple criteria, policy priorities and goals. It is capable of integrating into the analysis different stakeholders' preferences so as to stress different perspectives. For this type of analysis, we rely on a stakeholder survey conducted among experts and policy makers in the field. To determine group priorities and trigger the discussion on how certain "types" of stakeholders tend to prioritize over certain policy parameters (i.e. criteria), the various stakeholder profiles were considered for the application of cluster analysis. The results reveal three distinct weighting strategies indicating rather standout concerns in the range of expressed opinions: ***A)*** *Practical priorities concerned*: The first group of actors put most emphasis on issues concerning the practical implementation of PIs, ***B)*** *Holistic cost-effectiveness concerned*: This group of actors allocates emphasis on intended or unintended policy effects as well as on the associated costs incurred due to policy intervention and ***C)*** *Cost and market competitiveness concerned*: Finally, the last group considers that successful policy implementation heavily relates to the return on investments (i.e. yielded benefits and costs on investment-projects due to policy intervention). The evaluation results were obtained by implementing a MCA for each strategy.

In **Chapter 4**, we take a deeper look at the one of the most important target groups of financial subsidies for EE, namely residential end-users, to get more insights into their preferences as well as their indigenous characteristics relevant to targeted policy outcomes of technology adoption. We develop a theoretical model on factors driving technology ownership of various EEMs in the Greek household sector. We test this model empirically with more than 1500 observations from a recent on a National Household survey in Greece. We then use the empirical model to simulate the additional effect of financial subsidies on technology adoption trends for different income levels. By focusing on a variety of high-to low cost measures our analysis adds to the empirical evidence on factors driving adoption of EEMs. Our results confirm the positive correlation among technology ownership and household location, size, year of construction and dwelling types for a variety of EEMs in the Greek households sector. The choice of heating fuel and thus associated energy costs also appear detrimental in the propensity for technology ownership and thus future adoption of EE measures. Whereas for features such as climatic zone, income and age we corroborate earlier findings from literature in investments and adoption of EE improvements, indicating that the influence of the latter is rather inconclusive or technology specific. The empirical model also extends prior knowledge on EE technology adoption by providing evidence that households familiar with synchronous and advanced technologies are more likely to own smart EE features, whereas households with elderly tenants were found to negative correlate with owning a room thermostat. These findings should be considered especially in view of the eminent recast of the EPBD entailing increased attention on the smart performance of the Greek building sector. Government planning should thus consider that technology ownership, and therefore potential adoption of EEMs, is differentiated with regards to such consumers' socio-economic and demographic characteristics.

In **Chapter 5** of this thesis we make use of the information from the National Household survey as well as additional evaluation studies from the literature to estimate programme participation rates for alternative financial subsidy scenarios which corresponding to different income eligibility categories. We combine these estimates with estimates on future market trends to calculate the long-term savings potential until 2030 that can be pragmatically tapped by different financial subsidy scenarios in the Greek household sector and for alternative EEMs. This approach allowed us to include a behavioural realism aspect to our estimates of potential savings for EEMs promoted through financial subsidies which is usually not included in engineering or techno-economic assessments. Our estimated programme participation rates express net-to-gross ratios and are formulated so as to reflect the savings potential that exist for individual EEMs as well as for each financial subsidy scenario and income-eligibility category. Therefore, our estimates on the potential for energy savings and the required investments to materialize them are differentiated per EEM and subsidy scenario/income eligibility category, embedding in this way consumer preferences over a variety of high-to-low cost EEMs as well as consumer intrinsic characteristics relevant to their disposable income. Finally, the view from policy makers was embedded in this step in the form of validation for key outputs from the assessment framework and support the data-collection process best reflecting the past as well as the future implementation of PIs. Our results suggest that LED lamps, Efficient cooking ovens, condensing natural gas heating systems and windows replacement seem to hold a significant share of savings, whereas SOL_HEAT systems present significant savings potential yet only under the highest subsidy level and from a social evaluation perspective. Electrical appliances with a higher efficiency rating (e.g. WASH_A++, DISH_A++) remain rather unexploited across all subsidy levels, while roof insulation, LED lamps, NG boiler upgrades and TRV systems remain cost-effective and are fully exploited across almost all financial options. According to our calculations, 190 to 461 ktoe of cumulated first year final energy can be realized cost-effectively by 2030 through a 7-year financial subsidy depending on the subsidy rate. This translates to a contribution of approximately 3 to 6% to the national target set under Article 7 for 2030 (i.e. target range of 7.3 Mtoe) (MEE, 2019). When accounting for the additional benefits associated with energy security, final energy savings are uplifted by 1.5% to more than 22% under the highest subsidy-scenario. The present value of total funding costs to materialize these benefits range from 28 M€ 2018 to more than 438 M€ 2018.

3. Which key factors should be taken into account when designing effective EE PIs?

As highlighted in the previous sections, policy underperformance or unintended policy outcomes can be explained by the occurrence or lack of favorable or impeding factors and market barriers occurring during their implementation. This research question refers to key issues concerning the design and planning of EE PIs and for this reason is analyzed from different perspectives and is dealt in all evaluation components of our proposed framework. **In Chapter 3**, we present an evaluation MCA framework, through which PIs can be evaluated against process-related criteria.

Making use of our methodological considerations in Chapter 2, in Chapter 3 we identify the following key performance criteria:

- **Incentive to invest/comply** is defined as the strength of the incentive provided to invest/comply with the policy.
- **Familiarity** refers to public awareness regarding the existence, operation and terms associated with the PI as well as its yielded benefits.
- **Fairness** in distribution principles is defined as the fairness of the PI in distributing compliance costs and benefits among target groups.
- **Adaptability to exogenous changes** is defined as the property of the PI to be flexible in case of exogenous market signals.
- **Transaction costs** are considered to be the costs accompanying transactions during execution of policies and do not concern costs directly related to project implementation (such as investment or administrative costs) (Mundaca, 2007).
- **Institutional management and coordination** refers to the coordination and management links among pertinent governmental authorities that ensure regular information flows resulting in accelerating procedures.
- **Compatibility with the national policy strategy** refers to absence of contradictions or evidence of synergies with energy and climate policies as well as policies of the broader national policy framework.
- **Institutional set-up and capacity** is defined as the capacity of governmental authorities to implement a PI.
- **Monitoring and control** refers to the activities performed in order to identify non-compliance, delays or other barriers and enforce the PI.
- **Financial Viability** refers to the ability of the instrument to be administered and funded with low overall costs by the regulatory authorities.

Through a MCA decision-support framework we then evaluate PIs against the aforementioned criteria to identify successful policy practices during the implementation phase as well as to unveil cases of policy underperformance or unintended policy outcomes. The MCA results showed that the country under assessment (i.e. Greece) is still missing significant energy saving opportunities in the building sector that could be reached through more streamlined implementation practices and political support. In times of fiscal crisis, the Greek government should also revitalize the implementation of alternative funding mechanisms and support policy alternatives such as green public procurement, voluntary agreements, and energy performance contracting.

In **Chapter 4** we recognize that EE PIs, all the more financial support PIs, promoting the adoption of energy savings technologies risk of being ineffective or unsustainable, should they do not consider the relative characteristics of potential adopters in the market, along with their needs and preferences. We thus introduce a theoretical model for predicting the technology-relevant behaviour for residential end-users which accounts for a variety of contextual factors, such as dwelling demographics, socio-economics characteristics, householders' attitudes and behaviour etc., as well as the influence of financial support policies. We test this model empirically to get an estimate of the incremental effect of financial subsidies in the adoption of a variety of EE measures while accounting for the influence of aforementioned factors in driving the observed adoption rates. Our results confirm prior evidence on traditional determinants of technology adoption and extend those by validating that households familiar with synchronous and advanced technologies are more likely to own EEMs with smart features. We were also able to highlight the positive influence of participation in a subsidy as well as other support programmes for vulnerable consumers in households' ownership of EEMs. Our results are then used to simulate the change in technology ownership rates due to participation in a subsidy programme and for three distinct income levels. These suggest that the probability for technology ownership is greater for higher income households benefitting from a subsidy and for almost all EEMs. Nevertheless, the change in the probability of technology ownership due to the subsidy is larger for lower-income households participating in the programme, further encouraging thus support for financial policies targeting lower income households. Financial incentives should thus continue to target primarily lower income households, although these may also take other forms than grant schemes such as on-bill financing or tax-rebates. For the latter, these should be designed so that lower-income households can indeed benefit from such incentives and that these have a progressive rather than a regressive effect.

Finally, in **Chapter 5**, we apply the insights and evidence from analysing Household survey data to perform a cost-benefit assessment of EE financial subsidies under Article 7 of the EE so as to estimate their long-term EE potential. To do so we adopt a methodological framework that determines a portfolio of EEMs that considers consumer preferences and technical as well as feasibility constraints for the different technologies realizing this potential. The methodological framework accounts for the following key elements required to perform the assessment per EEM and financial subsidy scenario:

- setting the **scope** that is addressed by the instrument under assessment in terms of fuels sources, sectors, end-uses and end-use technologies depending on market availability and future potential
- determining **the baseline final energy consumption** which is of particular significance since under Article 7 only energy-savings that go beyond a certain energy performance standard defined by the baseline can be considered additional
- determine **policy additionality** which translates to energy-savings that can attributed to financial subsidies. These should go beyond an autonomous development which occur in the absence of the policy either due to the general technical progress or due to existing EE policies setting minimum efficiency standards
- the **rationale for accounting energy savings under a programme portfolio of EEMs**; this is a precondition for an effective and efficient design of a new energy policy since we demonstrate that the savings potential and CE of the financial subsidy can vary significantly, depending on the rationale and approach for determining the final portfolio of EEMs

Through the use of the Savings to Investment Ratio (SIR) we then evaluate the long-term savings potential for the variety of EEMs under consideration and for the three alternative financial subsidy scenarios under assessment. As we already concluded, 190 to 461 ktoe of cumulated first year final energy can be realized cost-effectively by 2030 through a 7-year financial subsidy depending on the subsidy rate. This translates to a contribution of approximately 3 to 6% to the national target set under Article 7 for 2030 (i.e. target range of 7.3 Mtoe) (MEE, 2019). When accounting for the additional benefits associated with energy security, final energy savings are uplifted by 1.5% to more than 22% under the highest subsidy-scenario. Notably under the programme level test, the sum of energy cost savings is lower than under the measure CE test and across all subsidy levels.

This is mainly due to the inclusion of EEMs with lower cost-savings (e.g. oil & NG EEMs result is smaller energy cost savings that electricity savings) under the portfolio of EEMs to materialize the savings. However total programme benefits are uplifted through the ancillary benefits due to improved energy security, that are larger under the CE Programme and especially under the higher subsidy rates. This underlines the influence of the inclusion of fuel-switching measures and especially to non-imported fuels (i.e. BIO_PEL, SOL_HEAT and GEO_PUMP) to the portfolio's collective CE. To achieve these potentials, the public budget would have to provide up to 600 million € for incentive payments. The equivalent level of private investments required to materialize these savings were found to be equally high (i.e. 348 million €) yielding a total benefit of 1 billion €, out of which 16% relate to ancillary energy security benefits. Under more conservative rates (i.e. 15% or 35% subsidy rate) 3 to 4% of the total savings target set could be achieved at a much lower cost of approximately 30 to 112 million € accrued to the public budget. The proposed level of public spending for the 2018–2030 period to yield the estimated energy savings, especially under the highest subsidy rate, consists definitely a challenge both for the public budget as well as private households.

4. How to assess and quantify the net effects that can be attributed to EE PIs, while accounting for non policy determinants and consumer heterogeneity?

This sub-question is similar to the previous one, but it turns the focus from the types of determinants and their influence on policy effects back to the methods applied to capture these within a policy evaluation framework. Determining net policy impacts or additionality consists one of the most difficult issues in policy evaluation and still remains a very challenging issue (Voswinkel et al., 2018). To operationalize the assessment of policy additionality and translate these effects into quantifiable energy savings, we assess policy additionality from two perspectives.

First in **Chapter 4**, we discuss ex-post evaluation approaches that have been applied in a variety of datasets to determine the additional effects for such PIs on the household sector and highlight the advantages and problems of these methods in determining the additional effect of policy interventions. The most frequently adopted in EE policy evaluation practice include: Randomized Controlled Trials (RCTs), Quasi-experimental designs, Survey-based approaches and Deemed or stipulated Net-to-Gross ratios. In our analysis, we adopt a survey-based approach and develop an econometric model to assess the additional impact of financial subsidies, in terms of change in the probability of technology ownership of EEMs. Technology ownership constitutes one of the key determinants of technology-related behaviour that has been found to positively correlate with technology readiness and acceptance (Godoe and Johansen, 2012). It is thus important to understand the key determinants of ownership of different EEMs, from the more mature ones (e.g. thermal insulation, etc.) to the less (e.g. room thermostats, etc.). We apply a discrete choice econometric model to determine the marginal effect of financial subsidies on technology ownership for EEMs. The model is formulated appropriately so that the effect of the variable in question (i.e. y participation in the "ESH" subsidy programme) is treated as an explanatory factor among others influential over technology ownership. We make use of a nationally representative data-set for Greek households from the "Survey on the Energy Consumption in Households (SECH), 2011-2012". These essentially consist RP data with regards to households' technology ownership which we couple with discrete choice modelling. To the best of our knowledge this is the first time that the "SECH 2011-2012" data are coupled with a discrete choice model to analyse the key determinants of the technology-relevant behaviour of households and the ownership patterns of several EEMs in the residential sector in Greece. The empirical model is then applied to conduct Monte-Carlo simulations for different scenario formulations (i.e. with or without the policy) to further explore the additional effect of the policy for different income level households. For the simulations, all the control variables are simulated according to their empirical distribution, assuming that a change in the programme participation would not affect other model parameters.

Then in **Chapter 5**, we focus on ex-ante assessment frameworks and present an overview of methodological approaches to quantify the additional EE savings that can be attained by EE PIs. In efficiency potential studies, the technologies market share is often calculated as a function of the payback time, benefit to cost ratio or other CE metric (e.g. levelized measure cost) of the efficient technology relative to the inefficient technology. Although such evaluation methods include considerable limitations, they are directionally reasonable and straightforward enough to allow estimating of the market share for the multitude of technologies that are assessed in EE potential assessments (Navigant, 2017). Based on these methodological insights we adopt an approach whereby the increase in technologies' market share due to a financial subsidy is calculated as a function of the SIR of the efficient technology relative to the inefficient technology. A financial incentive offered in the form of a subsidy will reduce the higher costs of the more efficient technology and increases the SIR of hi-efficiency products. With a higher SIR, the product sales of higher efficiency technologies are assumed to increase proportionally to a net-to gross ratio, which is deemed according to consumers' past response rate to similar financial incentives offered for investing in EEMs. The net-to-gross ratio consists a literature-based estimation approach that relies on market averages and secondary data. It is recognized by EE policy evaluation studies as an approach to use in case of low data availability or strong budget constraints, to give a first estimate of net policy effects (Voswinkel et al., 2018). To estimate the measure-specific consumer response to a financial subsidy, we use secondary data from the National Household survey conducted in Greece (ELSTAT, 2013b) as well as information from past programme evaluation studies. The proposed bottom-up economic-engineering framework focuses on the direct and indirect learning effect that a PI may bring about on efficient technologies in the market, which can affect the diffusion of energy-efficient technologies and their CE in the long-run. The proposed framework: (i) enables the attribution of energy savings to EEMS for which a direct link can be established between the causality mechanism of financial subsidies (i.e. cost reduction) on the acting decision (i.e. technology adoption) and (ii) allows the inclusion of empirical observations to increase transparency and validity in the evaluation results. The results and insights then are discussed to suggest ways for more targeted and effective programme design per EEM, subsidy scenario and income eligibility category under assessment.

5. What are the net effects that can be attributed to financial subsidies and how can these support the process of policy planning & (re-)design?

As already discussed in the above-research question (i.e. see question 4), we adopt a two-fold approach to determine and quantify the net effects that can be attributed to a financial subsidy. The quantifiable net effects of these assessments are presented along with each evaluation approach undertaken, whilst we discuss how these can facilitate the policy planning process for more effective PIs.

First in **Chapter 4** we adopt a survey-based approach and conduct an ex-post evaluation for quantifying the additional policy outcomes (i.e. technology adoption) of financial subsidies, accounting for the diversification of these outcomes across EEMs and characteristics of target groups. Our results essentially express the influence of a variety of factors in predicting/explaining the probability of owning alternative of EEMs. These confirm the positive correlation among technology ownership and household location, size, year of construction and dwelling types for a variety of EEMs in the Greek household sector. The choice of heating fuel and thus associated energy costs also appear detrimental in the propensity for technology ownership and thus future adoption of EE measures. Whereas for features such as climatic zone, income and age we corroborate earlier findings from literature in investments and adoption of EE improvements, indicating that the influence of the latter is rather inconclusive or technology specific. The empirical model also extends prior knowledge on EE technology adoption by providing evidence that households familiar with synchronous and advanced technologies are more likely to own smart EE features, whereas households with elderly tenants were found to negative correlate with owning a room thermostat. These findings should be considered especially in view of the eminent recast of the EPBD entailing increased attention on the smart performance of the Greek building sector. Government planning should thus consider that technology ownership, and therefore potential adoption of EEMs, is differentiated with regards to such consumers' socio-economic and demographic characteristics. Since there is a limit in the public budget available for financial support, policy makers may thus need to prioritize the types of houses that are both more energy-intensive, as well as more inclined to invest in EEMs. From a utilities' perspective, hybrid marketing campaigns targeting segments of householders with different needs and aspects of lifestyle should also be introduced. Financial as well as other types of incentives should target beyond the obvious promising market segment of middle-class owner-occupied single-family households, and new solutions may need to be found in, for example, owner-occupied and rented multifamily buildings. The renter's split-incentive dilemma remains unsolved and need also to be accounted for, as our results acknowledge that renters are less likely to adopt EEMs, and when they do, they focus on easy-to-install, mobile options, with limited energy saving potential.

In addition, we estimate the marginal effects of the explanatory variable of participating in the "ESH" subsidy programme on technology ownership. Our results suggest that households receiving financial support in the form of a grant combined with a soft-loan through the "ESH" programme, are more likely to own room thermostats, thermal insulation, EE window systems and lighting bulbs, while are less likely to own shading systems. Especially for the case of EE window systems the corresponding marginal effects indicate about 17 percentage points of more likelihood of technology ownership. This was expected as retrofit windows was one of the main actions eligible under the programme.

Finally, we use the empirical model to simulate the change in technology ownership rates due to participation in a subsidy programme and for three distinct income levels. In tandem, our results suggest that that there is a great deal of heterogeneity in the impact of the "ESH" programme in technology ownership rates and that ownership for more mature EEMs that are easy to install and operate was positively affected, especially during the phasing-in of the programme. Therefore, public subsidies can potentially help to overcome credit constraints and prompt ownership of EEMs, yet owing to the large variability in our estimates, this conclusion cannot be stated with the appropriate level of statistical confidence. When differentiating our simulations for different income levels, these suggest that the probability for technology ownership is greater for higher income households benefitting from a subsidy and for almost all EEMs. Nevertheless, the change in the probability of technology ownership due to the subsidy is larger for lower-income households participating in the programme, further encouraging thus support for financial policies targeting lower income households. Financial incentives should thus continue to target primarily lower income households, although these may also take other forms than grant schemes such as on-bill financing or tax-rebates. For the latter, these should be designed so that lower-income households can indeed benefit from such incentives and that these have a progressive rather than a regressive effect.

In **Chapter 2** we have discussed that ex-ante policy evaluations and more in particular EE potential assessments facilitate the development of EE plans and are relevant especially for the (re-)design of single PIs promoting EE. They can offer a realistic view of what might occur within a certain context due to a policy intervention and essentially due to the allocation of funding, which can be useful for EE planning purposes of public-support programmes or utility integrated EE plans. In **Chapter 5,** we use a bottom-up, economic engineering approach to calculate the achievable potential that can be attributed to alternative financial subsidy scenarios when applied in the Greek household sector. This enable the quantitative evaluation of the suitability of different subsidy rates to meet the national energy savings targets as well as their potential to fulfil the requirements from the side of utilities in view of the recent introduction of the EEO scheme in Greece. Our analytical results demonstrate that EE potential could be integrated in the policy as well as resource planning and (re-)design process of PIs as a key element supporting this process by proving strong analytical grounds required to develop an effective EE policy strategy. We coupled our economic-engineering approach to a CE evaluation based on the SIR index for determining a portfolio of EEMs to realize this potential. In fact, CE is examined by estimating the SIR from three perspectives:

- **participant perspective:** savings include and are limited to all fuel energy savings occurring throughout the project's EUL while investments are narrowed down to net investment costs (i.e. equipment and installation expenditures account for incentives or potential rebates) as well as other maintenance costs expected to occur through the EUL of the EEMs.
- **program perspective:** savings include energy savings as in the participant SIR. Investments are extended to include programme administrative and overhead costs along with the equipment and installation expenditures.
- **societal perspective:** compares society's costs of EE to resource savings while including non-cash benefits and costs. Savings include energy savings and are extended to include monetary values of non-energy benefits and investments include the same investment costs as in the program perspective. Societal SIR also uses a lower (i.e. social) discount rate than the other two perspectives. For non-energy benefits, we include additional cost savings resulting from the reduction in energy imports and improved national energy security.

Such an approach thus captures both the cost-effective potential from the side of consumers while also considering total programme CE. It also reflects gaps in existing knowledge on the savings potential for financial subsidies under Article 7 of the EED and in part informs future financial support programmes for demand side management in Greece. The latter is attained by offering an estimate of the achievable programme potential that would more accurately reflect the energy savings opportunities that can be attributed to a financial subsidy in the Greek household sector under no budget restrictions. This type of CE evaluation is important in the context of the "economic potential" notion, since most policy planning practices require that EEMs to be included in a programme portfolio to be financially cost-effective. Therefore, it becomes increasingly important to determine the dimensions and perspectives under which EEMs can be evaluated as financially attractive and showcase how to expand the traditional CE evaluation to include monetized ancillary non-energy benefits. From our evaluation in Chapter 5, we demonstrate that more ambitious savings potential is to be anticipated when conducting an evaluation of what is possible to achieve in the form of EE potentials. We also show that an EE potential assessment study, when coupled with a CE evaluation may assist in the comparison of different policy development scenarios with regards to their efficiency in delivering the anticipated EE potential and ultimately facilitate in their (re-) design to improve their CE overall.

Our assessment of the EE potential for alternative subsidy scenarios in the Greek household sector suggests that financial subsidies can play a significant role in driving residential EE investments in the household sector, especially when considering ancillary benefits such as energy security related ones. As we already concluded, 190 to 461 ktoe of cumulated first year final energy can be realized cost-effectively by 2030 through a 7-year financial subsidy depending on the subsidy rate. This translates to a contribution of approximately 3 to 6% to the national target set under Article 7 for 2030 (i.e. target range of 7.3 Mtoe) (MEE, 2019). When accounting for the additional benefits associated with energy security, final energy savings are uplifted by 1.5% to more than 22% under the highest subsidy-scenario. This potential can be used to set the long-term EE target for financial incentives under Article 7 as well as to determine the contribution of such type of incentives included in the PI mix of alternative measures as well as EEOs to meet with Article 7 requirements. Then we estimate the costs for realizing such potential and for the three subsidy rates, i.e. from the more conservative rates of 15% to 35% to the more generous ones of 70%.

Whether this potential will be exploited depends primarily on the state-budget available. According to our estimates, to achieve this potential, the public budget would have to provide up to 600 million € for incentive payments. The equivalent level of private investments required to materialize these savings were found to be equally high (i.e. 348 million €) yielding a total benefit of 1 billion €, out of which 16% relate to ancillary energy security benefits. Under more conservative rates (i.e. 15% or 35% subsidy rate) 3 to 4% of the total savings target set could be achieved at a much lower cost of approximately 30 to 112 million € accrued to the public budget. The proposed level of public spending for the 2018–2030 period to yield the estimated energy savings, especially under the highest subsidy rate, consists definitely a challenge both for the public budget as well as private households. Notably, the funding requirements to capture the estimated savings potential under the highest subsidy cases are more ambitious and costly than the budget foreseen by the Ministry for the continuation of the financial support 'ESH' programme. These are estimated to be almost twice as high as the funds allocated for an equivalent 7-year implementation period. Accounting for the aforementioned budget constraints, government support should continue to be pivotal in driving EE investments, yet it needs to target a portfolio comprising measures higher in the CE ranking such as highly efficient condensing boilers, particularly fuel-switching ones to NG as well as heat pumps, LED lamps and TRV systems. These are supported by highly-favourable participant SIR even under the lowest subsidy levels and also present significant programme market potential until 2030. In addition, according to our model and assumptions, higher adoption rates and thus programme potential are also estimated for less cost-effective, yet more mature technologies such as efficient window-frames with double glazing, solar heaters, and roof insulation measures. This may contradict consumer preferences over measures, for which their savings potential and thus CE is considerably lower under the stricter eligibility and materiality requirements of Article 7. The preference over these technology categories has also been recently demonstrated by findings on the frequency of measures across applications during the first months of continuation of the ESH programme under Article 7 of the EED (Tsalemis, 2018). Financial incentives may thus need to take the form of direct subsidies (i.e. grant schemes) for less mature measures while for more mature ones, financial support could be offered in the form of tax-deductions or through on-bill financing. With regard to the latter, focus should be placed on the newly launched EEO scheme for the development of appropriate financing tools as well as for the diversification of the portfolio of measures to include demand-response schemes. Finally, the portfolio of EEMs should be diverse enough to tap harder to reach savings potential and should be formulated to target packages of EEMs which ensure the programme CE collectively.

When it comes to programme CE, all subsidy scenarios considered to promote the portfolio of EEMs were found to be cost-effective within a strict or societal evaluation framework. The most cost-effective subsidy scenario was deemed to be the most generous one, both under a strict or societal CE framework, since higher adoption rates are assumed to be driven by higher subsidy rates that increase the measures' SIR for the participants. Nevertheless, CE may decline from a program-administrator or non-participant perspective. In addition, as the level of the subsidy goes up, larger differences can be observed in the assessed programme SIR. In fact, when comparing CE across evaluation perspectives, the more moderate subsidy scenario (i.e. FI2-35% - MEAUSRE) was deemed more cost-effective than the more generous one (i.e. FI3-70% - PROGRAMME). This suggests that total programme CE is highly dependent on the rationale for determining the cost-effective potential and the subsequent types of measures included in the final portfolio eligible for support.

After summing up the main findings for the sub questions, we now return to the central research question of this thesis:

- How can the policy planning and design of effective EE PIs be improved by evidence-based evaluation frameworks and practices?

To answer this overall question, we refer back to the conceptual framework of this dissertation thesis that we developed in the Introductory section (i.e. Section 1.2), where we embed PI evaluation practices within and in relation to the policy cycle process. A concrete evidence-base is created to support each evaluation including: a thorough review of policy evaluation literature, implementation guides and official NEEAPs and market reports across the EU, key stakeholders and policy-makers perception as well as representative survey data

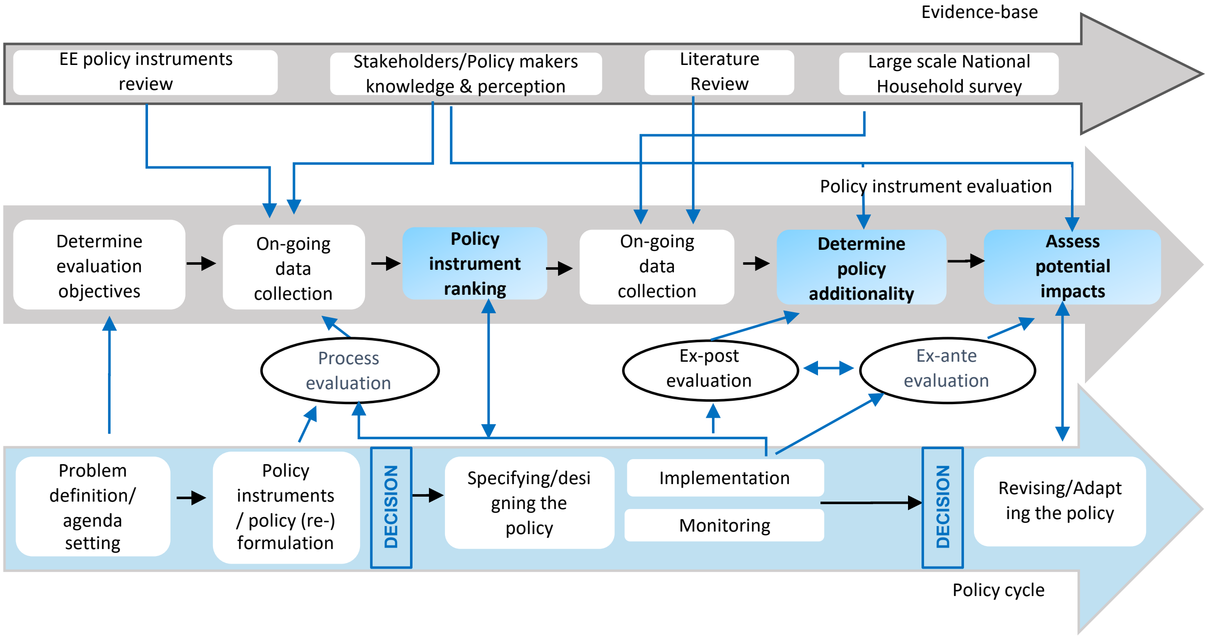


Figure 6.1 Conceptual framework of the thesis

The unit of analysis and the central point of the conceptual framework of this thesis concerned EE PIs. EE PIs are the mechanisms which determine how to foster or oblige energy end-use consumers to adopt energy savings actions and meet desired policy targets and objectives. PI target setting and (re-)design are thus highly interlinked to the monitoring and evaluation steps of the policy cycle. We have identified two key points in this policy cycle, where policy decision making takes place and where decision-support frameworks are most required. These concern the point of PI selection to materialize the set targets as well as the point after policy implementation, when policy evaluation is more than necessary to facilitate and support improvements and revisions in the PI mix, based on evidence and ex-post monitoring performance data.

To support the problem of effective PI (re-)design towards their more effective implementation, first we demonstrated how the policy monitoring and evaluation system can be improved so that progress towards interim policy outcomes can be assessed. Apart from the potential of the PIs to achieve a certain amount of energy savings, a variety of process evaluation criteria should also be accounted for. Alongside cost and savings aspects, other interim outcomes and considerations include: (i) the level of Incentive to invest/comply (ii) fairness in distributing compliance costs and benefits among target groups, (iii) compatibility with the national policy strategy, (iv) financial viability as well as other issues which describe the potential for a policy mechanism to overcome barriers and market failures to attain its saving potential. These can be assessed discretely through the establishment of appropriate qualitative evaluation criteria and semi-quantitative assessment scales. To integrate these insights into the policy planning stage, we propose the adoption of a multi-criteria evaluation approach that makes-use of key actors' viewpoints and experience on the functionality of the PIs under assessment. Through such an approach more robust results are fed back into the decision-making step of assessing and ranking PIs based on their ease of implementation increasing thus their potential for effective performance.

Next to move towards more efficient and effective policy (re-) formulations, we demonstrated how to assess the additional outcome that can be attributed to a PI (i.e. financial subsidies) by accounting for the social and behavioural context within which EE investment decisions occur. During this process, non-policy factors need to pragmatically be considered when formulating a PI which further points out to the evidence that need to be collected to adequately support the process of evaluating and adapting a PI (see figure 6.1). Evaluation frameworks thus need to account for social as well as behavioural factors influential over the targeted policy outcomes and establish direct links between the PI under evaluation and the acting decisions in the policy planning and design process. We conclude that there is a need to better understand and predict technology-relevant behavior for targeted end-users, and to better integrate these aspects in the policy planning and design process, since such factors hold significant implications for the CE of PIs. We recommend an ex-post evaluation on the grounds of a survey-based approached to appropriately quantify the additional policy outcomes while accounting for the diversification of these outcomes across EEMs and characteristics of target groups. Through survey-based approaches and appropriate ex-post evaluations, a better account for the barriers to EE can be identified for stakeholder groups that play a decisive role in the effective implementations of EE PIs.

We also found that the policy instrument planning process needs to be supported by suitable methods for its monitoring and evaluation to allow for a more pragmatic assessment of the long-term EE potential that can be captured by EE PIs. A significant conclusion drawn is that, the achievable EE potential that can be attained by a PI, is highly dependent on the rationale for determining the cost-effective potential and the subsequent types of EEMs included in the final portfolio eligible for support. This is primarily because CE estimations are highly sensitive to what benefits and costs are added in the numerator and denominator of the SIR approximations, and the latter can be uplifted through the careful consideration of ancillary non-energy costs and benefits. To design a PI that is suitable for exploiting the entire CE savings potential, bottom up evaluation frameworks need to be adopted that will include behavioural and social realism aspects to their estimates. The evaluation approach and data requirements need to be considered in the beginning of the policy planning process to assure that the monitoring activities and appropriate evidence and data required to conduct a more pragmatic evaluation, become available.

Finally, an effective process for PI design necessitates the consideration of the views and standpoints of different stakeholders, market actors as well as target groups. In this thesis, we demonstrate this for national policy makers, key market actors as well as research-experts in the energy and building sector. For designing effective financial subsidies, apart from the policy makers' perspective we integrate the preferences and characteristics of the main group of targeted end-users that are crucial to the effective operation of financial PIs.

6.3 Overview of Thesis Contribution

By challenging common evaluation approaches and methods developed to assess EE PIs, this dissertation contributed to the EE policy evaluation literature by developing individual decision-support methodologies comprising an integrated methodological evaluation framework. These aimed to support national policy makers as well as utility-programme implementers in a variety of ways during the policy planning and design of effective EE policy instruments and comprised multi-criteria analysis, a survey-based econometric approach, and a bottom-up, economic-engineering, assessment framework (see Figure 6.2).

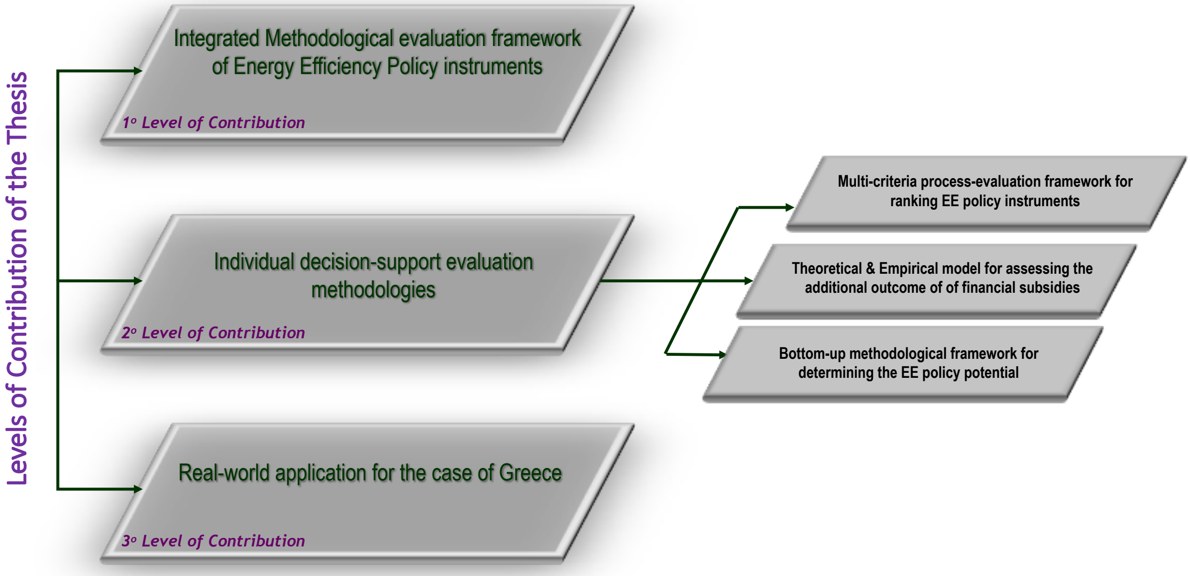


Figure 6.2 Summary of thesis contribution

The thesis began with a review of the multitude of methods applied to assess energy policy instruments and their mixes and discuss the advantages as well as drawbacks of using each type for method, in relation to their evaluation focus and overarching evaluation design (**Chapter 2**). We found that the majority of past research in energy policy evaluation has been focused on assessing the potential or observed outcomes and impacts that can result from policy interventions, and very few of them have turn their focus on earlier stages in the policy life-cycle. Consequently, the methodologies and evaluation practices developed to date to support the design of effective EE PIs were found to rarely focus on discrete stages of the policy cycle to successively account for the context within which they are implemented. We concluded that evaluation approaches need to extend the traditional "goal-achievement model" to fine tune the performance criteria in accordance to their context (Spyridaki and Flamos, 2014),(Spyridaki et al., 2016b). Evaluation frameworks should also combine qualitative and quantitative information based on empirical observations and incorporate both ex-ante and ex-post viewpoints. Such frameworks would then be able to provide a better understanding of how and why a (set of) PI(s) was or can be effective and how it might be reconfigured to make it more cost effective in the future.

Accordingly, the third research chapter (**Chapter 3**) developed a qualitative evaluation framework of EE PIs through MCA against criteria reflecting their performance during the implementation process in the policy cycle. The majority of multi-criteria policy evaluation studies adopts a rational view on policy and assess PIs by estimating their impacts and congruently their effectiveness as a result of their implementation. In addition, most multi-criteria evaluations tend to focus primarily on the assessment of policy impacts. Hence most multi-criteria policy evaluations carried out use criteria, which concentrate largely on policy effects and to a lesser extent on policy processes and implementation (Spyridaki et al., 2016a), (Popiolek and Thais, 2016). The MCA evaluation framework outlined in the third chapter, extends research on MCA policy evaluation literature as it comparatively evaluates and ranks PIs by focusing on how these have performed during the implementation stage. The evaluation problem was thus set not to identify the "best" performing policy since PIs were not considered as mutually exclusive solutions to the problem. Instead, the objective of the policy analysis was to rank actions (i.e. PIs) so as to exploit results obtained and elaborate on policy recommendations of effective policy implementation and underline aspects that hinder lower-ranked PIs. From the ranking of PIs, the highly ranked PI (i.e. financial subsidies) was selected to be thoroughly assessed in the following steps.

The following two research chapters (i.e. **Chapters 4 & 5**) were then focused on the quantification of the potential outcomes and impacts that can be attributed to the selected PI (i.e. financial subsidies). The fourth research chapter (**Chapter 4**) attempted to quantify the additional outcome of financial subsidies through a survey-based approach and discrete choice modeling. Stated-preference survey-based approaches are usually applied to provide relevant insights on the characteristics of technology adopters and assess the influence of policies on technology adoption. A major point of differentiation is that our study used revealed preferences (RP) survey data regarding households' technology ownership for EEMs. Consumers have a tendency to respond differently in real market conditions than they would have under hypothetical choice experiments (Godoe and Johansen, 2012), whereas the literature examining technology relevant behaviour for EE improvements using RP data is more narrow. Furthermore, in addition to more commonly investigated factors by relevant studies (i.e. demographic, socio-economic and dwelling characteristics), this chapter extended the empirical work on EE investment decisions and consumer behavior by accounting for: households energy conservation behaviour, their readiness for the uptake of smart EE features, as well as the role of subsidy programmes and support schemes in the uptake of EEMs, especially in the case of vulnerable consumer groups. Through such an approach the influence of social and behavioral aspects of EE related decisions was thoroughly investigated, by also including Monte-Carlo simulations to explore how the observed policy outcome (i.e. technology ownership) changes across different income levels.

Following the insights gained from the ex-post evaluation, the final research chapter (**Chapter 5**) was dedicated to estimate, for the selected policy mechanism, the long-term, potential effect in terms of energy savings, CO2 emissions savings, import cost-savings, as well as their monetary benefits and costs to society. Therefore, a third contribution of this thesis stems from the development of a bottom-up, economic-engineering framework to model the multitude of alternative EEMs usually comprising financial subsidy portfolios. The number of achievable potential assessments has been growing, however these rarely include a behavioural realism aspect to the estimates of potential savings for policy induced EEMs, under resource and data-availability limitations that usually restrain policy makers. Our approach accounted for the direct policy effect, the indirect policy effect, as well as for autonomous developments that would have happened in the absence of the financial subsidy, in a consistent and transparent manner. It also incorporated consumer preferences heterogeneity in the modelling of alternative EEMs when prompted by different subsidy rates (i.e. financial subsidy scenarios). This approach also directly supports policy decision-makers and utility planners in the process of selecting the main EEMs for financial support to reach their savings requirements by providing a more realistic portrayal of their savings potential when prompted by financial subsidy scenarios. The proposed analytical framework relies on much less data and uses more simplified assumptions than the detailed and complex formulations used in model-based assessments for EE policies and measures. These are often non-available to most national policy makers and practitioners due to budget and resource constraints and is thus considered an evaluation practice that can be easily adopted and tested alongside model-based evaluation results (when available).

Overall the research chapters, consist stand-alone yet consecutive evaluation parts of an integrated methodological evaluation framework that supports the decision-making process of (re-) designing more effective EE PIs. The proposed evaluation framework maps the current situation with regards to the existing policy instrument mix within a domestic market. This forms the basis for the comparative assessment of PIs with regards to their ease of implementation. This results in the ranking of alternative EE PIs based on evidence of their functionality and ease of implementation. For the highly ranked PI, the proposed framework then evaluates and plans for a portfolio of EEMs to materialize the more pragmatic EE potential by including a behavioral and social realism aspect in those estimates (see Figure 6.3).

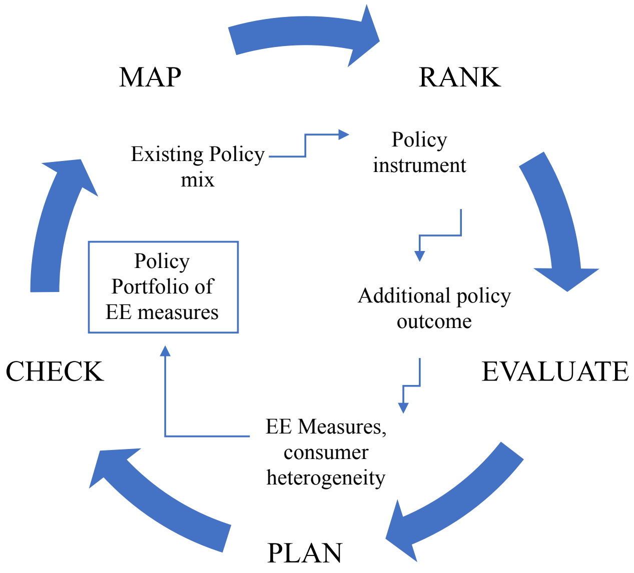


Figure 6.3 Rationale of the proposed approach

Finally, the application of the proposed methodological framework in a real situation (i.e. the mix of national policy instruments and technical measures operating and market available targeting the Greek building and household sector), has allowed the evaluation of the results' completeness and reliability. Most importantly, the methodological framework was developed in close cooperation with national policy-makers and key stakeholders (i.e. technology suppliers, energy agencies and energy utilities). The final contribution of this dissertation thus stems from its national application. The results and insights obtained (as summarized in section 6.2), are quite informative of how EE PIs in the Greek building sector have performed by including aspects on their implementation context to a greater extent than previous evaluations. Most EE evaluation studies for the Greek building sector have thus far provided only some rough estimates on the technical savings potential (Dascalaki et al., 2016), (Georgopoulou et al., 2006), or more recently have assessed the cost-effectiveness (Pallis et al., 2019) of EEMs without the consideration of the effect of PIs. Ex post policy evaluation studies regarding EE PIs implemented in Greece are also scarce and have not yet accounted for the influence of EE PIs on EE technology adoption nor have they zoomed in the existing PI mix to assess their implementation and performance. This thesis contributed to fill this gap by mapping and assessing the current situation with regards to the existing EE policy instrument mix implementing in the Greek buildings sector. This formed the basis for their comparative evaluation that ranked EE financial subsidies on top with regards to their ease of implementation and operation in the Greek domestic market (Chapter 3). An empirical national study of the effect of the "ESH subsidy programme" on EE technology ownership further contributed by scrutinizing the additional effect of the largest national subsidy programme on Greek households' decision to invest in EE (Chapter 4). A final assessment of the achievable long-term EE potential for alternative subsidy scenarios in the Greek household sector suggests that that financial subsidies – as discussed above - can play a significant role in driving residential EE investments in the household sector, especially when considering their ancillary benefits such as energy security related ones. The availability of real as well as nationally representative data and information, collected within the framework of the European projects "APRAISE-Assessment of Policy Interrelationships and Impacts on Sustainability in Europe" and "ENSPOL - Energy Saving Policies and EE Obligation Scheme" determined the feasibility as well as the design of the proposed assessment framework and consist an important element of the proposed approach as well as of the results obtained.

6.4 Prospects for further research

With the completion of the proposed dissertation thesis, a series of thoughts and suggestions for further research in the field of EE PI evaluation has been formed that are presented in brief below.

- Our analytical approach has highlighted the need to distinguish between policy outcomes and final policy impacts (related to target achievement) in the evaluation of EE PIs. We suggest that different stages in the policy cycle should be examined in a more systematic manner through policy performance criteria in their own right to better capture how and why actual policy outcomes differ from intended ones. MCA can facilitate the consideration of a wider set of policy outputs and outcomes based on appropriately defined indicators and criteria enabling policy makers to quantify and assess the results of policy decisions in a wider context.
- When conducting the ex-post policy evaluation (i.e. Chapter 4), data limitations prevented our methodological approach from empirically estimating the exogenous effect of the "ESH" programme in technology ownership across different income levels. Important factors or types of technologies, such as education profiles or motion detector devices were also not included. A more thorough econometric assessment would thus be required to investigate whether the "ESH" subsidy programme in Greece has indeed had a progressive effect on technology ownership and extend this analysis to technology adoption investment decisions as well as other steps in the investment decision-making process relevant to other consumer characteristics such as social norms and lifestyle features. Accurate high-resolution data, stripped of missing values and interview errors, are of paramount importance to reflect on adoption trends and tailor-made strategies to diffuse successfully EEMs. In addition, assessing ex-post the effectiveness of financial subsidies for different types of retrofits, from an econometric perspective and through dedicated surveys targeting a representative sample of programme participants examining whether they would have participated in the absence of the programme (i.e. free ridership) or how much they consume after the retrofits (e.g. rebound effect), would be off added value. Such a study has not yet been undertaken in Greece and would provide significant insights in the response of Greek householders to financial incentives and the real CE of such incentives.
- During our assessment of the EE potential for financial subsidies (i.e. Chapter 5), we were seriously hampered by the lack of available data to determine past and future estimates of annual sales for hi-EE technologies, which constituted the basis for our evaluation. These can be improved in the future by a more comprehensive data-set to provide a clearer picture of the distribution of market shares between different levels of energy performance and for emerging technologies entering the market. The establishment of a systematic monitoring of sales data at a national level is required to allow for regular analysis based on up-to-date market data towards more effective policy design. This would also allow to account for substitution effects between different products or products of the same technology type yet different in energy class that are not included in the present assessment as data on the distribution of sales across product classes were non-existent for most of the EEMs under evaluation.
- Accounting for additional effects such as, marketing, word of mouth or the influence by social learning, along with the acquisition of new data on end users' actual investment decisions and programme participation, could further help to scrutinize the estimated effect of financial subsidies across different subsidy rates and consumer characteristics.
- In the last part of our methodological framework (i.e. Chapter 5) we demonstrate different ways of using the outcomes to produce CE estimates showcasing how CE estimations are sensitive to what benefits and costs are added in the numerator and denominator of the SIR approximations, and how the latter can be uplifted through the careful consideration of energy security related benefits. Scenario analysis was also applied for different subsidy rates to determine the impact of key assumptions used in the SIR calculations. Nevertheless, the savings potential and SIR calculations at measure and programme level would need to be confirmed by a thorough sensitivity analysis considering alternative economic growth rates, variability in energy prices, fuel escalation and discount rates, energy savings estimates, programme participation rates, investments costs and monetary benefits for import savings.
- The methodological approach presented in this thesis has demonstrated that with the appropriate use of information on total market shares for alternative retrofit options, energy performance before and after measure implementation, it becomes possible to determine which measures should be included in financial support programmes. It also becomes feasible to evaluate more realistically their anticipated impacts, funding requirements and associated benefits. Overall, the portfolio of EEMs to be promoted by financial incentives should not be determined solely on CE considerations since consumer preferences as well as domestic market conditions should be accounted for to avoid implementing less effective or efficient incentives which would fail to tap their realistic EE potential. Most importantly there is a need to take a broader view on the cost-benefit assessments of EEMs by considering ancillary non-energy benefits such as energy security related ones as well as additional ones (e.g. health and living comfort benefits) to further encourage their diffusion and savings potential. Applying a mutli-objective optimization framework to determine the optimal portfolio of EEMs (i.e. characterized by different programme market potential and consumer preferences) to satisfy the programme objectives and/or budget constraints as well as CE thresholds would also improve the proposed methodological framework

- ➢ Finally, the better integration of statistical models to policy planning and evaluation frameworks would be an area of high interest for further research. In essence this would allow to adapt growth scenarios for technology diffusion using probability scaling for estimating a diversified adoption of EEMs. Using statistical models for predictions and correlations between adoptions of different technologies would improve the prediction accuracy of technology adoption for the variety of EEMs usually included in bottom-up assessment frameworks and thus their EE potential assessment.

6.5 Conclusions & Recommendations

In this thesis, we have found a number of indications which suggest that there is still a need for more transparent evaluation frameworks to support the policy planning and design of EE PIs for their more effective deployment and implementation. We have identified the following key elements for improving the (re-)formulation and planning of EE PIs:

- Evaluation approaches and monitoring processes established at the PI level measuring what (qualitative and quantitative) changes are anticipated from the implementation of the PI against transparent assumptions made with regards to the required resources to attain them.
- The documentation of the anticipated performance of PIs beyond target setting, including explanations of the intervention logic for each type of PI in alignment with measurement and evaluation requirements.
- The adoption of multi-criteria evaluation frameworks complemented by properly defined set of indicators and assessment means to measure qualitative aspects characterizing policy processes during the implementation stage of the PI.
- The establishment of periodic, ex-post evaluation requirements of PIs, on the grounds of bottom up and econometric methods and collecting data to assess the assumptions made in the intervention logic with regards to the anticipated policy outcomes and impacts.
- The establishment of bottom-up monitoring procedures making use of existing monitoring and verification practices to provide sufficient, statistical and measure-related data as a key requirement for all evaluation approaches of EE PIs.
- The better integration of stakeholders and target groups relevant to and affected by the entire policy cycle of EE PIs, in the policy planning and re-design phase, by considering their viewpoints on the anticipated policy changes and functionality, as well as their intrinsic characteristics and motivations.
- The proper definition and assessment of the EE potential for individual PIs based on bottom up statistical and measure-related market data to guide the process of effective policy target setting and re-design.
- For budget-intensive (i.e. financial support) PIs, a calculation methodology should be established to explain and document the intervention logic on the grounds of econometric assessments to design the financial incentives, explaining the choice of financial aid (e.g. grant, soft-loan, guarantee etc) as well as the level of incentives (i.e. subsidy rate, interest rate for loans etc.).
- In case of data scarcity and resource constraints, existing evaluations should be fully exploited, and their results should be used as a benchmark for determining the “deemed savings” of a PI provided these savings are specified under similar implementation conditions and target groups.

We believe that, the present timing is a good opportunity for the application of at least some of the aforementioned findings in real EE policy cases. The new framework for National Energy and Climate Action Plans (NECPs) until 2030 along with the requirements for the establishment of a national Long-term Strategy to be regularly revised and updated will allow the establishment of measurable progress indicators reflecting national conditions and measuring the real progress against these. To meet with the regular measuring and evaluation requirements, efforts are foreseen to be undertaken in Greece for the mainstreaming of a centralized monitoring system for EE interventions undertaken across governance levels and implementing structures. For the determination of the long-term renovation strategies, national authorities should also engage and cooperate with key market actors to ensure acceptance and cooperation towards market progress and growth to meet with the national EE objectives. Methods and practices, as developed and presented in this Thesis, to integrate their viewpoints into the policy planning process for determining the long-term renovation strategy in Greece should be considered.

In addition, in September 2019, the EC has introduced, three recommendations to help MS countries put the clean energy transition into practice. The guidelines comprising these recommendations lay out detailed measurement and verification requirements on policy materiality and additionality for different types of EE PIs. These are expected to allow for the establishment of improved monitoring and evaluation procedures at the PI level, which have rarely been undertaken for EE PIs in Greece thus far. It is suggested that systematic ex-post evaluations are conducted, supported by dedicated surveys, especially concerning financial support schemes that have been implemented during the past ten years to promote EE across sectors in Greece.

At the same time, to meet with the increasing energy savings requirements under the EED, the mobilization of adequate financial resources is a key requirement for the scaling up of EE investments in Greece and the achievement of the national EE targets. The public sector is expected to continue to support EE investments during the period from 2021 to 2030, through the establishment of dedicated financial instruments funded from the public budget as well as from European Structural Investment Funds. These should be carefully designed, based on the experience and evaluations of financial support programmes implemented thus far in Greece to properly define the average grant rate to improve the leverage rate of public funds and most importantly the cost-effectiveness of future financial support schemes. The level and type of financing support should also be further differentiated according to the characteristics of the variety of target groups (e.g. subsidies for low-income, energy poor households, preferential loans for private enterprises, tax-incentives for households) in order to mobilize increased financing from the private sector which is more than required to effectively scale-up investments in the next decade.

Effective energy policy planning is thus primarily concerned with optimising the cost effectiveness of PIs, while safeguarding the interests of all stakeholders and keeping the risk of implementation failure at the lower levels. To overcome these challenges to achieve more effective EE policy planning and design, Greek policy makers need improved funding conditions, legal framework and administrative procedures, transparent evaluation methods, streamlined monitoring and verification practices as well as infrastructure, updated databases and tools to support the process of identifying solutions. Ultimately, the creation of conditions for attracting EE investments in Greece can be achieved by the appropriate design rules and verification procedures governing the implementation of each policy measure. Mechanisms to be considered in order to strengthen this framework, should be aligned with consistent monitoring and evaluation practices established on a regular basis. These would standardise procedures and methodologies to reduce the risk of the parties involved, to increase the scale of mainly small and diversified EE projects through aggregation, to set up structures for technical support at a decentralised or central level, to remove legislative and regulatory barriers and to maintain transparent and equitable procedures, competitive or not, across all relevant stakeholders and beneficiaries. The existence of high-quality scientific potential, the great national and international interest in investing in EE and the European initiatives for the direct involvement of the political leaders in the European Union's climate change policy consist the footing that can lead to a better anchoring of EE policies in Greece and across other EU countries.

Appendix

Published articles in (peer-review) Scientific Journals

- Fujiwara, N., van Asselt, H., Böβner, S., Voigt, S., Spyridaki, N-A., Flamos, A., Alberola, E., Williges, K., Tuerk, A., ten Donkelaar, M. "Climate change policy evaluations in the European Union and its Member States: Results from a meta-analysis". Sustainable Earth (in press)
- Reckien, D., Salvia, M., Pietrapertosa, F., Simoes, S.G., Olazabal, M., De Gregorio Hurtado, S., Geneletti, D., Krkoška Lorencová, E., D'Alonzo, V., Krook-Riekkola, A., Fokaides, P.A., Ioannou, B.I., Foley, A., Orru, H., Orru, K., Wejs, A., Flacke, J., Church, J.M., Feliu, E., Vasilie, S., Nador, C., Matosović, M., Flamos, A., Spyridaki, N.A., Balzan, M. V., Fülöp, O., Grafakos, S., Paspaldzhiev, I., Heidrich, O., "Dedicated versus mainstreaming approaches in local climate plans in Europe". (2019). Renewable & Sustainable Energy Reviews. vol 112, 948–959.
- Reckien, D., Salvia, M., Heidrich, O., Church, J.M., Pietrapertosa, F., De Gregorio-Hurtado, S., D'Alonzo, V., Foley, A., Simoes, S.G., Krkoška Lorencová, E., Orru, H., Orru, K., Wejs, A., Flacke, J., Olazabal, M., Geneletti, D., Feliu, E., Vasilie, S., Nador, C., Krook-Riekkola, A., Matosović, M., Fokaides, P.A., Ioannou, B.I., Flamos, A., Spyridaki, N.A., Balzan, M. V., Fülöp, O., Paspaldzhiev, I., Grafakos, S., Dawson, R., "How are cities planning to respond to climate change? Assessment of local climate plans from 885 cities in the EU-28". (2018). Journal of Cleaner Production. vol 191, pp 207–219.
- Stavrakas, V.; Spyridaki, N.-A.; Flamos, A.(2018). "Striving towards the Deployment of Bio-Energy with Carbon Capture and Storage (BECCS): A Review of Research Priorities and Assessment Needs". Sustainability. vol 10, pp 2206.
- Lieu, J., Spyridaki, N.A., Alvarez-Tinoco, R., van der Gaast, W., Tuerk, A., and van Vliet, O., (2018). "Evaluating Consistency in Environmental Policy Mixes through Policy, Stakeholder, and Contextual Interactions". Sustainability. vol 10(6).
- Michas, S., Stavrakas, V., Spyridaki, N-A Flamos, A. (2018). "Identifying Research Priorities for the further development and deployment of Solar Photovoltaics". International Journal of Sustainable Energy. vol. 38, pp. 276-296.
- Anagnostopoulos, P., Spyridaki, N-A., Flamos, A. "A New-Deal for the development of photovoltaic investments in Greece? A parametric techno-economic assessment." (2017). Energies Journal 10(8):1173
- Spyridaki N.-A., Banaka, S., Flamos, A. "Evaluating public policy instruments in the Greek building sector", (2016) Energy Policy, vol. 88, pp. 528–543.
- Spyridaki, N.-A., Ioannou A., Flamos, A. "How can the context affect policy decision-making: The case of climate change mitigation policies in the Greek building sector" (2016), Energies Journal, 9(4), 294.
- Spyridaki, N.-A., Ioannou A., Flamos, A., Oikonomou, V."An ex-post assessment of the Regulation on the Energy Performance of Buildings in Greece & the Netherlands - A cross country comparison". (2015), EE, pp. 1-19.
- Spyridaki, N., Flamos, A. "A paper trail of evaluation approaches to energy and climate policy interactions", (2014). Renewable & Sustainable Energy Reviews. vol. 40, pp. 1090–1107.
- Oikonomou, V., Flamos, A., Spijker, E., Spyridaki, N.-A., van der Gaast, W. (2012). "Domestic offset projects, in the built environment", EE, vol. 5, no. 3, pp. 335-350.*
- Oikonomou, V., Flamos, A., Spyridaki, N.-A., van der Gaast, W. "White Certificates and Domestic Offset schemes: possible synergies". (2012). Mitigation and Adaptation of Strategies for Global Change, vol. 17, no. 2, pp. 187-205.

Published articles in Scientific Conferences

- Spyridaki N.A., and Flamos A. "What is the achievable EE potential for subsidies under Article 7 of the EED? The case of the Greek household sector". (2019). ECEEE Summer Study 2019, Hyeres, France; 06/2019.
- Spyridaki N.A., Dragovic-Matosevic M, Papapostolou K, Oikonomou V, Flamos, A "Benchmarking EU cities capacity for innovative energy financing" (2019). ECEEE Summer Study 2019, Hyeres, France; 06/2019.
- Bertoldi, P., Castellazzi, L., Oikonomou, V., Fawcett, T., Spyridaki, N-A., (2015). "How is Article 7 of the EE Directive being implemented? An analysis of national EE obligation schemes" ECEEE Summer Study 2015, Hyeres, France; 06/2015.
- Spyridaki N.A., Ioannou, A. and Flamos A. "Expanding the policy theory behind the Climate and Energy Package in Greece" (2014). IEPPEC - International Energy Policies & Programmes Evaluation Conference, 9-11 September 2014, Berlin, Germany.

- Tuerk A., Fruhmann C., Frieden D., Spyridaki N.A., van der Gaast W., Sartorius C., Prizlan B. and Gubina A. (2014). “Efficacy and the 3 E method: a new concept in environmental policy assessment”. IEPPEC - International Energy Policies & Programmes Evaluation Conference, 9-11 September 2014, Berlin, Germany.

Articles under review for publication in Scientific Journals

- Spyridaki, N-A., Flamos, A. “A methodological framework for assessing the long-term potential of EE incentive mechanisms in the Greek Building Sector”. Energy Policy (under review).
- Spyridaki, N-A. Stavrakas, V., Flamos, A “What do ownership rates tell us about the propensity of households to invest in building innovation technologies? An econometric analysis in the Greek Household Sector”. Energy Policy (under revision).

Working papers to be submitted for publication in Scientific Journals

- “Getting to Grips with untapped energy efficiency potential: An integrated methodological framework for more effective policy instrument design” Spyridaki, N-A., Flamos, A. Energy Policy (to be submitted).
- Spyridaki, N-A., Dendramis Y., Flamos, A., “A multi-objective optimization assessment framework for designing cost-effecting EE PIs”. working paper.
- Spyridaki, N-A., Kleanthis, N., Tzani, D., Papapostolou, K., Flamos, A., “Setting the Benchmark for strengthening financing for local sustainability planning: A city capability assessment framework.” Sustainable Cities and Society (to be submitted).