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An Indicator based Approach to the Energy Efficiency First Principle

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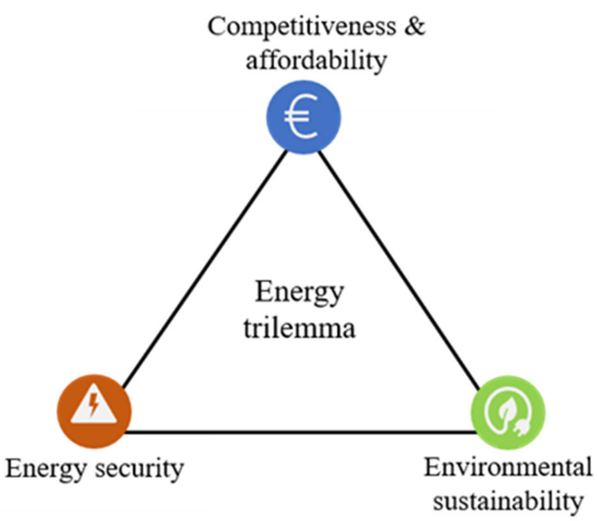
BAU	Business-as-usual scenario
CE4ALL	Clean Energy for All Europeans Package
CBA	Cost-benefit analysis
EE	Energy Efficiency
EE1	Energy efficiency first
EU	European Union
GDP	Gross domestic product
GHG	Greenhouse Gas
IEA	International Energy Agency
ktoe	Kiloton of oil equivalent
MS	Member States
Mtoe	Million tons of oil equivalent
MBs	Multiple Benefits
NECP	National Energy and Climate Plan
OECD	Organization for Economic Cooperation and Development
RES	Renewable Energy Sources
U.S.	United States

1 Introduction to the Energy Efficiency First Principle

1.1 The Energy Efficiency Gap - a major obstacle to the Energy Efficiency First Principle

This quotation stems from the year 2007, but still describes the paradox surrounding energy efficiency (EE) today. The relevance of EE in a green energy transition and in combating climate change has long been recognized on the international level. According to the International Energy Agency (IEA), greenhouse gas (GHG) emissions would have been 12 percent higher in 2017, if EE had not improved since 2000. In addition, EE improvements have the capability to contribute 40 percent to the total GHG reductions required by the Paris Agreement until 2040 (IEA 2019, p. 2). The European Union (EU) has also acknowledged the unique role of EE in building a secure, sustainable, and affordable energy system. Figure 1 summarizes those three policy goals with the energy policy triangle, which is also known as the energy trilemma due to the difficulty to satisfy all three constraints without negatively affecting one of them.

Figure 1: EU energy policy triangle



Source: Own elaboration

EE reduces the demand for energy and thus, positively impacts the security of the energy supply. Furthermore, since “*the cheapest and cleanest source of energy is the energy that does not need to be produced or used*” (EC 2016, p. 4), EE also promotes the affordability and sustainability of the energy system. Therefore, EE policies constitute a complementary measure to all goals and thus, solve the energy trilemma.

Consequently, EE should be at the forefront of European policymaking (**Energy Efficiency First EE1**). However, in practice, the opposite can be observed. Over the last decade, the progress in EE has slowed down across the EU. While EE improvements in final energy consumption grew by 1.4 percent annually between 2000 and 2007, this progress decreased to an annual growth rate of 1.1 percent afterwards. This slowdown becomes particularly evident in the industrial and transport sector. The rate of improvements has almost halved since 2007 across industries and in the transport sector, the progress is limited to an annual growth rate of 0.6 percent since 2000 (ODYSSEE-MURE 2020b). The decelerated growth and the continuous underinvestment of the Member States (MS) in energy-efficient opportunities, leaves a significant share of economic EE potentials untapped (Economidou et al. 2011, p. 19).

This paradox of consumers failing to make energy-saving investments, even though they present a positive net present value to them, is also referred to as the energy-efficiency Gap (EE Gap) and has been subject to scientific research for many decades (Hausman 1979; McKinsey&Co 2009). The debate around the existence of the EE Gap started with an empirical study by Hausman in 1979. He examined purchase decisions of durable, energy-consuming goods and thereby assessed that individuals behave as if they heavily discount future energy savings (Hausman 1979). Similar patterns emerged from other studies on the purchase behavior of vehicles, whereby individuals seem to undervalue attributes associated with EE, e.g., future fuel savings (Allcott and Wozny 2012; Helfand 2011). These and other studies suggest that the way individuals make decisions about EE leads to a slower diffusion of energy-efficient products than expected. Therefore, in broad terms, the EE Gap can also be described as the slower than the socially optimal rate of diffusion of energy-efficient products (Jaffe and Stavins 1994, p. 804).

A variety of barriers have been identified to slow down and inhibit the uptake of EE compiled into different categories, e.g., economic, organizational, and behavioral barriers (Thollander et al. 2010; Schleich 2009; Sorrell et al. 2004; Gerarden et al. 2015). For instance, in the United States (U.S), empirical studies estimated that the alleviation of barriers in the residential sector could reduce annual heating costs by 24 percent (Myers 2020, p. 14) and annual energy expenditures by 93 million USD (Davis 2012, p. 313). However, market barriers are not the only explanation for the existence of an EE Gap. Gerarden et al. (2015) argue that measurement errors and modeling flaws continuously lead to overestimations or underestimations on the size of the Gap. The EE Gap is usually assessed through the comparison of an optimal scenario, which includes the realization of all cost-efficient EE investments, with the realized level of EE. However, the definition and establishment of the optimal scenario is associated with a range of challenges. In particular, the difficulty to correctly map the heterogeneity of costs and benefits across potential consumers as well as the anticipation of uncertainty and unobserved costs are stated as potential causes for biased results (Gerarden et al. 2015, p. 3). As a consequence of those challenges, the estimates for the size of the Gap are wide-ranging with results between 20 and 60 percent depending on the study (Allcott and Wozny 2012; McKinsey&Co 2009).

In summary, there is a consensus on the potential influence of barriers on EE investments and potential existence of an EE Gap, but due to the mentioned measurement and modeling errors uncertainty remains around the exact size of the EE Gap (Allcott and Greenstone 2012). Therefore, **the application of a reliable method to assess the EE Gap across different countries as a major barrier to the EE1 principle continues to present a significant research gap**.

1.2 Research description

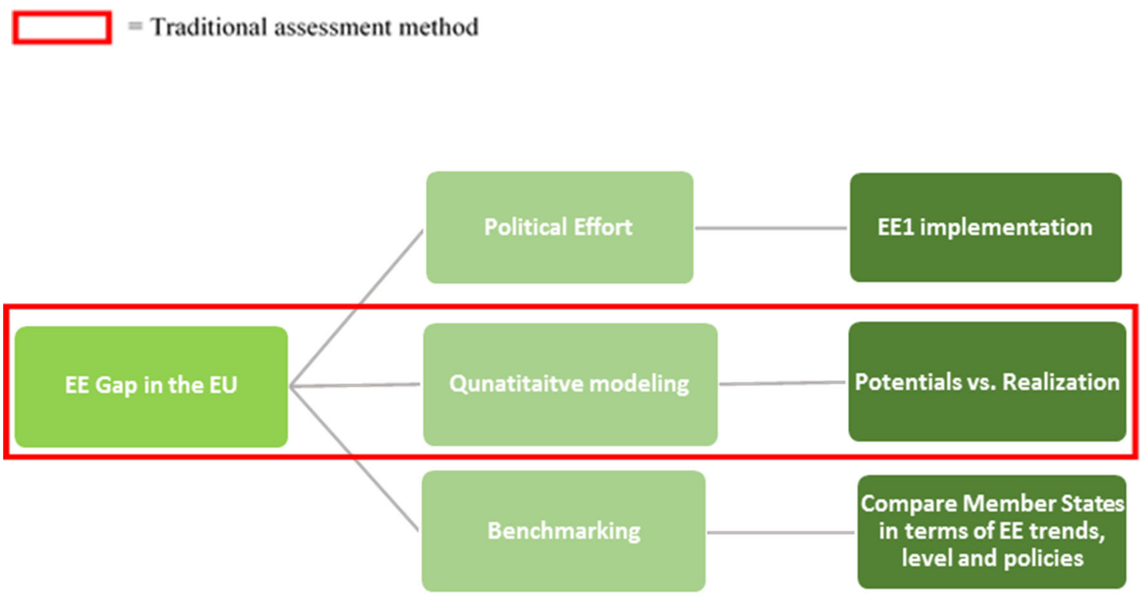
Regarding the European context, no studies have formally assessed the total EE Gap on the national level. Sectoral studies in Sweden found significant deficiencies with an EE Gap of 14–19 percent in the residential sector and up to 39 percent in the industrial sector. But even without formal assessments of an EE Gap the EU is highly criticized for its shortcomings in EE. The EE target for 2020, which was set by the EU as a non-binding objective in 2012, is described as the biggest miss of all the EU's targets for 2020. According to the current forecast most countries are also likely to miss the EE target set for 2030 (Euroactive 2020). However, a gap to a specific EE target does not necessarily imply an EE Gap. Therefore, the question is whether besides potential shortcomings regarding the EE targets, the MS continue to be affected by the existence of EE Gaps in 2030?

This paper aims to answer this question since understanding the EE Gap **and reinterpreting in in the sense of an EE1 Gap**, is necessary for it to be closed and for the societies to be able to exploit the benefits associated with EE improvements. However, due to the weaknesses of the traditional measurement approaches, a new assessment methodology will be developed and applied to answer this question. Therefore, the following two bullet points summarize the intention of this paper:

- Research Question: Is there an EE Gap in the EU by 2030?
- Methodology: Development of an indicator-based approach to assessing the EE Gap as a major barrier for the EE1 principle

Regarding the assessment method, an indicator-based approach is chosen. Instead of only relying on one single channel or key figure, this approach allows the consideration of different channels to get a more holistic impression of potential EE deficiencies within countries. In this paper, the indicator consists of three dimensions, whereby every single dimension evaluates the EE Gap from a different perspective. Those three channels are illustrated in Figure 2 and explained more in detail below.

Figure 2: Assessment channels of the EE Gap as a barrier to the EE1 principle across the MS



Source: Own elaboration

Channel I: Political Effort regarding EE1

The first source constitutes the measurement of political efforts regarding EE1. This channel was chosen due to the importance of governments and policymakers in overcoming the barriers to EE and closing the EE Gap: „ *Although some of the barriers are economic, they are in most cases institutional, political, and social. Overcoming them requires a government policy that champions conservation, that gives it a chance equal in the marketplace to that enjoyed by conventional sources of energ*y.” (Yergin et al. 1979) Findings from the IEA in 2017 support the essential role of governments since they argue that a vast amount of energy-saving potentials remain untapped because of the lack of regulations and mandatory standards regarding global energy consumption. As an example, they examined the area of space cooling, where the introduction of average stringency standards can lead to a reduction in energy needs by 30 percent (IEA 2017).

For this purpose, we take advantage of **the recently introduced EE1 principle in the EU**, which was implemented to solve the problem of the continuous underinvestment in EE technologies across the MS. In short, this principle requires demand resources to be considered on par with supply-side solutions and prioritized whenever they are less costly or deliver more value than alternative options. The principle requires more than simply implementing a certain number of policies, but rather for EE to actually be moved on top of the agenda and to be treated equally to alternative resources. The idea behind using the EE1 principle is that full compliance with the principle should lead to the full exploitation of the cost-efficient EE potentials and this, in turn, would imply the closure of the EE Gap. Thereby, this dimension gives an indication to what extent the economic EE potentials are exploited without being confronted with the measurement and modeling challenges associated with determining the potentials. Therefore, the second source of information on the EE Gap within the EU is the degree of compliance with the EE1 principle.

Channel II: Quantitative Modelling of the EE1 gap

The second dimension equals the conventional approach to the EE1 Gap, whereby quantitative modeling determines the existence and the size of the EE1 Gap. This channel evaluates the EE1 Gap from a technology-based perspective by focusing on the potentials of EE technologies and the extent to which this potential is realized. The idea is to model an optimal scenario of energy savings and compare this with the realized level of EE. The difference between the two scenarios constitutes the EE Gap. Since in this paper the aim is to assess the EE

Gap in 2030, the optimal EE level is compared with predictions for 2030 and the difference between those levels is used to assess the EE Gap in 2030. To minimize impact of the potential measurement and modelling errors, which are usually associated with this approach, two additional steps are implemented. Firstly, composite indicator includes two further dimensions, which are used to offset some of the potential shortcomings of this approach. Secondly, instead of relying on the precise results, the output is categorized. The use of categories allows the true EE Gap to differ from the modelling results to a certain extent without having an impact on the overall assessment.

Channel III: Benchmarking the Performance of MS with respect to EE1

The third channel consists of benchmarking the performance of the MS against each other. This method is chosen since one criticism of previous calculations is the overestimation of the optimal scenario due to hidden cost, behavioral attributes, or unforeseen events. The benchmarking of the MS against each other solves this problem, as the best performing MS is used as a benchmark, instead of a possibly unrealistic scenario of an optimal level of EE. In this channel, the performance of the MS is examined for three different categories: level, trend, and policies. Together these three indicators provide a solid impression on the path of the MS. The results for the three categories are merged to a single indicator, which reflects a holistic view of the general performance of the MS concerning EE.

1.3 Structure of the paper

This paper intends to provide an answer to the question, whether EE1 Gaps are present across the MS in 2030. This is particularly interesting since the attention of EE on the political sphere has increased over the last years as demonstrated by the introduction of the EE1 principle. The novel approach of considering three different channels instead of a single one to assess the performance of each MS is applied to offset the weaknesses, which are usually associated with EE Gap assessment. Through this, the aim is to generate more viable results on the possible existence of an EE Gap across the EU.

For this purpose, the paper is structured as follows. The second chapter starts with explaining the role of EE in the energy system and how its relevance has increased over the years. The multiple benefits of EE are described in detail to provide an understanding of why the implementation of EE measures is important or rather why it is important to care about the lack of implementation. The third chapter presents the paradox of the EE Gap. This includes the concept and the underlying reasons for the EE Gap. Furthermore, the common ways on how the EE Gap is measured and the weaknesses associated with each approach are outlined. As the geographical focus is on the EU, the fourth chapter describes the general energy policy framework in the EU and the role of EE in this context. In this context, the concept of the EE1 principle is introduced, and the different steps of its implementation are presented. In chapter 5, the implementation of the EE1 principle by the MS is assessed. Since the EE1 principle is a relative recent concept, so far, no official assessment method has been established. Channels II and III follow in chapter 1 and 2, whereby the necessary data is extracted from external data sources. In chapter 3, the research question on whether an EE Gap exists across the MS is answered. For this purpose, a composite indicator is developed, in which the results of the three dimensions are unified. The composite indicator provides a holistic view on the EE in the MS and thus, allows to derive conclusions on the potential occurrence of an EE Gap across the EU. Afterward follows the discussion, in which the results of the three channels are discussed and united to one single conclusion, on the research question, whether there is an EE Gap in the EU.

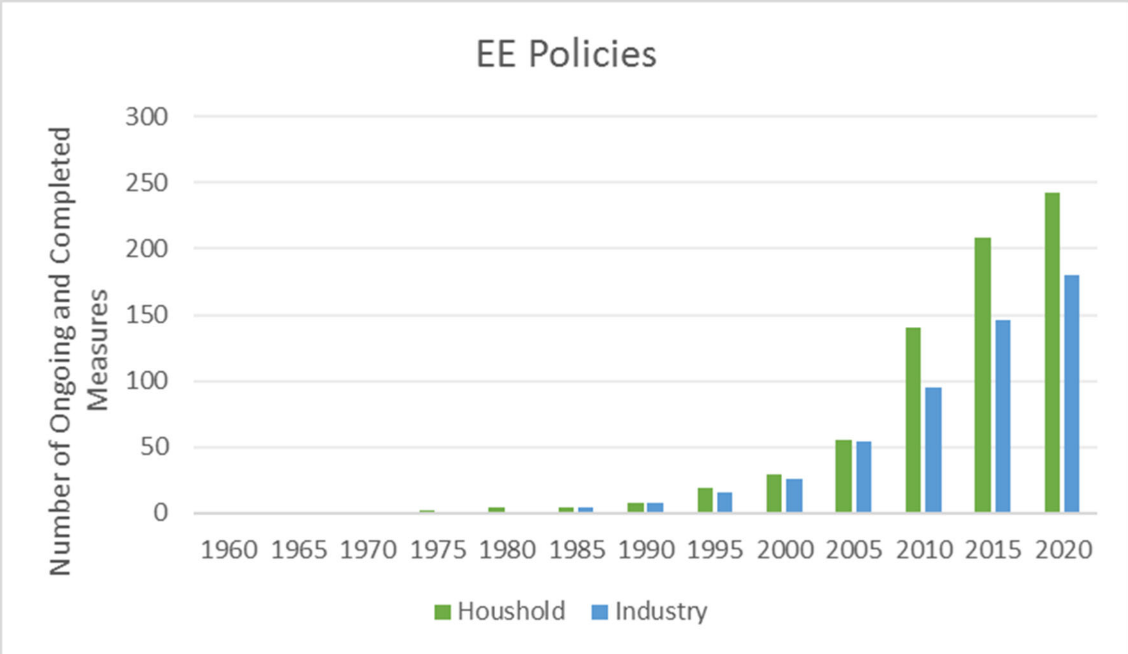
2 Energy Efficiency

2.1 The Role of Energy Efficiency

In general terms, EE refers to the ratio of energy consumed to the output produced or service performed (IEA 2014). The EU agreed on a similar definition in the EU EE Directive: "'*Energy efficiency' means the ratio of output of performance, service, goods or energy, to input of energy*" (European Parliament 2012) Depending on the context and sector, the outcome can take on a variety of forms. For instance, in the residential sector, it might be heating and lighting or in case of performance output, the focus might be on thermal comfort. In the industrial sector, the output of interest might be the production of a smartphone or television, while in the transport sector the energy input required for the service of transporting people is assessed (EP 2015).

The relevance of EE in the political and economic sphere started to grow in the 1970s as a reaction to the increasing oil prices due to the Arab oil embargo. Therefore, originally the main purpose of EE policies was to reduce energy demand or to increase energy savings. Because energy reductions reflect an amount of energy not consumed or energy costs avoided, EE has long been considered a "hidden fuel" since negative quantities are often perceived to be elusive (IEA 2013). In 1989, the physicist Amory Lovin coined the term "negawatt" in order to describe those units of energy saved through conservation measures (Lovins 1990, p. 137). However, it was not until 2010 that the relevance of EE was recognized and started to grow globally. Over the last decade, the mixture of a growing number of effective policies as well as high energy prices has increased the investments and has led to an expansion of the EE market. In 2011, the investments in EE amounted up to 300 billion USD worldwide and thereby were on par with the investments in renewable and fossil fuel generation for the first time (IEA 2013). This growing interest in EE is also reflected by the number of implemented EE measures and policies. Figure 3 demonstrates this development within the EU for policies and measures in the residential and industrial sector.

Figure 3: Implemented EE measures for households and industry.



Source: Data based on MURE (2020)

In the EU, the increasing focus on EE resulted in energy savings of 231 Mtoe in final energy consumption between 2000 and 2018 (ODYSSEE 2020). Among the IEA MS, the energy savings made through EE equaled 420 billion USD and thus were higher than from any other fuel source. This boom led to the acknowledgment of the EE as a major energy resource and to the notion that EE should rather be considered our "first fuel" instead of "hidden fuel" (IEA 2013). This expression of EE as the "first fuel" was officially adapted by the EU on their 2030 climate and energy framework.

By now, EE is not considered to be only a tool to save energy but is widely recognized to be the cornerstone of a secure and clean energy transition as well as to play an essential role in the achievement of all major energy and climate goals (IEA 2018). The particular advantage of EE is grounded in the multiple benefits associated with it. Those benefits are wide-ranging and include a positive impact on the environment, on social issues like health and poverty as well as on economic benefits like increasing productivity. A detailed overview of all the benefits and how EE interacts with those different areas is given in chapter 2.2. The wide-ranging impact of EE makes it a useful tool to reach a variety of policy targets, which otherwise might even contradict each other. This becomes visible considering three policy objectives of the energy triangle affordability, security of supply, and environmental soundness as already mentioned in the introduction. While

EE improvements are compatible with all three objectives, the example of renewable energy shows that this is not the case for all energy policies. An expansion of renewable energy satisfies environmental requirements and might support energy security by diversifying the electricity generation portfolio but might lead to higher prices in the electricity sector.

In 2019, the EE market still held vast untapped potential and as stated by the IEA "in terms of supply, it is abundantly available and cheap to extract" (IEA 2019) According to estimates, the realization of all economic EE potentials in the EU can lead to end-use energy savings of 41 percent by 2030 compared to 2009. Depending on economic growth and the development of the renewable energy share, this can further result in a reduction of greenhouse gases of 49–61 percent compared to 1990 (Fraunhofer ISI 2013).

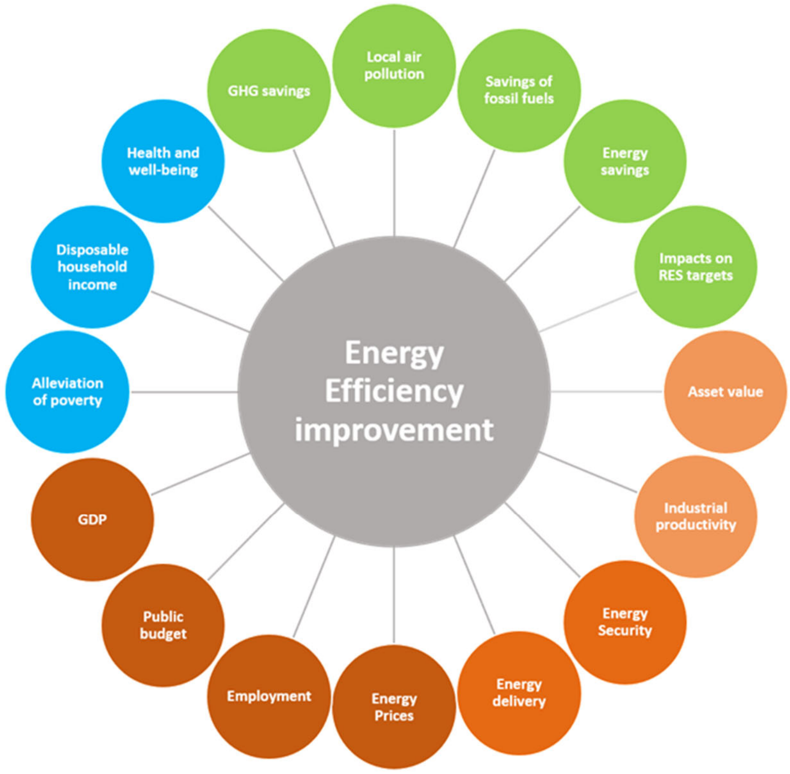
2.2 Multiple Benefits of Energy Efficiency

According to a large body of research, the majority of implemented EE measures turn out to be cost-effective for the participants (Yushchenko and Patel 2017). As indicated above, EE improvements are also associated with a range of benefits, which go beyond energy demand reduction and lower greenhouse gas emissions. Those benefits have been recognized by many policymakers and are often used to justify policies. At the EU level, the benefits of EE are presented in the European Energy Directive of 2012:

"The Union is facing unprecedented challenges resulting from increased dependence on energy imports and scarce energy resources, and the need to limit climate change and to overcome the economic crisis. EE is a valuable means to address these challenges. It improves the Union's security of supply by reducing primary energy consumption and decreasing energy imports. It helps to reduce greenhouse gas emissions in a cost-effective way and thereby to mitigate climate change. Shifting to a more energy-efficient economy should also accelerate the spread of innovative technological solutions and improve the competitiveness of industry in the Union, boosting economic growth and creating high quality jobs in several sectors related to EE." (EED 2012/27/EU).

While many studies have been conducted to review the different impacts, the IEA was the first to provide a holistic view of all the different aspects and to unify them under the concept known as the Multiple Benefits (MB) of EE in 2014 (IEA 2014). An assessment of a broad set of indicators was performed by Reuter et al. (2020).

Figure 4: The Multiple Benefits of EE improvements



Source: Own illustration after (IEA 2014)

Figure 4 demonstrates the multiple positive effects, which can be divided into environmental, social, and economic benefits.

Depending on the country and context, some aspects might be more relevant and prioritized than others. While the IEA recommends the MBs to be applied in the assessment of policies and projects, they also stress of being cautious of the rebound effect, which poses a potential risk and might counteract the benefits (IEA 2014).

2.3 Rebound Effect

The rebound effect is responsible for situations, in which the uptake of EE technologies leads to lower energy savings than expected or even an increase in total energy consumption (IEA 2014, p. 23). For instance, a company might redirect the energy savings from efficiency improvements to expand its production. Further, common trade-offs might take place in the residential sector as a consequence of refurbishments and enhanced insulation. Instead of saving money from the lower energy bills, households might decide to reinvest into accessing further energy services like increased heating or additional appliances (EP 2016, pp. 10–

11). This rebound effect is assumed to be higher for low-income households as the rebound effect is often used to improve their living standards. This shows that rebound effects should not necessarily be considered to be negative. If rebound effects are the result of improvement in living standards, health, and productivity, they can be regarded as having a net-positive impact (IEA 2014, pp. 23–24).

3 Understanding the Energy Efficiency Gap

3.1 Concept of the Energy Efficiency Gap

The scientific discussion about the failure of consumers to invest in EE opportunities, which provide them with a positive net present value, started with Hausmann in 1979 (Hausman 1979). Further authors joined this debate and a decade later Hirst and Brown first coined the term EE Gap. In this first reference, the EE Gap was simply defined as “a significant Gap between the current and the optimal levels of EE” (Hirst and Brown 1990, p. 267) In this case the optimal level relates to the state of social optimality. In contrast, the failure to reach the private optimum due to insufficient investment in EE is described as an energy paradox (Gerarden et al. 2015, p. 1). Multiple studies and academic articles examined the EE Gap and the barriers responsible for slowing down the diffusion rate of energy-efficient products to a rate, which differs from the optimal rate.

Those barriers can be understood as “mechanisms that inhibit a decision or behavior that happens to be both energy efficient and economically efficient” (Sorrell et al. 2004, p. 4) and can be divided into different categories. Among the first authors to categorize them are Brown and Hist, who propose behavioral barriers in regard to the decision-making process of end-user and structural barriers, which the end-users do not influence (Hirst and Brown 1990, p. 267). While most authors follow this approach with slight modifications to the taxonomy of the barriers, they have mostly contained behavioral, organizational, and economic barriers in their studies (Ordonez et al. 2017, p. 1462). Another manner to categorize them is to differ between market failures and non-market failures. This distinction is particularly relevant for governmental entities since according to neoclassical assumption market failures are a perquisite for market interventions. Therefore, the identification of market failures as a barrier to EE investments helps policymakers to justify policy interventions to overcome those obstacles (Brown 2001, p. 1199).

However, market barriers are not the only explanation for EE Gaps, which were assessed in different studies. Gerarden et al. (2015) argue that measurement errors and modeling flaws may lead to overestimating or underestimating the Gap (Gerarden et al. 2015, p. 3). The main reason for this lies in the difficulty of accounting for all relevant costs and capturing all aspects of the individual decision-making process correctly. The sensitivity of the estimations to those challenges explains the discrepancies about the extent of the EE Gap within the scientific literature and the wide-ranging results regarding the estimations (Gillingham and

Palmer 2013, pp. 2–3). For instance, depending on the study format and the assumptions about electricity costs the estimates for the EE Gap in the electricity use can range between 20 and 60 percent (Brown et al. 1998).

Closing the EE Gap is in the interest of households, businesses, and government alike as it allows them to take full advantage of the social, environmental, and economic benefits as described in chapter 2.2. In order to close the Gap, it is necessary to understand the assessment of a possible Gap and why the adoption of cost-effective energy-efficient technologies may occur at a suboptimal rate. Therefore, in the following chapter, an overview is given of the barriers to EE improvements. The taxonomy used in this paper is displayed in Table 1. This categorization was developed by Thollander et al. (2010), who differentiate between market failures, non-market failures, behavioral, and organizational barriers (Thollander et al. 2010). After the presentation of the barriers, the common assessment methods of the EE Gap are discussed in chapter 3.3. In this context, the weaknesses of the different approaches are outlined in order to examine, why critiques argue that modeling and measurement errors might cause biased results and thus, provide over- or underestimations of the EE Gap (Allcott and Greenstone 2012).

Table 1: Classification of barriers to energy efficiency

Category	Barrier
Market failures	Split incentive
	Principal-agent relationship
	Imperfect information
Non-market failures	Financial access
	Hidden cost
	Heterogeneity
	Risk and uncertainty
Behavioral barriers	Inertia
	Bounded rationality
	Form of information
	Values
	Credibility and trust
Organizational barriers	Power
	Culture

Source: Own elaboration

3.2 Barriers to Energy Efficiency

3.2.1 Market Failures

Split incentive

Split incentives address the lack of incentives to implement EE and occur when one party invests in EE improvements, while another party enjoys the benefits of it. In the context of EE, the most well-known example is the landlord-tenant dilemma. On one hand, the landlord is reluctant to invest in EE measures, if the investment costs cannot be passed on to the renter, even though the renter is the one profiting from the improvements through lower utility bills. On the other hand, high upfront costs might prevent tenants from implementing EE measures as they might move out of the dwelling before the investment pays off. Hence, neither the landlord nor the tenant might be incentivized to make the energy consumption of buildings more efficient (Bird and Hernández 2012, p. 507). In a similar manner, occur split incentives within companies in various situations. For instance, managers might be disinclined to make investments with longer payback periods such is the case for EE investments, if they only remain in their position for a short time or if their compensation depends on short-term results. The situation can also be similar to the landlord-tenant dilemma, where in large companies due to complex cost structures one department invests, while another department benefits from the energy savings (Schleich 2009, p. 4). The third setting of relevance regarding split incentives arises in the relationship between utility companies and residential rate payers. Utility companies are often the entity responsible for informing the consumers about available EE programs. In order to maximize their profits, utility companies are incentivized to sell more energy. However, efficiency improvements in the residential sector lead to lower energy demand and hence, contradict their business goals.

Principal-agent relationship

A principle-agent problem arises whenever one party – the agent – makes a decision or performs a task on behalf of another party, without the ability of the principal to ensure that the agent acts according to her interests. The issue derives from a combination of the limited capacity of the principal to monitor the agent, asymmetric information, split incentives, and transaction costs. In the context of EE, this can translate into an unwillingness of the decision-maker to implement EE technologies or disincentives the user to adapt energy-saving behavior. For instance, in the residential sector, this problem occurs when the landlord pays for heating, while the tenant determines the use of energy. In organizations, the principal issue becomes visible in situations when different individuals are responsible for energy bills and capital accounts and conflicting interests arise between them (Gillingham and Palmer 2013, p. 5).

Imperfect Information

If consumers lack inadequate information about the opportunities and potential of energy-efficient technologies, they may be less inclined to invest in EE improvements. In this context, imperfect information occurs mainly in three formats. The first form is insufficient information about the level and patterns of the own energy consumption, which might stem from deficiencies in the level of sub-metering, the information on the utility bill, or the time invested in engaging and analyzing the consumption information. Secondly, households and companies might lack information about the availability of energy-saving opportunities. This includes the failure to properly evaluate EE measures or to provide transparent information about the costs and performance of available technologies. The third issue relates to inefficient outcomes due to asymmetric information. A common example of this is in the residential sector the information discrepancy between the seller and the potential buyer of a building. The seller is aware of the EE status of the building and might want to include this factor in the selling price. However, unless the seller can prove those benefits in form of credible information, it is difficult for potential buyers to recognize and assess the energy performance upfront. This might result in adverse selection and a real estate market, which is dominated by energy-inefficient buildings as the bids for efficient buildings may be too low (Schleich 2009, pp. 2–3).

3.2.2 Non-Market Failures

Financial Access

EE improvements require a high upfront investment and hence, access to capital. If the consumer is dependent on external capital, limited access to credit can impede the consumer from investing in EE-improving technologies. Despite the prospect of high energy saving payoffs, consumers may hesitate to take out a loan in case of high interest rates. Among other factors, the reason for high-interest rates can be due to information asymmetries regarding the performance of EE measures as discussed above. In this context, the lenders might lack information about the payoffs of EE investment and therefore, are not able to accurately estimate the credit risk. This issue aggravates households with low income or poor credit as well as smaller companies (Gillingham and Palmer 2013, p. 5). In the case of internal financing, EE projects may also face obstacles within companies. Investments in EE seem less attractive as they pay off over the long run, which is incompatible with the application of short payback periods as an investment criterion (Schleich 2009, pp. 3–4; Gillingham and Palmer 2013).

Hidden cost

In contrast to expectations of an outside observer, individuals and organizations might be reluctant to invest in apparently cost-efficient and energy-efficient technologies due to additional costs, which the investor is aware of, but which are not visible to the observer. Consequently, modeling approaches to the EE Gap like engineering economic models might fail to capture and quantify those hidden costs and thereby, overestimate the size of the Gap. Those additional costs include administrative costs or costs related to finding information, seeking capital, and installing EE technologies (Schleich 2009, p. 3). Furthermore, hidden costs come in form of opportunity costs of investing in EE. Especially a lower quality of the energy services presents an important opportunity cost. For instance, the lighting of more energy-efficient bulbs might deliver less pleasing or lower quality lighting (Gillingham and Palmer 2013, p. 3).

Heterogeneity

The issue of heterogeneity describes the fact that although energy-efficient measures and technologies seem to be cost-efficient, this may not apply to some individuals or firms. Because consumers are heterogeneous, the investment in additional EE improvements might be economical for the majority of them, while for a subset of the consumers the additional efficiency turns out not to be cost-effective (Cagno et al. 2012, p. 292). In the industrial sector, small differences like the size and shape of an otherwise identical product can influence the cost-effectiveness of EE improvements in the production process (Thollander et al. 2010, p. 54). Among households, the profitability of EE investments depends on preferences, cost of capital, and the expected use of the product (Gillingham and Palmer 2013, p. 3). The effect of heterogeneity can also be amplified through other barriers, which affect single companies or households to a different extent. Therefore, ignoring the heterogeneity of potential consumers in the design of policies, measures and products might lead to a lower uptake of EE products than expected.

Risk and Uncertainty

In general, investment decisions are associated to some extent with risks like fluctuations of the exchange rates, future economic conditions, and business cycles. However, the high discount rates for investments related to EE, indicate a particularly high perceived risk. One source of risk lies in the uncertainty about future energy prices, which influences the rate of return on energy savings. Lower energy prices translate into lower-cost savings from reductions in energy consumption and hence, into lower returns on the overall investment. Therefore, fluctuations in energy prices lead to uncertainty about long-term cost savings and thus, pose a risk to investments in EE (Thollander et al. 2010, p. 53). A second risk factor constitutes the technological risk associated with EE improvements. Concerns about reliability, possible disruptions, and high maintenance costs may prevent investors to decide on more efficient technologies despite the range of potential benefits. Thirdly, uncertainties about future regulations may increase the option value, which is associated with postponing the investment in irreversible EE technologies. For instance, investment in EE might be postponed on grounds of the possibility that future governments might introduce grants or subsidies for EE improvements (Schleich 2009, p. 3).

3.2.3 Behavioral Barriers

Inertia

Inertia describes the tendency of individuals and companies to be creatures of habit and hesitant in regard to changing their behavior and routines (Abrardi 2019, p. 31). A study about the inertia of consumers in electricity markets showed that consumers are reluctant to move from the status quo. Even though staying with the status quo meant a higher probability of electricity interruptions, the consumers were content staying with their provider rather than switching to a new one (Hartman et al. 1991, pp. 158–161). An excessive number of policy options, energy packages, and multiple tariffs can amplify inertia due to the overload of choices. Similarly, it has been observed that risk and uncertainty enhance inertia. A study of the residential sector in Switzerland found that uncertainty around energy prices intensifies the preference for the status quo compared to investments in EE improvements (Alberini et al. 2013, pp. 31–33).

Bounded rationality

According to the assumptions of neoclassical economics, individuals are rational decision-makers, who choose the optimal solution to maximize their utility and profit based on all information available. Bounded rationality describes a market failure, which is independent of the economic environment and rather concerns the shortcomings of the behavioral patterns of fully rational agents. Instead of solving complex optimization problems, behavioral and organizational economics suggest that the assumed rationality is bounded by inattentiveness, cognitive limits to not adequately process all information or biases. Individuals rather satisfy than optimize their decisions by turning to heuristics and rules of thumb to simplify the decision-making process (Thollander et al. 2010, pp. 55–56). As a consequence, “opportunities for improving EE are neglected - even if there is access to perfect information and the incentive structure is appropriate” (Schleich 2009, p. 4) For instance, whenever companies make investment decisions, they might solely focus on the core production process and less on saving energy costs due to their order of priorities. Furthermore, consumers of appliances or cars might only take the price and delivery time into account, while ignoring the life-cycle costs of the new investment (Sorrell et al. 2004, p. 19).

Form of Information

People are not active information-seekers and as a result, the sole provider of information might not be sufficient to promote EE investments. Instead, people tend to be selective about attending and assimilating information. The form of information influences the likelihood of processing as well as understanding the input. Specific and personalized information, as well as information designed vividly, are among the attributes, which increase the likelihood of the receiver to assimilate and remember the information (Thollander et al. 2010, p. 54).

Values

Additional to economic considerations, personal values serve as a motivation to implement EE improvements. In particular, concerns about the environment, moral commitments, and cooperativeness may positively impact the implementation of EE measures. Within households, the weight of values in energy-related decisions depends on the cost of the measure and the difficulty of implementation. In the context of low-cost energy conservation measures, personal norms and values serve as a reliable predictor for their implementation, but this relationship weakens in regard to more costly investments (Stern and Aronson 1984).

The values within companies are mainly influenced by the corporate culture. However, the personal values of individuals in the top management might lead to an increased sensitivity to EE opportunities, which otherwise might go unnoticed. In short, values might not present a barrier in the classical sense, but ignoring their relevance in decisions related to EE, can cause missed opportunities in the promotion of EE (Sorrell et al. 2004, pp. 17–19).

Credibility and Trust

Another reason why information can fail to achieve the desired effect is due to the lack of trust the receiver has in the provider of the information. One possible source of distrust can stem from the nature of the provider. A study on households in New York, who received information about energy saving opportunities from the state regulatory agency used around 8 percent less electricity than those, who received identical information from local electric utilities. Further factors of influence are past experiences and the relationship with the information provider. In general, information is predominantly considered to be trustworthy, if it comes in form of recommendations from contacts within the own social and professional network (Sorrell et al. 2004, p. 22). This is also why in business decisions, consultants and sectoral organizations often play an influential role as they tend to be viewed as trustworthy (Thollander et al. 2010, p. 55).

3.2.4 Organizational Barriers

Power

This barrier focuses on the actors responsible for implementing possible EE improvements and the power position within the company or organization. The departments in charge of energy matters within firms are often at the lower end of the hierarchy. Furthermore, the topic of EE often receives little attention from the top management as it is not considered to be relevant for the business strategy. The lack of power and management support may lead to deficiencies in resources, funding, and authority and hence restricts the implementation of EE measures within an organization (Sorrell et al. 2004, pp. 26–27).

Culture

This barrier is analogous to the concept of values as discussed in the section above. The culture of a company or organization can be considered to be the sum of the individual values of the employees, whereby the norms and values of the top executives shape the culture to a greater extent than a worker at a lower level of the organizational hierarchy. The standing of environmental concerns and moral aspects within the company's culture may impact the likelihood of implementing EE improvements (Thollander et al. 2010, p. 56).

3.3 Measurement Approaches

3.3.1 Methods of Quantifying the Energy Efficiency Gap

"*Analysts' predictions of energy savings from efficiency investments have tended to overstate the magnitude of the energy-efficiency Gap.*" – (Gerarden et al. 2015, p. 17)

This quotation is from a study by Gerarden et al. (2015), in which they examine potential explanations and their contribution to the assessment of the EE Gap. To understand this statement, it is necessary to know how the EE Gap is usually assessed on the national level.

Ex-ante vs. ex-post estimates

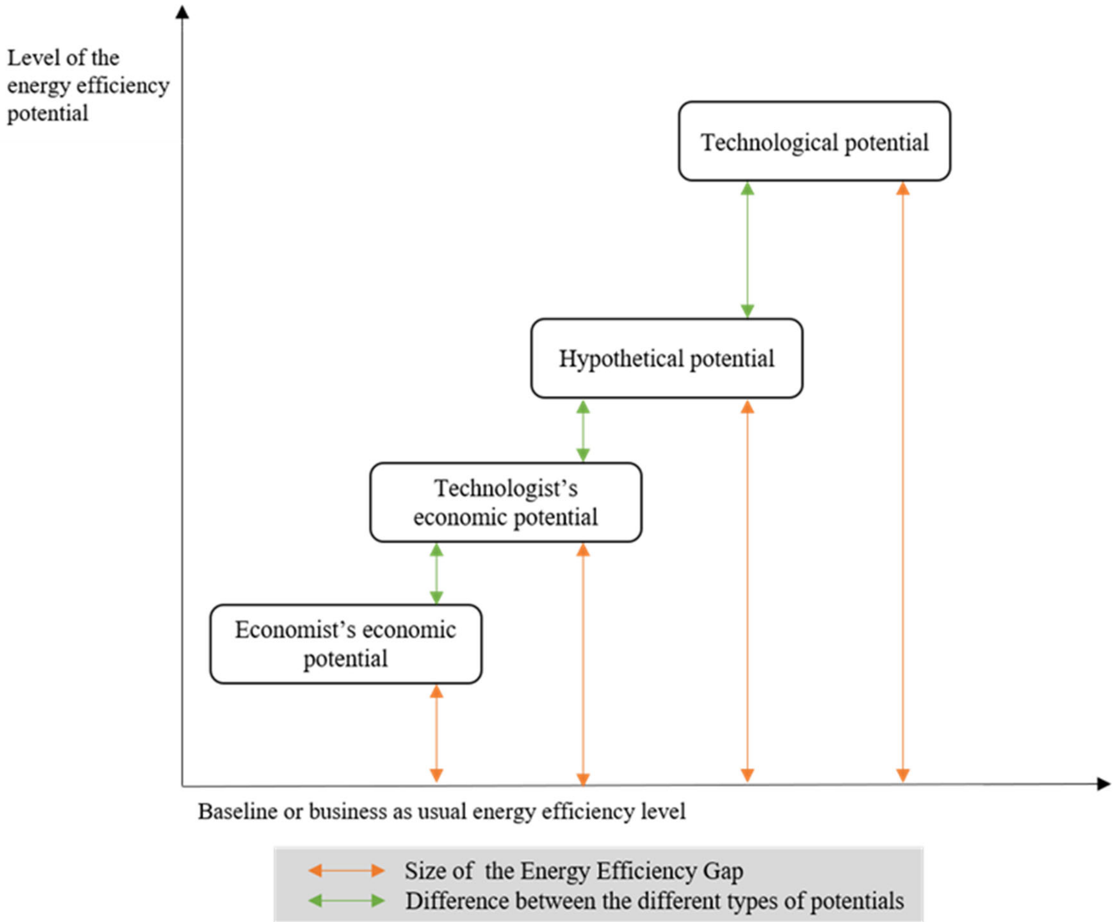
Analysts can choose between different approaches to estimate the EE Gap. The first distinction can be made between ex-ante and ex-post assessment. Ex-post evaluations are often assumed to be more credible as they rely on observed energy consumption instead of physical models and predicted results as it is the case for ex-ante analyses. However, ex-ante assessments have an advantage over ex-post assessments since predictions are a useful tool to evaluate different EE investment alternatives based on cost-effectiveness as well as to evaluate the energy savings, which are associated with different policy options (Gerarden et al. 2015, p. 17). The detection of deficiencies upfront also allows stakeholders to make the necessary adjustments along the way. For the purpose of this paper, ex-ante estimates are more relevant since the aim is to assess potential EE Gaps across the EU in 2030.

Baseline vs. optimal scenario

In order to assess an EE Gap, analysts evaluate two scenarios, which usually provide them with the magnitude of the EE Gap in form of percentage or ktoe. The baseline level equals the business-as-usual scenario (BAU). In the ex-ante analysis, the BAU reflects the level of energy savings, which occur under forecasted market conditions. The BAU scenario is then compared to an optimal scenario, which as noted above is associated with a range of challenges. The difficulty starts with the definition of EE potentials.

Technological EE potentials include all energy savings, which would be possible if the baseline technologies were replaced with more efficient technologies and further available energy-saving measures were implemented. However, this level is rarely used as a reference scenario. Instead, analysts tend to examine the economic EE potentials as those cover all energy savings, which can be achieved through the implementation of cost-effective EE improvements. However, as Jaffe and Staving pointed out, there are different interpretations of economic saving potentials. The level of cost-effective savings, which can be reached by eliminating all market failures for EE investments, falls under the notion of economic potentials from the perspective of economists. The removal of market failures as well as non-market failures is described as the technologist's economic potential. A third optimal scenario, which is called hypothetical potentials, is suggested to result from internalizing the environmental effects, which are caused by energy generation and use (Jaffe and Stavins 1994, pp. 808–809). Therefore, as illustrated by Figure 5, the definition of what postulates an optimal scenario highly influences the existence and size of the EE Gap.

Figure 5: Different level of energy efficiency potentials



Source: Own elaboration after (Jaffe and Stavins 1994; Thollander et al. 2010)

The second source of discrepancies regarding the assessment of the EE Gap is the challenge of correctly mapping the heterogeneity of costs and benefits across the potential consumers in the model. Differences in costs and benefits can lead to variations in the adoption of EE products and thus, to lower energy savings than expected. This means that the failure to take the heterogeneity of consumers into account can introduce bias in the estimation of the size of the EE Gap (Gerarden et al. 2015, p. 20). Examples of heterogeneity among consumers are different values, priorities, perception of risk, and access to information or finance (Ó Broin et al. 2015, p. 976). Further modeling and measurement errors include the failure of considering uncertainty and unobserved costs as well as the application of different discount rates (Gerarden et al. 2015, p. 2). These possible model and measurement flaws stimulate the debate around the size and the overall existence of the EE Gap.

Bottom-up vs. top-down approach

After deciding on the definition of the optimal scenario, analysts continue with the question of how to model this scenario. The most common approach to assess the EE Gap is based on ex-ante engineering analysis, which relies on physical models to predict energy savings (Häckel et al. 2017, p. 415). Engineering studies are also known as bottom-up models since they are based on data, which builds on a hierarchy of disaggregated components (Gerarden et al. 2015, p. 17). Bottom-up models are technology-based and assess energy saving potentials by using information about energy services as well as the technologies associated with them. In contrast to top-down models, which rely on historical data, bottom-up models are considered to be a useful tool for evaluating and quantifying different technological alternatives for meeting energy and climate goals. They allow to make an impact assessment of different combinations of technological as well as political measures and provide policymakers with the least-cost combination of those alternatives (Kavgic et al. 2010, pp. 1684–1686). However, economist like Allcott and Greenstone state that “the available evidence from empirical analyses […] suggests that while investment inefficiencies do appear in various settings, the actual magnitude of the energy efficiency Gap is small relative to the assessments from engineering analyses” (Allcott and Greenstone 2012, p. 25) This is in accordance with findings from other authors, who also argue that bottom-up models tend to overstate the EE Gap (Gerarden et al. 2015; Ó Broin et al. 2015). The underlying issue is the sensitivity of the EE Gap assessment to correctly account for all relevant costs and to correctly capture the individual decision-making process. While engineering studies contain detailed information on current and prospective technologies, they often fail to fully capture behavioral aspects like bounded rationality, risk aversion, consumer heterogeneity, cultural and social aspects as well as the cost of collecting information or opportunity costs (Ó Broin et al. 2015, p. 976).

Top-down models meet many of these challenges as they are based on observed interactions of producers and consumers in the market and hence, reflect actual market behavior. These models are based on historical data, work on an aggregated level and investigate the inter-relationship between energy and the economy at a large. Macroeconomic variables like income, energy prices, and GDP are assumed to be the main drivers behind changes in energy demand. In the context of energy and climate policies, this presents a challenge as those relationships are based on historic patterns and past macroeconomic trends. The reliance on the past prevents top-down models to capture discontinuous technological changes and to deal with social, economic, and environmental shifts (Kavgic et al. 2010, p. 1684). However, this reliance on historical data presents a challenge to the applicability of top-down model in policymaking since those past patterns are precisely the ones that policymakers often aim to change with energy and climate measures (Mundaca et al. 2010, p. 333). While bottom-up models solve this problem by building their calculations directly on specific technologies to assess the cost and saving potentials to reach climate and energy targets, they have their other weaknesses as mentioned above.

Role of Discount rates

A further topic of discussion regarding the EE Gap is agreeing on an appropriate discount rate to evaluate energy savings. The choice of the discount rate for investments related to EE highly influences the optimal scenario and hence, the size of the EE Gap. Investments in EE usually require a relatively high upfront cost and promise energy savings, which are spread over many periods. Thus, the discount rate plays a crucial role in assessing the net-present value of investment decisions related to EE. Choosing a high discount rate means that investments only seem attractive if the payback period occurs within the first years of investment. Therefore, models with higher discount rates, result in lower economic efficiency potentials as fewer investments will prove to have a positive present net value (Klemick and Wolverton 2013). This means, that the application of different discount rates across studies is one factor, which can explain the wide-ranging results on the assessment of the EE Gap.

Regarding the correct value of the discount rate, no consensus has been reached yet. Empirical studies found that the implicit discount rate, which consumers appear to use in their investment decision, varies substantially across and within technologies. Furthermore, the implicit discount rates tend to exceed other interest rates at the market. For instance, the implicit discount rate for investments in refrigerator range from 45 to 300 percent (Gately 1980, p. 373). The underlying reason for investors to apply high discount rates can stem from general preferences (e.g. time preference, risk preference), behavioral aspects (e.g. bounded rationality), and external barriers (e.g. lack of capital) (Schleich et al. 2016, p. 327). Therefore, high implicit discount rates are rather a restatement of the EE Gap than a source of it (Jaffe and Stavins 1994, p. 807).

In conclusion, two main aspects of the discount rate should be considered in the discussion around the EE Gap. Firstly, the choice of the discount rate is decisive for the calculations of the cost-efficient EE potentials and hence, influences the size of the EE Gap. And secondly, the observed implicit discount rates are wide-ranging across technologies and households. This means that ignoring the heterogeneity of those decisions can lead to overestimating the size of the EE Gap (Schleich et al. 2016, pp. 328–329).

3.3.2 Empirical Evidence on Measurement and Modelling Errors

In the description of the assessment methods of the EE Gap, the weakness of the approaches and the different factors, which might introduce bias to the results, were explained. In this section of the paper, the empirical evidence on those issues is examined to evaluate if the mentioned issues only pose a theoretical risk to the validity of the results or actually generate distorted outcomes.

We started with a quotation, in which it was argued that analysts tend to overestimate energy savings from EE improvement and thus, the size of the EE Gap. Potential explanations for this were given like the heterogeneity of consumers, which might differ in the utilization of the product, the failure of the models to anticipate hidden costs or the rebound effect of such investments. Empirical research on energy savings from different utility programs in the U.S. showed that the realized savings are indeed often lower than the predicted savings by ex-ante engineering studies. In a utility weatherization program, two groups of participants only saved on average 47 and 78 percent of the predicted saving potentials (Hirst et al. 1986, p. 300). Similar outcomes were observed in another utility program, in which participants achieved savings between 50 to 81 percent of the predicted energy savings (Sebold and Fox 1985, p. 83). An evaluation of a tool used for weatherization home audits even found that it overpredicts the energy savings by 186 percent (Ternes and Gettings 2008, p. 1). An indication of the neglect of the rebound effect was also observed in a study in Mexico. The program predicted that the replacement of air conditioners would lead to annual savings of 1200 kWh. However, the result was an increase in total energy consumption by around 2 percent (Davis et al. 2014, p. 225).

Empirical evidence on the negligence of consumer heterogeneity is provided by a study on refurbishment programs in the residential sector of Sweden. According to a bottom-up assessment, the installation of quadruple glazed windows would lower energy demand and present a cost-efficient investment for all homeowners in Sweden. However, this assessment assumed that all homeowners have the same values, preferences, and resources and thereby, ignores the heterogeneity among homeowners (Ó Broin et al. 2015, p. 976). Equally influential is the failure of recognizing the heterogeneity among products. A study from McKinsey & Co from 2009 estimated that the EE Gap would amount to 23 percent in the U.S. in 2020 (McKinsey&Co 2009, p. 2). However, in this context fluorescent light bulbs are treated interchangeably with other sources of light. This means, that their bottom-up assessment omits the opportunity costs associated with the different products. For instance, the opportunity cost of requiring information on new technologies can reduce the willingness of consumers to invest in them. Other examples of opportunity costs are unobserved implementation costs, research for investment alternatives, or the relocation of resources within companies (Gerarden et al. 2015, p. 35).

The relevance of including such opportunity cost to generate an unbiased analysis is supported by various empirical studies. In the UK, homeowners state the hassle of clearing out stored items from the attic spaces as the main obstacle, which prevents them from investing in improvements to the attic insulation (Caird et al. 2008, p. 156). Another study on the adoption of thermal insulation found that the opportunity costs of the refurbishment are double the costs of the material and labor (Sharma 2011, p. 61). Within the industrial and commercial sectors, empirical studies showed that production disruptions and temporary inconvenience as a consequence of EE improvements impede firms from investing in EE (Thollander and Rohdin 2006, p. 1838).

Discount rates constitute another factor, which highly influences the cost-effectiveness of EE investments and thus, the size of the EE Gap. In 2014, the European Commission conducted an impact assessment of different decarbonisation scenarios with the targets for EE ranging from 27 to 40 percent (EC 2014). The discount rates applied in this context vary by sector and are listed in Table 2.

Table 2: Discount rates applied in the impact assessment for 2030.

Sector	Discount rate
Industry	12%
Residential	17.5%
Commercial	12%
Transport	15%

Source: Own elaboration with data from Scheuer et al. (2016); EC (2014)

In 2015, the European Commission introduced the Better Regulation tool box, in which the application of a social discount rate of 4 percent across all sector is recommended (EC 2017a, p. 303). A comparison of the impact assessments, whereby all input parameters remain the same except for the discount rates, demonstrates the role of discount rates in determining the economic EE potentials. On basis of the original discount rates, only the 27 percent EE target scenario could be achieved with cost-efficient EE measures. When applying the recommended social discount rate of 4 percent, an EE target of up to 35 percent could be achieved with cost-efficient EE measures (Scheuer et al. 2016, p. 10). This shows that in the evaluation of different assessments on EE Gaps, it is necessary to take into account the underlying assumptions such as the discount rates or the definitions applied for the optimal scenario as illustrated by Figure 5.

In summary, the empirical evidence shows that the risk associated with the current assessment approach to the EE Gap is not just theoretical but contributes to biases in the results. The overestimation of energy saving potentials shows that current estimations on the size of EE with bottom-up models should be considered with caution. Furthermore, the significance of factors such as the heterogeneity of products and consumers as well as opportunity costs and the fact, that current assessment models fail to capture them, is another indication for the current lack of a reliable assessment approach to the EE Gap.

4 The role of Energy Efficiency in the EU energy policies

4.1 The European Energy Policy Framework

4.1.1 Previous Energy Strategy until 2015

Energy has played a major role in the EU since it was established in 1952. The first decades of European integration were dominated by coal and nuclear power. Supply issues shaped the political agenda in the early stages in order to protect the economies from supply reductions or interruptions. The MS acted largely isolated from each other and focused on protectionism and the national energy market. A push towards more intergovernmental cooperation to jointly secure energy supply was triggered by the oil crisis in 1973. Consequently, a common energy policy, as well as common goals for 1985, were passed. While this already emphasized the value and intention of closer cooperation to tackle energy issues, it took a few more years for the first serious attempt to deepen the integration and create an internal market. To realize this goal the Single European Act was issued in 1987 with the purpose to remove barriers to cross-border energy trade (Langsdorf 2011, pp. 5–6).

In the initial phase, the ambitions for an integrated energy market were impeded by the monopolistic structure of the energy markets. Hence, the beginning of the 1990s constituted a new phase with a shift in the political agenda towards restructuring and liberalizing the energy markets. For this purpose, the competition between operators was increased, an unbundling process initiated, and trans-European networks established (Jegen 2014, p. 6). The first directives concerning these issues were adopted in 1996 (Directive 96/92/EC) on a liberalized electricity market and in 1998 (Directive 98/30/EC) on a common gas market. Those directives were then extended and updated as part of the Second Energy Package in 2003. The third Energy package followed in 2009, which aimed to further disentangle vertically integrated energy utilities and liberalize the internal electricity (Directive 2009/72/EC) and gas markets (Directive 2009/73/EC) (EP 2020, p. 1).

The Lisbon Treaty in 2009 constitutes the first time that energy was included as a separate issue in a treaty of the EU (Langsdorf 2011, p. 5). Energy became a “shared competence”, which means that the MS can only act if the EU has chosen not to. A common energy policy strategy was endorsed, and three major challenges were identified: Sustainability, competitiveness, and security of supply. As described in the introduction, these three constraints are also known as the triangle of EU energy policy and still form the core of the European energy policy today. In order to tackle those challenges, the “action plan 2007–2009” contained a range of measures and binding targets. Among them were the so-called 20/20/20 targets, which describe three 20 percent targets to be reached by 2020. They required a 20 percent reduction in greenhouse gas emission, a 20 percent share of renewable energy in final energy consumption, and an increase of EE by 20 percent compared to 1990 (Jegen 2014, pp. 7–8). The energy triangle as well as the three targets clearly demonstrate the shift from a sole focus on energy security and supply to an increasing attention on environmental issues related to energy use. Indeed, the growing awareness of environmental damages and climate threats caused by energy became a driving force behind the energy policy across the EU (Langsdorf 2011, p. 5).

4.1.2 Current Energy Strategy

In 2015, the Energy Union [COM/2015/080] was launched by the European Commission as the new EU vehicle to shape the policymaking in energy and climate-related issues. The goal of the Energy Union is to provide secure, sustainable as well as competitive, and affordable energy for all MS. In order to achieve this goal, the strategy of the Energy Union is built on five dimensions, which are interrelated and mutually influence each other:

1. Energy security, solidarity, and trust
2. Creation of an internal energy market
3. Energy efficiency
4. Decarbonizing the economy
5. Research, innovation, and competitiveness

Among the five pillars, special weight is put on EE due to its overarching role. The energy savings induced by EE improvements simultaneously reduce GHG emissions, the energy bills for consumers, and increase the competitiveness of the EU due to lower energy costs (European Commission 2015).

In order to realize the energy and climate strategy of the Energy Union, a new energy rule book was introduced in form of the Clean Energy for all European package (CE4ALL). As part of the CE4ALL, the EU established binding climate and energy targets for 2030 to comply with the commitments made in the Paris Agreement. Until 2030 the EU targets call for a reduction of emission by 40 percent, a least a 32 percent share of renewables, and a 32,5 percent improvement in EE. In course of this process, the national energy and climate plans (NECPs) were introduced under the Regulation on the governance of the energy union (EU 2018). The NECPs require each MS to outline a plan, on how they intend to reach the national and European energy and climate goals, starting from 2021 until 2030. Apart from the specific targets set by the CE4ALL, the MS have to address the five dimensions defined under the Energy Union strategy: research and innovation, market interconnectivity, decarbonizing the economy, EE first, and energy security (European Commission 2020). Thereby, the importance of and the necessity to apply the EE1 principle in the NECPs is emphasized in the Regulation on governance:

“*With regard to their integrated national energy and climate plans, Member States shall (…) take into account the interlinkages between the five dimensions of the Energy Union, in particular the EE first principle*” (EU 2018, p. 56)

The innovative aspect of the NECPs lies in the integrative part of the plans. It is the first time, EU states developed plans, which combined the objectives of energy and climate policy. This improves the coordination between the government departments and ensures that both energy and climate policies are governed in the same direction. This provides a more efficient process as well as clarity, which translates into more predictability for businesses and investors. Furthermore, NECPs might improve the cooperation between and offer synergies with neighbouring states as all MS have to publish similar plans within the same time (European Commission 2020).

4.2 The Role of Energy Efficiency in the EU

The U.S. was the pioneer in terms of shifting the sole focus away from the supply side to including demand-side alternatives as well as the promotion of EE measures. The rising electricity prices caused by the oil shocks in the 1970s forced the U.S to explore the additional possibilities offered by demand-side resources. For this purpose, the concept of "Least-Cost-Planning (LCP)" was developed. It required participants of the electricity market to compare costs and benefits of supply and demand-side options and to consider those in their investment decisions. This approach was expanded in the 1980s and 1990s by adding environmental and social aspects to the cost-benefit comparison. This extended version of the LCP is known as "Integrated Resource Planning (IRP)" (ENEFIRST 2019, pp. 10–12).

The first European attempts to implement measures comparable to LCP or IRP were separately done by Denmark and Germany in the early 1990s. Similarly, further countries like Ireland, Greece, and the Netherlands developed methodologies for LCP and IRP and explored its applicability in their respective medium- and long-term energy plans. The first directive on the European level to involve IRP was proposed in 1995 by the European Commission. Despite further modifications made to the proposal in 1997, it was never passed (ENEFIRST 2019, p. 15). A major reason for this and the general failure to enforce LCP and IRP in Europe are the different conditions between Europe and the U.S. While the U.S. designed LCP and IRP for monopoly utilities, Europe pursued the liberalization of electricity and gas markets. The competition impeded long-term planning and the financing of demand-side management (Thomas et al. 1999, pp. 1–2).

Nevertheless, directives aiming to reduce final energy consumption through EE measures were passed. The main directives to achieve this goal were the Eco-design Directive [2009/125/EC] in 2009, the Energy Performance of Buildings Directive [2010/31/EU (EPBD)] in 2010 as well as the EE Directive [2012/27/EU] in 2012 (ENEFIRST 2019, p. 33). As implied by its names, the Eco-design Directive refers to the EE of products, while the Energy Performance of Buildings Directive (EPBD) regulates the energy use in buildings (Fawcett et al. 2019, p. 59). The most recent directive – the EE Directive (EED) – includes a variety of different provisions. For instance, according to Article 3 of the EED the MS are required to set binding national EE targets. It also covers the building sector by obliging the MS to develop national building strategies (Article 4) and to renovate 3 percent of public sector buildings each year (Article 5). However, the cornerstone of the EED is Article 7 as it was promised to be highly influential in reaching the EE target of 20 percent energy savings by 2020 and 32.5 percent by 2030. It demands from the MS to implement EE Obligations (EEO) in order to successfully reduce the final energy use by 1.5 percent each year (Rosenow et al. 2017, p. 73).

However, despite those efforts, the MS continued to underinvest in EE and demand-side measures (Bayer 2015, pp. 1–3). As a consequence of this gap, the Energy Union agreed on the necessity for an overarching mandate to ensure the exploitation of the economic EE potentials. For this purpose, the energy efficiency first (EE1) principle was defined and established as a leading principle with the Clean Energy for All Europeans package in 2016 (EU 2018). The following chapter explains the concept and the implementation of the EE1 principle in detail since the EE1 principle constitutes the core of the second dimension of the composite indicator in this paper,

4.3 The Energy Efficiency First Principle

4.3.1 Conceptualization

Even though the EU has recognized EE as an energy source on its own, a continuous lack of prioritization of EE and preferential treatment of supply-side resources left efficiency potentials untapped (Bayer 2015, pp. 1–3). In order to close this gap, the Energy Union agreed on the EE1 principle as an overarching mandate. The principle was developed in 2016 and first published within the Clean Energy for All Europeans package. In this context, the European Commission defined the principle of putting EE first as follows:

„*EE is the most universally available source of energy. Putting EE first reflects the fact that the cheapest and cleanest source of energy is the energy that does not need to be produced or used. This means making sure that EE is taken into account throughout the energy system, i.e., actively managing demand so as to optimise energy consumption, reduce costs for consumers and import dependency, while treating investment in EE infrastructure as a cost-effective pathway towards a low carbon and circular economy. This will enable retiring generation over-capacity from the market, especially fossil fuel generation." (EC 2016, p. 4)*

In agreement with the Clean Energy for all packages existing directives were amended, and new regulations developed. A variety of those legislative pieces include the EE1 principle like the Electricity Directive (EU, 2019/944), the Regulation on the Internal Market for Electricity (EU, 2019/943), the Directive on EE (EU, 2018/2002) as well as the Governance Regulation (EU, 2018/1999). For instance, the latter one describes the EE1 principle with the following paragraph:

„*EE first' means taking utmost account in energy planning, and in policy and investment decisions, of alternative cost-efficient EE measures to make energy demand and energy supply more efficient, in particular by means of cost-effective end-use energy savings, demand response initiatives and more efficient conversion, transmission and distribution of energy, whilst still achieving the objectives of those decision*" (EU 2018, Article 2, 18)

Furthermore, it is embedded in Article 3, in which the importance of EE towards the other four dimensions of the Energy Union is highlighted.

„*..take into account the interlinkages between the five dimensions of the Energy Union, in particular the EE first principle*" (EU 2018, p. 7)

EE has positive impacts beyond energy savings and since "the most sustainable energy, is the energy never produced" EE offers a cost-effective option to reach a variety of goals. The Energy Union aims to exploit this potential by applying the EE1 principle to every policy and decision related to the energy market. Based on the policy texts above and interpretations of a variety of think tanks (e.g. European Climate Foundation (2016); Cowart et al. (2015)), an overview of the EE1 principle is given in the following. The summary builds upon three statements, which capture core elements of the EE1 principle.

Statement 1: Energy demand is not fixed.

The EE1 principle moves away from the common approach of considering energy demand solely as a fixed variable in the energy equation to presenting it as an input variable, which can be altered. Hence, additionally to supply options - like grid expansion – demand-side management should be taken into account (Gellings 2017, p. 6).

Statement 2: Equality of supply and demand resources

The principle neither equals a specific level of EE nor does it promote a general superiority of demand side solutions. Instead, EE1 requires demand resources to be considered on par with other options and only prioritized whenever they are less costly or deliver more value than alternative options. Thereby, the principle acknowledges that both costs and benefits go beyond economic aspects and additionally include social and environmental benefits. The results of the CBA and thus, also the assessment of the economic EE potentials, depend on the definitions applied in this context as well as the assessment methodology (Bayer 2015, pp. 3–4)

Statement 3: Ubiquity in all energy policies and strategies at any level

As noted previously, according to the EE1 principle, EE is more than a tool to achieve a final target like energy savings. It rather transfers EE to a higher level by integrating it in energy policies and strategies. As a resource on its own or as a first fuel, EE contributes to all five pillars of the Energy Union. Consequently, policymakers on the national, regional, and local level are supposed to apply the principle in all energy planning, policy, and investment decisions in order to optimize the energy system. Furthermore, the respective governments are urged to involve private and business entities, so that the EE1 principle is also embedded in their investment decisions (ENEFIRST 2019, pp. 16–18).

4.3.2 Operationalization of the EE1 Principle

As the EE1 can be considered as a compass to guide policy- and decision making, its implementation resembles more a step-by-step approach rather than as specific action (Coalition for Energy Savings 2015; ENEFIRST 2019).

1. Systematic identification of policies and decision points, where efficiency measures and demand resources offer potential but are often overlooked or undervalued.
2. A cost-benefits assessment of the different supply- and demand-side options
3. The removal of market barriers to EE investments

Identification of relevant policy areas

The EE1 principle is an overarching concept, which should be applied in every policy and decision process. However, in order to make EE1 operational, it is essential to move away from a general level and instead identify its applicability in relevant policy areas and decision points concerning the energy system, where energy savings solutions might otherwise be overlooked or undervalued. As a result, all provisions, and policies, which reflect overall political targets and are instrumental for future development, should also incorporate and promote EE as the first fuel. For instance, in the EU among the most relevant policy areas are power market rules, climate, building and renewable policies as well as EE measures (ENEFIRST 2019, pp. 25–26).

A cost-benefits assessment of the different supply- and demand-side options

The application of a cost-benefit analysis (CBA) in the appraisal phase of policy development, allows policymakers to make decisions based on the best value for the whole society. In contrast to other approaches like the least-cost analysis, CBAs systematically compares both total cost and benefits. They go beyond a pure financial analysis as additionally to financial aspects, CBAs cover costs and benefits, which are not traded or cannot necessarily be monetized. This is particularly relevant in the case of EE due to the MBs, which are associated with improvements in this regard (Kavvadias 2015, pp. 35–36). The failure to take the economic, social, and environmental benefits of EE into account, might lead to undervaluation of EE opportunities and thus, contribute to the underinvestment in EE technologies. Besides, a neglect or only a selective inclusion of benefits in the CBA, overestimating the cost through inflated discount rates may also result in a bias against EE (Scheuer et al. 2016, pp. 8–9). Discount rates play a crucial role in the assessment of cost-efficient EE opportunities and different policy options in general. In the policymaking process, the social discount rate should be applied as it considers costs and benefits together from the point of view of society as a whole and not from the point of view of a single stakeholder. The recommended social discount rate for the MS ranges between 1 and 7 percent (Steinbach and Staniaszek 2015, p. 14). While the discount rates can be assumed to differ across sectors and vary within households by socioeconomic parameters like income, they should not depend on the applied technology. Furthermore, to map non-economic and behavioral barriers the use of the behavior model presents a more suitable tool compared to simply increase the discount rates. Therefore, to avoid biases and to ensure that EE competes on equal terms with supply-side alternatives, the discount rates are allowed to differ by sector and socio-economic attributes, but not between different technologies (Steinbach and Staniaszek 2015, p. 14).

The removal of market barriers to EE investments

A combination of deep-seated market barriers to end-use EE investments and historic preferences for supply-side investments across the policy landscape, contribute to a market imbalance in favour of supply-side solutions. The EE1 principle means recognizing the different barriers that prevent the uptake of EE investments and the necessity to overcome those. Hence, both reversing past policies as well as implementing new measures to overcome market barriers are part of guaranteeing a level-playing field (Rosenow and Cowart 2019). The degree to which market barriers are considered in energy scenarios also influences the results and thus, also what is considered to be an optimal EE target. If market barriers are not removed beyond the extent of existing policies, the projections ignore the possible impact of any additional policies. As a consequence, this scenario delivers rather a 'worst case' assessment of EE targets, instead of an optimal target level with policies and measures, which promote the realization of cost-efficient EE investments (Scheuer et al. 2016, p. 7)

5 Methodology: Composite Indicator approach to the EE1 principle

The application of composite indicators is increasingly recognized as a useful tool in area of policy analysis, benchmarking, performance monitoring, and public communications. A review on the development of composited indicators assessed an exponential growth over the last 20 years (Greco et al. 2019, p. 65). They are widely adopted by international organization such as the United Nations (Human Development Index), the EU (e.g., Sustainability Index) or the World Bank (e.g., Quality of Government).

While the literature offers variety of definitions on the concept of composite indicators, they can broadly be defined as the compilation of individual indicators into a single index, which represents as proxy of the phenomena that is being measured (OECD 2008, p. 8). In contrast to individual indicators, composite indicators allow the measurement and quantification of multidimensional concepts, which are not directly measurable or clearly defined such sustainability, human development, industrialization, or competitiveness. They help to identify and convey common trends among separate indicators and facility the comparison and benchmarking of the performance of different countries (Saltelli 2007, p. 71).

However, besides their widespread popularity and growth in application, there is also criticism surround their applications. This is due to the fact that the validity and usefulness of a composite indicators largely depends on its underlying construction scheme. A poor construction or misinterpretation of a composite indicator can lead to misleading conclusions. For instance, since composite indicators invite to an easy interpretation of otherwise complex matters, there is a risk of oversimplifying otherwise complex matters and hence, of drawing simplistic conclusion from the results. Another topic of controversy is the lack of transparency and consistency in the construction process of the composite indicator. The validity of the Human Development Index was highly criticized for this reason and accused of arbitrariness in its methodological framework (Ray 2007, pp. 44–45).

To reduce construction errors and improve the quality of composite indicators the Organization for Economic Cooperation and Development (OECD) and the Joint Research Centre (JRC) of the European Commission developed a methodological framework with technical guidelines on the construction of composite indicators. In this paper, the construction of the EE indicator is based on those guidelines. Accordingly, the following chapters resemble the multiple-step approach as suggested by the OECD. Table 3 lists those steps and gives an impression on the process of constructing the composite indicator on the EE Gap.

Table 3: Checklist for building a composite indicator

1.	Theoretical framework
2.	Data selection
3.	Imputation of missing data
4.	Normalization
5.	Weighting and aggregation
6.	Sensitivity analysis
7.	Visualization of results

Source: Based on (OECD 2008)

5.1 Theoretical Framework and Identification of the Three Dimensions

The aim of the indicator is to provide a reliable assessment on potential deficiencies regarding the exploitation of economic EE potentials and thus, the EE1 Gap. In chapter 2 and 3 the theoretical aspects of EE and the EE1 Gap were presented. While the concept of the EE Gap is straightforward, chapter 3.3 revealed that the traditional measurement approach to the EE Gap is associated with measurement and modeling errors. The bottom-up approach takes a strict technological perspective on the EE and thereby, ignores other relevant dimensions such as human behavior or political factors. Consequently, an exclusive focus on technological potentials might lead to misleading results regarding the extent of the EE1 Gap. Therefore, the intention behind applying a composite indicator approach to this topic, is to create a more reliable and holistic assessment by adding two further dimensions to the technological perspective. The result is a composite indicator, which considers the EE1 Gap from three different perspectives:

A) Political effort

B) Technological perspective

C) Country benchmarking

The first dimension evaluates the EE1 Gap from a political perspective. As described in chapter 3.2, a variety of market and non-market barriers impede the uptake of EE technologies. Consequently, overcoming those barriers is essential to ensure the full exploitation of the existing economic EE potentials. As stated in the introduction, policies and regulations play an essential role in removing those economics, institutional, and social barriers. Thereby, the focus on this dimension is not directly on the technological uptake, but instead on the political efforts to remove potential and existing barriers to the EE1 Gap. A removal of the barriers and thus, the theoretical causes of the EE1 Gap means that nothing should impede the exploitation of the economic EE potentials and thus, the closure of the EE Gap. For this reason, this dimension examines the EE1 Gap from a political perspective by focusing on the treatment of EE on the political level and the removal of barriers through governments.

The second dimension reflects the technological perspective on the EE1 Gap. This is the common approach to the EE1 Gap and conducted through quantitative modelling, whereby the EE1 Gap is assessed by comparing the realized EE level and the cost-efficient EE potentials with each other. This channel quantifies the size of the EE1 Gap and offers a technical perspective on the exploitation of the economic EE potentials.

In third dimension the untapped EE potentials and thus, the EE1 Gap are observed through comparing the performance of the countries with each other. Thereby, this channel addresses the challenge of establishing an optimal level off EE. The failure to capture hidden costs, unforeseen events and to correctly model behavioral often leads to the identification of unrealistic scenarios as the optimal level of EE. Benchmarking avoids the challenge of establishing an optimal scenario or level of EE, by comparing the EE performance of countries with the best practices of other countries. This approach was used by the IEA to detect untapped EE potential in the industrial sector across different countries (IEA 2021). For the purpose of this paper, the benchmarking approach is applied to detect potential EE deficiencies across all sectors on the country level.

5.2 Data Selection and Missing Data

Political effort

Similar to the EE1 Gap, the political effort to enable the full exploitation of economic EE potentials is a multidimensional matter. It goes beyond a simple aggregation of existing policies on EE, since this gives no indication on the actual impact as well as possible preferential treatment of alternative resources such as renewables. To the current knowledge, there is no index or indicator available, which measures the political efforts of removing the barriers to EE investment and closing the EE1 Gap. Therefore, a novel indicator approach is developed to generate the necessary data for the second dimension of the composite indicator on the EE1 Gap. The data for the respective indicator is derived from two main sources. Primary data is collected through semi-structured interviews, which consist of 12 main questions and are conducted with a variety of political stakeholders from the MS. For the second source of information secondary data is extracted from the NECPs and the ODYSSEE-MURE database. The total output is presented in form of absolute data.

In context of the interviews, missing values can be caused through two reasons. Firstly, the political stakeholders might not be able to answer certain questions. Secondly, a question might not be applicable to the country context. In this context, the missing inputs are replaced by using an unconditional mean imputation. This means that the missing values are substituted by the mean score of the total sample within the individual indicator (OECD 2008, p. 56).

Technological perspective

To assess the economic EE1 Gap in 2030 from a technological perspective, data is required on the realized and potential level of economic EE savings. For the European context, sufficient data exists and thus, external data sources are used. The necessary input is extracted from the study “Technical assistance services to assesses the energy savings potentials at the national and European level” by ICF for the European Commission (EC 2021). The study presents a detailed assessment of the technical and economic final energy saving potentials within the EU. The assessment is conducted for all 27 MS and covers energy intensive industries, commercial, residential and transport sector. Regarding the timeframe, the study examines the periods from 2020 until 2050. However, for purpose of this study, only the data until 2030 is extracted. The output is given in form of absolute data.

Since data is available for all 14 MS, the imputation of missing data is not a relevant step in the dimension.

Country benchmarking

In the third dimension of the composite indicator on the EE1 Gap in the EU in 2030, the MS are compared in the three different categories: EE level, EE trend, and EE policies. Thereby, the ODYSSEE-MURE database is used to collect the necessary data. The results of the three individual categories are merged to a single indicator to provide a holistic view of the general performance of the MS regarding EE. Since in this dimension, the performance of countries is compared against the performance of other countries, the results in this dimension are form of relative data.

Since data is available for all 14 MS, the imputation of missing data is not a relevant step in the dimension.

6 Channel I: Measuring the Political Effort

6.1 Political Effort as an Indicator for the EE1 Gap

In this dimension, the EE1 Gap is examined from a political perspective. As stated in the introduction, policies and regulations play an essential role in removing the barriers to EE investments and in closing the EE1 Gap. A study on the impact of the EE measures in Europe found that without EE policies and measures the energy consumption would have been 12 percent higher in 2013 (Bertoldi and Mosconi 2020, p. 11).

However, an impact assessment of policies is not sufficient to assess the EE1 Gap since the impact alone is no indication on whether all EE potentials are exploited. Therefore, another approach has to be chosen to assess if the political effort is sufficient to close the EE1 Gap. In this paper, advantage is taken of the recently introduced EE1 principle in the EU, which was specifically introduced to solve the problem of continuous underinvestment in EE and untapped EE potentials. As described in chapter 4.3, the EE1 principle goes beyond a certain number of policies, but also requires EE to be considered in every decision related to the EE market, to be treated on equal terms with alternative resources, and the removal of barriers. The idea behind using the EE1 principle is that in theory a full compliance with the EE1 principle should lead to the full exploitation of all cost-efficient EE potentials and this, in turn, would imply the closure of the EE1 Gap. In the NECP, which includes all planned and existing energy and climate policies until 2030, the MS were supposed to apply the EE1 principle. This means, that an assessment of the degree of compliance with the EE1 principle in the NECP, can be used to gather information on the extent of EE1 Gap by 2030 across the EU.

Since the EE1 principle is a relative recent concept, no official guidelines or measurement approaches are in place, to evaluate a country's compliance with it. This means in order to use the EE1 principle as the first channel, an assessment method for the compliance with the EE1 principle has to be developed first. For this reason, this paper also includes the assessment of the implementation of the EE1 principle in the NECP and its implication on the EE1 Gap.

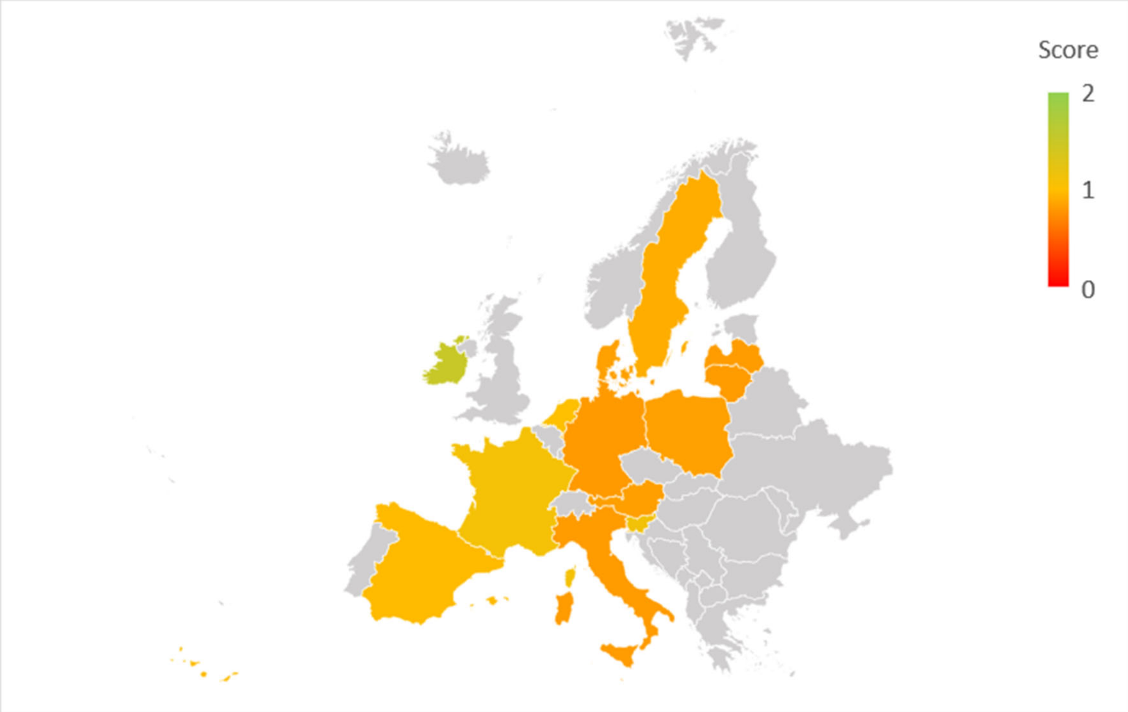
6.2 Assessment of political effort

To capture the multiple aspects of the EE1 principle, a multidimensional indicator approach was developed by Chlechowitz et al. (2022) to assess the degree to which the EE1 principle was adopted by national policymakers. This indicator-approach presents a novelty in the context of the EE1 principle. The same definitions and conceptualizations given on the EE1 principle in chapter 4.3 were used as a base to establish the relevant components of the EE1 principle. The results are the following five dimensions as the base for the EE1 indicator:

- *The EE1 principle in the policymaking process:* The EE1 principle requires the recognition of EE as a flexible input variable in the policymaking process, which should be considered on par with alternative resources (ENEFIRST 2019, p. 20). Therefore, the indicator in this dimension assesses the extent to which EE is treated a as resources on its own in the policymaking process and how it is compared with other options in this context.
- *The removal of market barriers to EE investments:* The core of the concept rests in the equality of supply and demand resources (ENEFIRST 2019, p. 20). However, a combination of historic preference for supply-side investments across the policy landscape and of deep-seated market barriers to end-use EE investments, often contribute to a market imbalance in favor of supply-side solutions (Rosenow and Cowart 2019). The EE1 principle means recognizing the different barriers that prevent the uptake of EE investments and the necessity to overcome those. Hence, both reversing past policies as well as implementing new measures to overcome market barriers are part of guaranteeing a level-playing field.
- *Consideration of challenges to EE:* This category encompasses societal trends and issues, which if they remain overlooked by policymakers, might impede, or even counteract the purpose of the EE1 principle.
- *Regional and local adaptation of the EE1 principle:* While the national level presents a good starting point for the introduction of the EE1 principle, the regional and local adaption is essential to guarantee that the EE1 principle is considered in all decisional related to the energy market (EU 2018).
- *Monitoring and verification process*: In context of the EE1 principle, a clear and high-quality monitoring and verification process has dual function. Firstly, it allows for more effective and targeted policy interventions. Secondly, monitoring and evaluating of the impact of EE measures provides a base for the quantification of the MBs of EE (Rosenow and Cowart 2019, p. 347).

In total, the EE1 indicator consists of 13 criteria, whereby the number assigned to each dimension differs. The indicator is used to assess the political efforts regarding EE and determine if the efforts are sufficient to exploit the cost-efficient EE potentials. Therefore, the maximum score of 2 implies the implementation of the necessary political instruments and measures to close the EE1 Gap by 2030. In Figure 6, the 14 MS examined in this paper are highlighted in colour and give a first impression of the degree of operationalization of the EE1 principle.

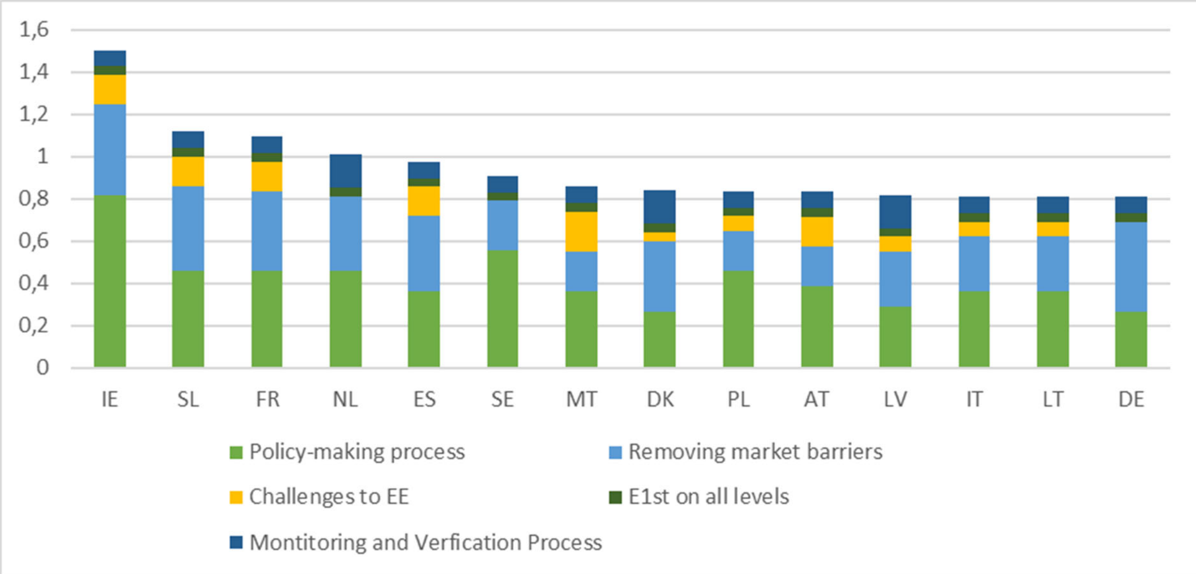
Figure 6: The EE1 principle across the EU



Source: Chlechowitz et al. (2022)

None of the countries reaches the maximum score, which implies that the current and planned policies and measures are inadequate for the full exploitation of the economic EE potentials and hence, insufficient to close the EE1 Gap. The highest score reaches Ireland with 1.50 points out of 2, which means that Ireland fulfils 75 percent of the requirements necessary for fully operationalizing the EE1 principle. Further four countries – Slovenia, the Netherlands, and France – have a score above 1.0 and the remaining countries range between 0.98 and 0.80 points. Regarding the distribution of the total scores, the MS show similar performances. Excluding Ireland, the discrepancy between the lowest and the highest score amount to 0.30 points, which resembles a difference of 15.5 percentage points. Figure 7 illustrates this distribution, by displaying the countries from the highest to the lowest score.

Figure 7: EE1 principle by categories across the EU



Source: Chlechowitz et al. (2022)

7 Channel II: Potentials of Energy Efficiency in Europe

7.1 Engineering studies to assess the Energy Efficiency First Gap

In this channel, the EE1 Gap is assessed from a technical perspective. The estimations for the EE1 Gap across the MS in 2030 are derived using a bottom-up model. Bottom-up models are the most common method to assess the potential existence on the national level even though the results should be considered with caution due to weaknesses associated with them. The advantage of those models lies in their ability to provide precise results on the size of EE1 Gap in form of ktoe or percentage. It allows the calculation of the costs of closing the gap or the GHG emissions, which could be avoided through additional measures. This information can help stakeholders and policymakers to promote investments and the implementation of measures related to EE

7.2 Data and Methodology

The data used to compare the optimal level of EE with the realized investments is extracted from the study "Technical assistance services to assess the energy savings potentials at national and European level" by ICF for the European Commission (EC 2021). The study presents a detailed assessment of the technical and economic final energy saving potentials with the EU. The assessment is conducted for all 27 MS and covers energy intensive industries, commercial, residential and transport sector. The results are presented separately for each sector, which makes it possible to determine which sector might be most affected by the EE1 Gap. Regarding the timeframe, the study examines the periods from 2020 until 2050. However, for purpose of this study, only the data until 2030 is extracted.

In order to make assertions about an ex-ante quantification about the EE1 Gap in 2030, the difference between the market and the techno-economic potentials has to be established (Ó Broin et al. 2015, p. 978). Regarding the market potential, the ICF study provides a BAU baseline with projections about the final energy demand until 2030. The base year information builds on data from 2015-2017 and were primarily obtained from Eurostat, ODYSSEE-MURE as well as national energy database. The techno-economic potentials were assessed by utilizing a bottom-up energy account framework. The EE measures in the model are based on extensive data about the technical and financial performance of different technologies as well as management best practices. In combination with detailed profiles on the MS and the national subsector end-use, the model delivers the technical saving potential for each country. Afterwards the technical saving potentials are tested for cost-effectiveness, which results in the economic EE saving potentials. The discount rates applied for the calculations of the economic efficiency potentials were mainly sourced from the EU countries' 2018 cost optimal reports. Figure 8. provides an overview of those discount rates as implied by the report of each country.

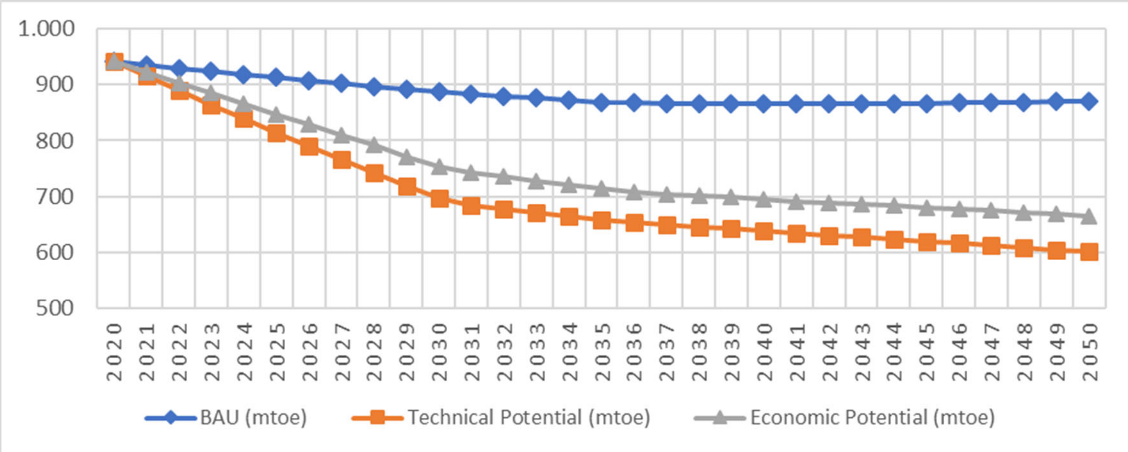
Figure 8: Discount Rates applied in the ICF Study

Source: Own illustration with data from ICF Study

7.3 Evaluation of EE1 Gap

Figure 9 presents the development of the aggregated technical and economic saving potentials across the four sectors within the EU until 2030. While the relatively small difference between the technical and economic saving potentials indicate that the majority of technical potentials are also cost-efficient, the early divergence from the BAU implies that a significant amount of EE potentials is left untapped.

Figure 9: Different EE scenarios until 2030

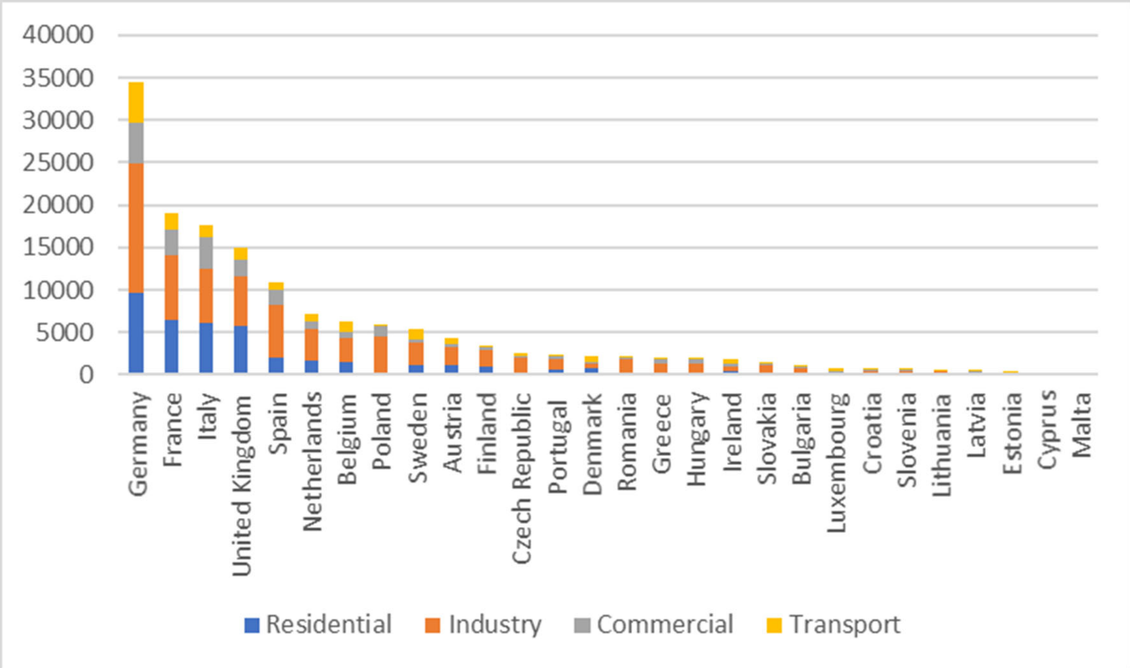


Source: Based on (EC 2021b)

According to the BAU scenario the final energy consumption declines from 948 Mtoe in 2020 to 887 Mtoe in 2030 across the EU. While this constitutes a reduction of 6 percent, this scenario fails to achieve the EE target for 2030 of at least 32.5 percent across the EU. In absolute terms, the target means that the final energy consumption in the EU should not surpass 846 Mtoe, whereby by the BAU misses the target by 41 Mtoe (EP 2019, p. 4). However, the graph demonstrates that an exploitation of the economic efficiency potentials allows the EU to meet the target of 32.5 percent and even to exceed it by 11 percent with a final energy demand of 752 Mtoe in 2030. The result is an EE1 Gap of 135 Mtoe, which represents an opportunity to reduce the final energy consumption in a cost-efficient manner by an additional 15.2 percent compared to the BAU scenario.

Figure 10 provides an insight into how the EE1 Gap is spread across all countries and sectors. The bars in the diagram show the total amount of economic EE potential, which is left untapped by each MS respectively. Furthermore, each bar breaks down the final economic saving potentials by the four sectors. Overall, it becomes visible that both the untapped potentials in residential sector and in the industry are responsible for the majority of the EE1 Gap across all MS. With a cost-effective saving potential of 34 Mtoe in the residential sector and 64.7 Mtoe within the industries compared to the BAU scenario, the two sectors make up more than 70 percent of the EE1 Gap.

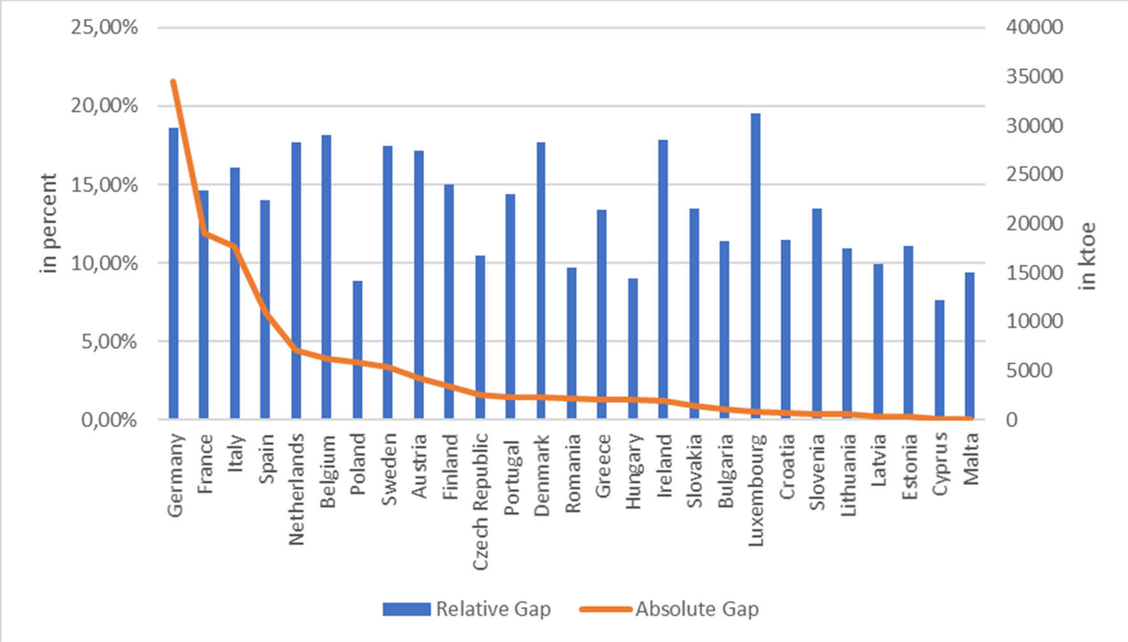
Figure 10: Absolute EE1 Gap across sectors in the EU



Source: Based on data from (EC 2021)

In absolute terms, the EE1 Gap is most profound in the larger economies of the EU like Germany, France and Italy and becomes less significant in the smaller MS such as Malta and Cyprus. In total, the top 10 MS with the highest amount of economic saving potentials amount to 84 percent of total EU economic potential savings. While this ranking demonstrates which countries hold the largest amount of economic savings potential potentials, it does not necessarily reflect the performance of countries regarding their efforts in EE. This is due to the fact that a range of macroeconomic factors like the size of the population, GDP or the structure of the economy influence total energy consumption and hence, also the absolute saving potential. To make any assertions about the performance of the MS, the relative EE1 Gap represents are more viable benchmark. Figure 11 shows both the absolute and the relative share of economic EE potentials, which are left unexploited by the MS. The lack of correlation between the two values demonstrate that the absolute EE1 Gap is not sufficient to make assertions about the performance of countries. For instance, Luxemburg has an absolute EE1 Gap of 766.1 Mtoe and thereby, is located at the lower end of the country ranking. However, the relative EE1 Gap amounts to 19.52 percent and is the highest in Europe. This indicates that the low absolute EE1 Gap may rather be related to the small country size and other macroeconomic factors than to strong efforts in EE.

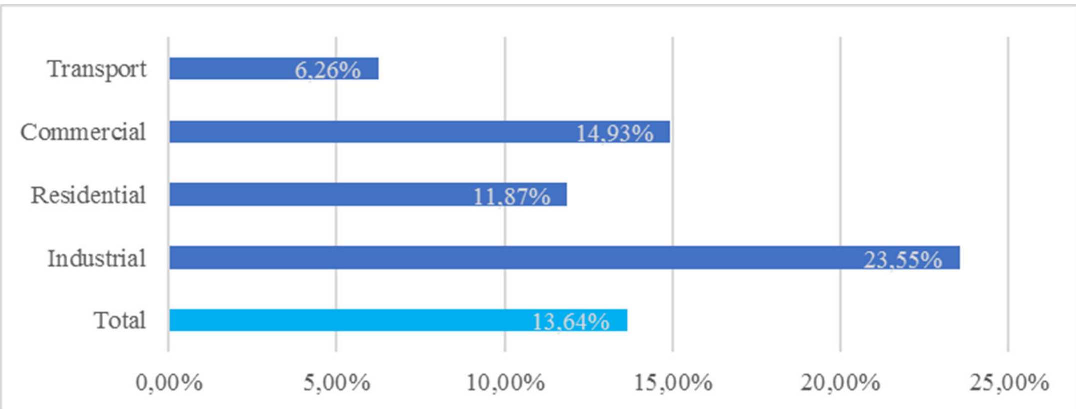
Figure 11: Relative and Absolute EE1 Gap



Source: Based on data from (EC 2021b)

Overall, the relative EE1 Gap of most countries ranges between 10 and 20 percent. Similar to the absolute EE1 Gap, the relative EE1 Gap is not spread equally across sectors. Across the EU the EE1 Gap is the largest both in absolute as well as in relative terms in the industrial sector. Figure 12 illustrates that with a relative EE1 Gap of almost 23.6 percent the share of economic EE potential overlooked within the EU industries by far exceeds the overlooked potential in other sectors and by around 10 percentage points the EU average. The lowest EE1 Gap is in the transport sector with 6.3 percent and 18 Mtoe economic energy savings untapped by 2030.

Figure 12: Relative EE1 Gap across sectors



Source: Own elaboration

8 Channel III: Country comparison

8.1 Benchmarking as a tool to detect untapped EE potentials

This dimension addresses the challenge of establishing an optimal scenario or target to which a country's performance should be compared to. The failure to capture hidden costs, unforeseen events and to correctly model behavioral attributes often results in the definition of unrealistic scenarios as the optimal level of EE. This channel solves this issue by comparing the performance of countries against each other and using the best-performing one as a benchmark. This ensure that the performance of countries is compared to realistic and achievable targets. As stated previously, this approach is commonly used by the IEA to the EE potentials in the industry. However, to the current knowledge the same method has not been applied across all sectors to detect the total EE deficiencies on the country level.

This raises the question on how to best assess the EE performance for the total economic across different countries. Energy intensity is often used to assess the EE of a country's economy. The advantage of this indicator is that the required data is relatively easily available and comparable across countries. However, using energy intensity as a proxy for EE ignores the influence of other components energy intensity such as the climate, or economic structure. For instance, a small service-based country with a mild climate would have a lower intensity than a large industry-based country with a cold climate, even if energy is used more efficiently in the latter country (IEA 2020). This means, that low energy intensity is not necessarily an indication for high EE and thus, benchmarking countries solely based on energy intensity is likely to lead to biased results. Therefore, another approach to the assessment of EE is the application of multiple indicators. This allows to solve the issue the issue of various drivers of energy consumption and trends as well as to capture the different aspects of EE.

Apart from organizations such as the IEA or American Council for an Energy-Efficient Economy, the approach of multiple indicators is also chosen by the ODYSSEE-MURE database, which provides the most comprehensive data on EE, energy trends, and underlying drivers in Europe. This database was developed with the purpose to improve the monitoring of EE progress and EE policies within the MS. It contains information on the 27 MS as well as Norway, Switzerland, and Serbia since the year 2000. The database contains the so-called EU EE scoreboard, which describes the EE performance of the MS based on three indicators: EE level, EE progress, and EE policies. Together the three indicators provide a holistic insight into the EE performance of countries and thus, are used in the dimensions to benchmark the countries against each other.

Regarding EE level, the ODYSSEE database sets the focus not on the aggregated energy consumption per country, but on the unit consumption of individual end-uses, for instance the unit consumption of cars. The second indicator on the EE progress of countries, was constructed in the same manner. This means, that the total EE trend is an aggregation of the individual trends on the level of different end-uses. The advantage of assessing the EE trend and level performance on the level of different end-uses instead of on the level of the whole economy, is the possibility to compare countries irrespective of country-specific attributes like the climate, demographic, and economic structure. The third indicator used in this dimension examines the performance of countries in respect to EE policies. In contrast to other scoreboards on EE such as the International Scorecard of the American Council for an Energy Efficient Economy, the ODYSSEE database focuses on the quantitative impact of EE measures and not just on the total number of policies. The impact is quantified in form of energy savings, which are then divided by the total energy consumption of the respective country. This step makes the assessments comparable across countries since the impact of the policies is evaluated in respect to the total consumption of each MS (ODYSSEE-MURE 2020a).

For the purpose of this paper, the results of the three indicators are merged to a single indicator to generate holistic and comparable views on the EE performance of countries. While the data in this dimension relates to the current performance of countries, it still has the capability to make implications on the state of EE in 2030. Firstly, the policy indicator already includes the NECPs and thus, considers all existing and planned policies until 2030. And while the EE level on its own is not sufficient to make predictions about the future, together with EE trends it constitutes the base for a range of forecasting methods, like the drift method (Hyndman and Athanasopoulos 2014, pp. 183–195). Therefore, the third dimension provides a simple, but reliable impression of the path the MS are on regarding their EE performance until 2030.

8.2 Methodology and Data

The main source of data for this dimension is the ODYSSEE-MURE database. This database was developed with the purpose to improve the monitoring of EE progress and EE policies within the MS. It contains information on the 27 MS as well as Norway, Switzerland, and Serbia since the year 2000. For this paper, three indicators are extracted from the database: EE Level, EE trends, and EE policies. The indicators are normalized, so that they range between 0 and 1. The minimum and maximum values reflect the best and worst scores, while the other countries rank between these two extrema. Since, only 14 of the 27 MS are examined in this paper, the indicators have to be adjusted accordingly. Therefore, the min-max normalization is applied to all three indicators to guarantee that 0 still presents the worst scoring country among the 14 MS and 1 equals the best performing one. The calculations are conducted with the following formula, whereby *i* stands for the different indicators and *j* depicts the countries.

$$x_{i,j}^{n} = \frac{x_{i,j} - x_{i,j}(min)}{x_{i,j}(max) - x_{i,j}(min)} \qquad i = 1,2,3 \qquad j = 1,2, \ldots .,14$$

The second step is to develop a combined score for each country based on the three indicators. While the ODYSSEE-MURE database already provides a combined indicator, this one is not used in the paper. The reason for this is the method, which was chosen to aggregate the three single indicators. In the ODYSSEE-MURE database the arithmetic mean of three indicators represents the combined score for each MS. However, for this paper, a geometric aggregation seems more suitable as it introduces some degree of non-compensability between the individual indictors and rewards the MS with higher scores. For the calculation of the geometric mean, the standard formula is the following:

$$I_j = (x_{1,j})^{1/3} * (x_{2,j})^{1/3} * (x_{3,j})^{1/3}$$

Since the worst performing MS receive a score of 0 in the three indicators, a simple multiplication of the three sources automatically leads to a score of 0 for the worst performing countries. Consequently, a score of 0 in one of the three indicators means that the achievements in the other indicators are not considered at all in the overall result. To avoid this, the standard formula for the geometric mean in this paper is slightly adjusted by adding a value of 1 to each indicator. As consequence the worst performing countries range at 1 and the best performing ones at 2. This way, the better performing countries are still rewarded, while the achievements in all three indicators of the worst performing MS are still considered in the combined score.

$$I_j = (x_{1,j} + 1)^{1/3} * (x_{2,j} + 1)^{1/3} * (x_{3,j} + 1)^{1/3}$$

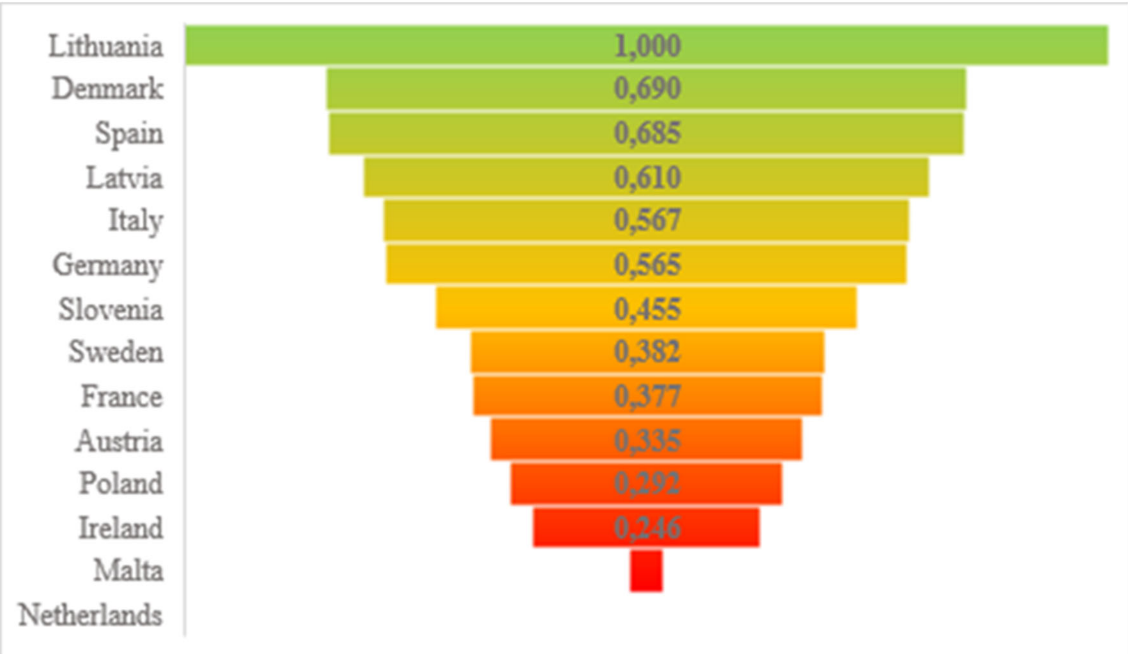
The final step is to normalize the combined score. This is done with the min-max normalization, which is the same method as applied in the normalization of the individual indicators level, trend, and policies.

8.3 Results

8.3.1 Level of Energy Efficiency

Figure 13 displays the ranking of the 14 MS in regard to their level of EE. Lithuania leads the ranking with a great Gap to the second place Demark. Below 0.30 points have Ireland, Malta and the Netherlands. Overall, the form resembles a bell shape with the majority of countries ranging in the second third of the bell. Furthermore, 6 of the 14 MS receive a score between 0.45 and 0.70. This means that the distribution for the level of EE is slightly skewed towards the best performing MS.

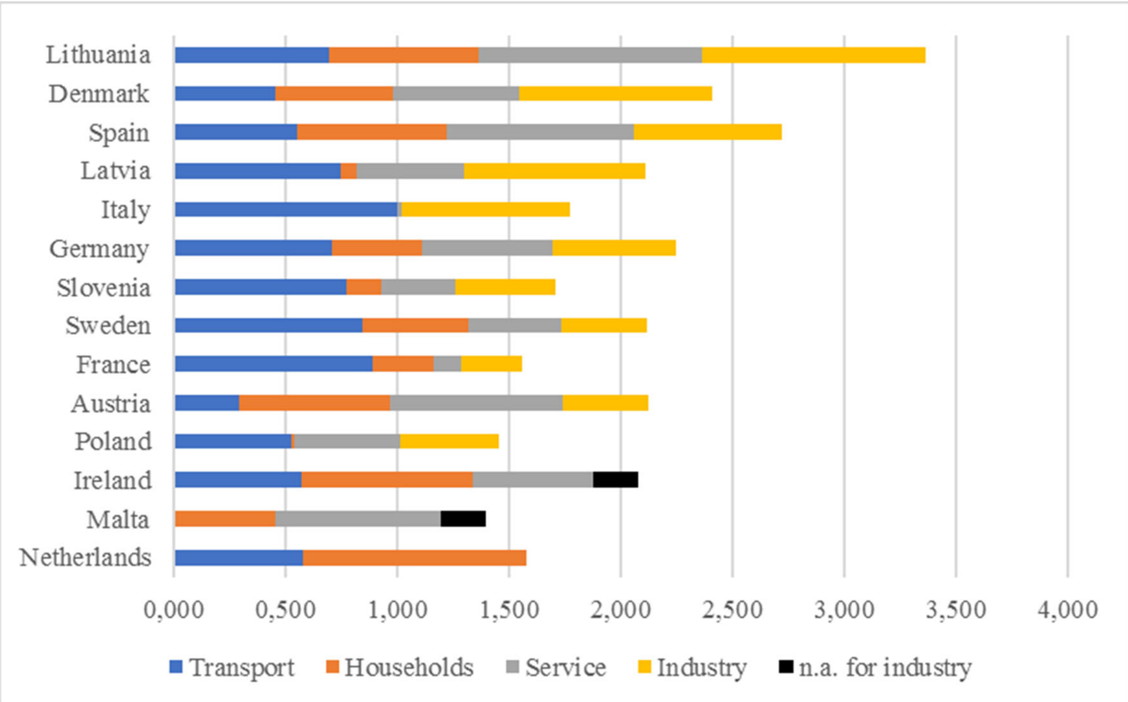
Figure 13: Level of EE across the 14 MS



Source: Own elaboration

Figure 14 displays the score each country received for the level of EE in the different sectors industry, transport, service and residential. The order is in accordance with the total score for the level indicator, whereby the performance of the countries descend from the top to the bottom. There are a few insights, which can be taken from the graph. Firstly, the transport sector has on average the highest level of EE within the MS. The average score is at 0.62 in the transport sector, while with an average score of 0.44 the residential sector has the lowest level of EE. Secondly, even though the Netherlands have the best EE performance in the residential sector, they hold the last position in total as they neglect the industrial and service sectors. A similar contrast can be observed in Italy, whose transport sector shows the highest EE level across the MS, while the opposite applies to the residential sector in Italy. This shows that the level of EE can partly vary considerably across the sectors within country and hence, underlines the necessity to evaluate sectors and even sub-sectors in order to get an impression of EE in national economies.

Figure 14: Level of EE by Sectors

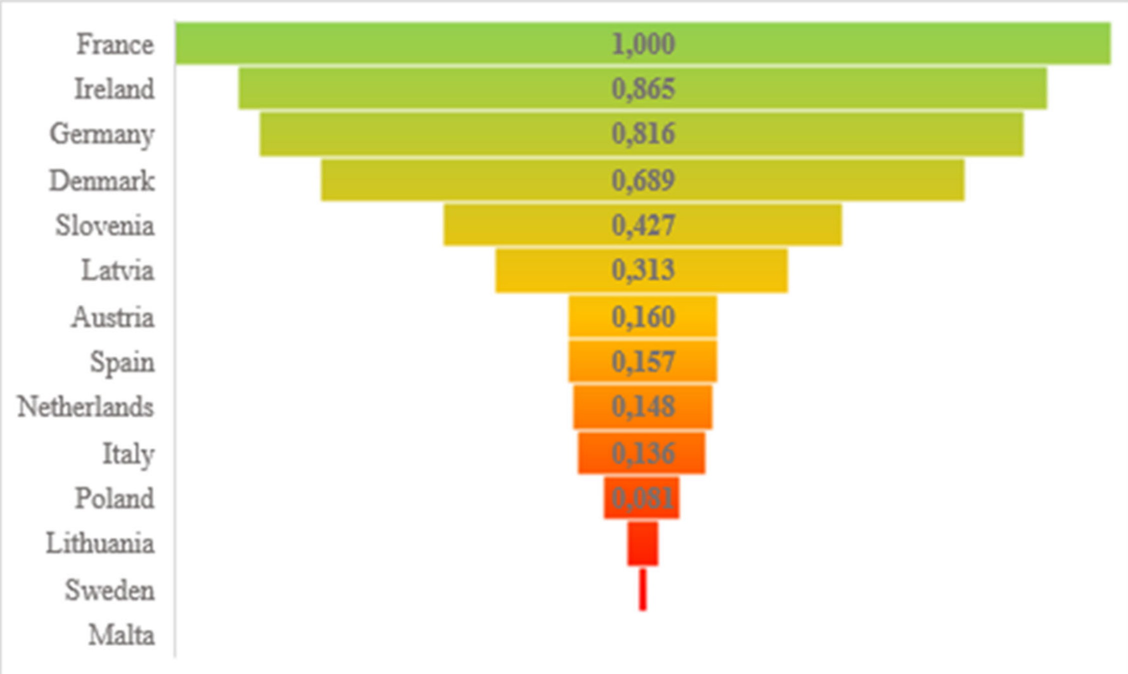


Source: Own elaboration

8.3.2 Policies on Energy Efficiency

The ranking of the MS regarding their EE policies is summarized in Figure 15. In contrast to Figure 14, the shape equals a steep pyramid, which implies skewness of the performance distribution towards the worst performing MS. In fact, with 9 countries the majority of MS are positioned within the lower third of the scoring system. With 0.48 points, Slovenia is the only country in the second third and the remaining five MS are located at the top. This distribution implicates that despite a few well-preforming countries, there are still a lot of deficiencies regarding the number and the impact of EE policies across the EU.

Figure 15: EE Policies across the 14 MS



Source: Own elaboration

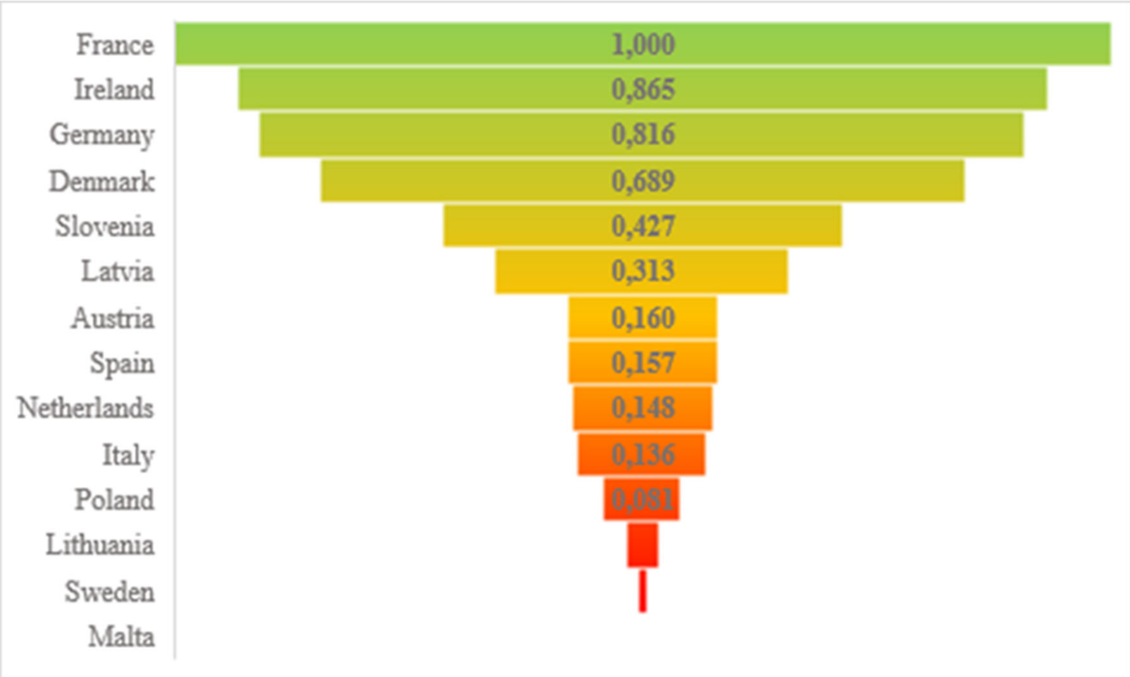
The comparison of rankings between the indicator level and the indictor trend implies that the policy ranking not necessarily determine the level of EE. This becomes obvious in the case of Lithuania, who rank first in regard to the level of EE but are among the three worst performing countries in regard to EE policies. The opposite applies to Ireland, who hold the second position in the policy indicator and are among bottom three countries at the level indicator. However, the results are not always contrary as demonstrated by Germany or Demark, whose performance ranks at the top half for both indicators.

With respect to the EE policies across the different sectors, the residential sector receives the least attention by EE policies and most extensive coverage experiences the industry. The average score in the industry and thus highest average score across sector lies at 0.40. This is in contrast to the lowest average score of 0.44 in context of the level indictor and underlines the prevailing deficiencies regarding EE policies across the EU.

8.3.3 Progress in Energy Efficiency

Figure 16 provides an overview of how the countries rank against each other with respect to the EE trends. The shape of the results resembles a bell shape with some outliers at the top. This implies that the scores are spread relatively equally across the scoring system. The top third constitutes the outlier with Ireland, Latvia, and the Netherlands. The remaining countries are distributed equally across the other thirds, whereby the bottom third includes 5 MS and the second third 6 MS.

Figure 16: EE trend across the 14 MS



Source: Own elaboration

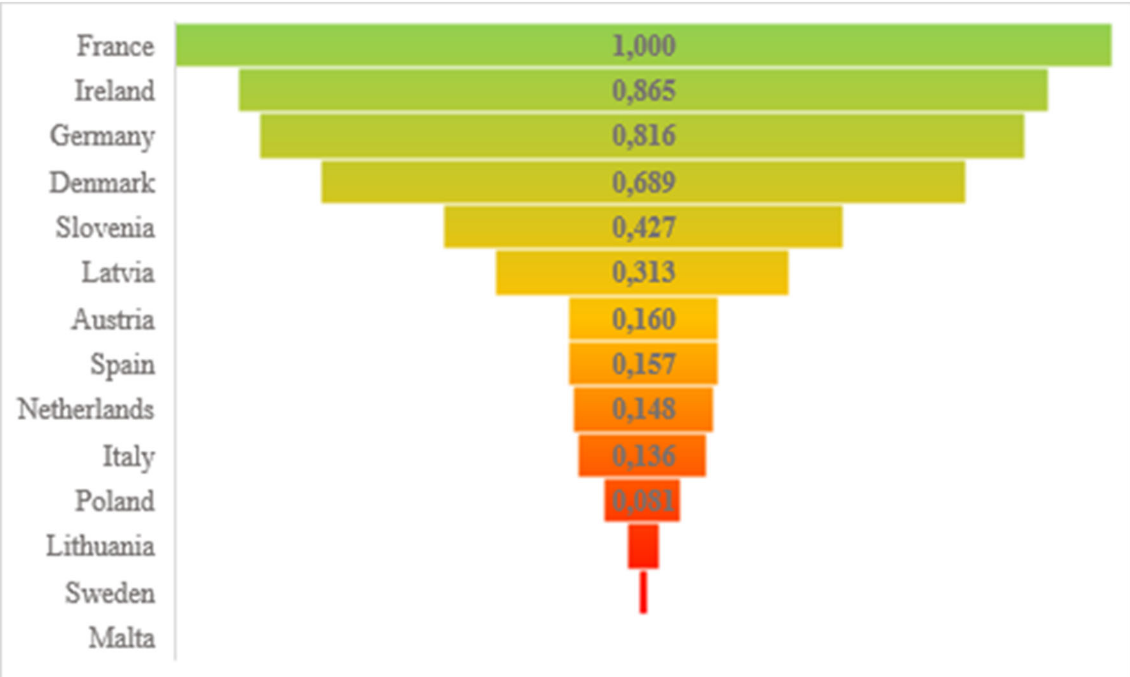
It can be observed that countries like Ireland and the Netherlands, which rank low at the score board of the level indicator, are located among the highest ranks regarding EE trends. In a similar manner, has Spain with a score of 0.68 a relatively high level of EE, but is among the bottom three with regard to EE trends. A possible explanation for this could be fact that countries with a high level of EE have less room for improvements and hence, make smaller progress, which translated into slower trends. However, this pattern is not clear due countries like Latvia, whose scores is in both cases above 0.60, or Poland and Austria, which rank among the bottom five with score below 0.35 for both indicators. Similar relationships emerge from comparing the rankings of the policies and the trend indicator. France and Ireland lead the scoring board of EE policies and are positioned among three steepest EE trends. This seems logical as good policies might lead to progress and hence, positive trends. On the other hand, the Netherlands only reach a sore of 0.15 for their EE policies, but still rank third on the scale of EE progress.

With the respect to the sectoral progress in EE, the steepest trend can be observed in the transportation sector and the lowest progress in the industry. The latter observation is contrast to the extensive coverage of policies in regard to the industry.

8.3.4 Combined Results

The combined score considers the performance of each country across the three indicators level, trend and policies. Overall, Ireland and France lead the total ranking. Further three countries are positioned in top third and thus, rank close to Ireland as best performing country and thus, benchmark. However, with 6 countries the most MS are within the bottom third. Across all indicators, Malta holds the last positions in total. Poland follows with a slight distance at a score of 0.12 (see Figure 17).

Figure 17: Combined score of the benchmarking process



Source: Own elaboration

9 Composite Indicator: The Energy Efficiency First Gap across the EU

9.1 Methodology

After assessing the EE performance of the MS from different perspectives through the three channels, the results are unified into a single indicator. The purpose of this indicator is to provide an insight on the performance of countries regarding EE, to detect potential deficiencies and hence, the existence of an EE1 Gap. The construction of the indicator follows the guidelines of the OECD (OECD 2008). In this context, the process and the theoretical reasons behind the selected tools and method for the indicator on the EE1 Gap were presented. In this chapter follows the practical application of the multiple steps required to establish the composite indicator.

Normalization

Since the quantitative information of the three dimensions differs, the data needs to be normalized make them comparable. For this purpose, the MS receive a categorical score for each indicator. Therefore, the first step of the normalization process is to create numerical categories, which are assigned to each indicator (OECD Economics Department Working Papers 2014, p. 44) For this purpose a scale from 1 to 7 is selected. Thereby, a value of 1 represents a low performance in the individual dimensions and a score of 7 is assigned to the highest scores. The decision chose a scale of 7 is based on the output of final indicator on the EE1 Gap, which consists of the seven EE label A to G.

Before the scores are assigned to the performance of the MS, all three dimensions are converted into a scale from 0 to 100. This means that the closer the score is to 100 points across all indicators, the smaller the size of the EE1 Gap, which facilitates the comparability between the indicators. While the first dimension distributes points from 0 to 2, a transformation of the scale to percentage allows to convert the results into a scale from 0 to 100. In this case, a score of 1, which means a 50 percent compliance rate, would translate into a score of 50. Therefore, the following formula is used for the conversion of channel two.

$$I^*_{1,j} = \frac{I_{1,j}}{2} * 100 \qquad\qquad j = 1,2,\dots\dots,14$$

The values of the second dimension are already in percentage and thus, range between 0 and 100. However, the scores are reversed for the development of this indicator to match the direction of the score. This way across all dimensions 100 constitutes the desirable outcome and 0 the worst results.

$$I^*_{2,j} = \left(100 - I_{2,j}\right) \qquad j = 1,2, \dots \dots ,14$$

The results of the third dimension are distributed on a scale from 0 to 1 and hence, the values were simply multiplied by 100. Thereby, a score of 100 equals the best performing country and 0 the worst performing one. The adjustment is conducted as follows:

$$I^*_{3,j} = I_{3,j} * 100 \qquad j = 1,2, \dots \dots ,14$$

After converting the three dimensions, the scales are classified into the seven different categories. The classifications are adjusted to the information of the individual indicator on the EE1 Gap and thus, differ slightly across the different dimensions. The scoring system is displayed in Table 3.

Table 3: Scoring system of the three channels

Score	Political Effort	Technological	Benchmarking
7	92-100	100	100
6	81-91	92-99	85,7
5	69-80	84-91	71,4
4	55-68	76- 83	57,1
3	39-54	68-75	42,9
2	21-38	60-67	28,6
1	0-20	< 60	14,3

Source: Own elaboration

Aggregation and weights

To combine the three individual dimensions into a single indicator, simple additive weighting is applied. The linear aggregation ensures that all perspectives are accounted for in the total assessment, while at the same time allows for some degree of compensability between the three dimensions. Different weights are assigned to the dimensions to compensate for the issue of combing relative and absolute performances. The result is the following formula as the base for the composite indicator on the EE1 Gap.

$$I_j = \frac{2}{5} * I^*_{1,j} + \frac{2}{5} * I^*_{2,j} + \frac{1}{5} * I^*_{3,j} \qquad j = 1,2, \dots \dots ,14$$

9.2 Results on the EE1 Gap in the EU

The EE1 Gap describes a state in which “some energy-efficiency technologies that would be socially efficient are not adopted” (Gerarden et al. 2015, p. 1). The purpose of this paper was to examine to which extent this applies to the European context. Due to the measurement and modeling errors associated with the assessment of the precise economic EE potentials, the common approach of bottom-up modeling was not chosen to answer this research question. Instead, similar to the EU energy labels, which are applied electric appliances, an EE rating system for the country-level was developed. Table 4 presents the rating system applied to the 14 countries as well the distribution of countries across the EE label A to G.

Table 4: Distribution of results across the EE rating system

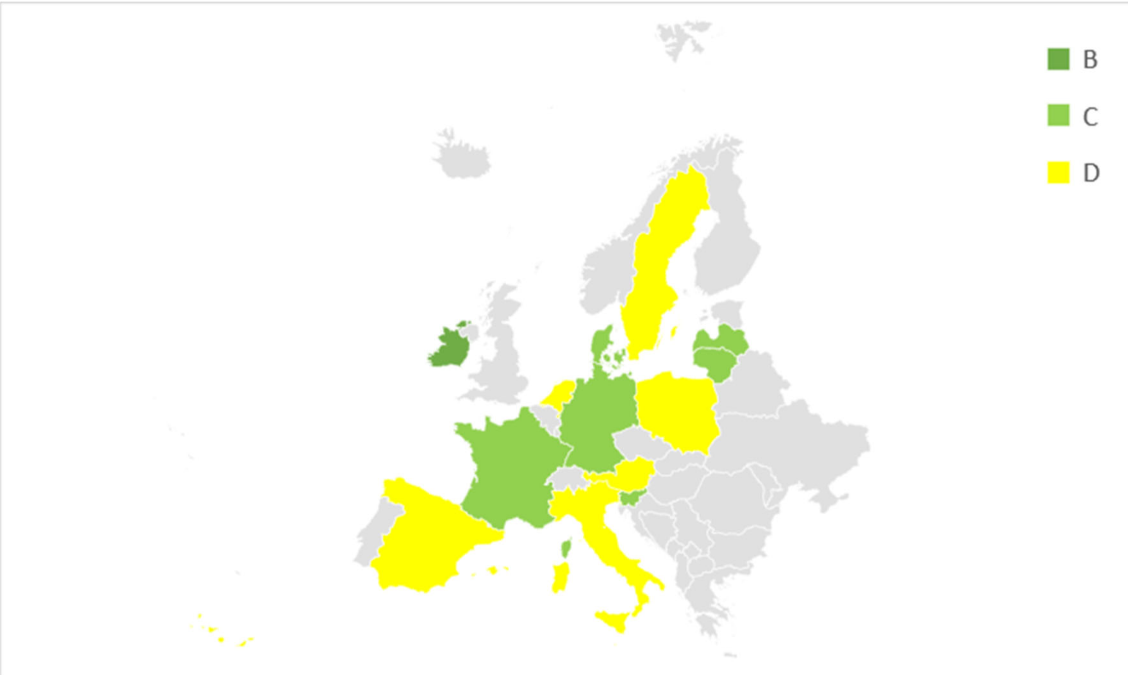
Score	Rating system	Number of MS
A	85,8 – 100	0
B	71,5- 85,7	1
C	57,2- 71,4	6
D	43,0- 57,1	7
E	28,7-42,9	0
F	14,4- 28,6	0
G	0- 14,3	0

Source: Own elaboration

To facilitate the interpretation of the results, the rating system ranges from 0 to 100. The size range of each EE label is kept constant across all scores and amounts 14.3 points. While this scale provides no description on the exact size of a potential EE1 Gap, it uncovers in a simple manner, in which countries still prevail deficiencies with respect to EE. The existence of deficiencies can in turn be interpreted as an existence of an EE1 Gap. This interpretation is in alignment with two of the dimensions used to calculate the score for the EE rating. In dimension I, the highest score is allocated to countries, which exploit the total economic EE potentials and dimension II measures the implementation of a regulation, whereby a full compliance with it allows the full exploitation of the economic EE potentials. Therefore, lower scores in those two dimensions imply a failure to fully exploit the cost-efficient EE potentials and thus, the existence of the EE1 Gap. This way the EE rating scale allows both the detection of an EE1 Gap as well as to differentiate between the sizes of the EE1 Gap. The lower the label in the alphabet the bigger the EE deficiency in the country and thus, the greater the EE1 Gap.

To answer the research question on the potential existence of EE1 Gaps across the EU, 14 MS were examined in this paper. The assessment is based on external data sources as well as on interviews, which were conducted with a range of political stakeholders. A first impression of the EE1 Gap across the EU is given in Figure 18. The 14 MS examined in this paper are highlighted in color. The map shows that the 14 countries range between rating of D to B and thus, are overall positioned in the upper half of the scale.

Figure 18: EE1 Gap across the EU

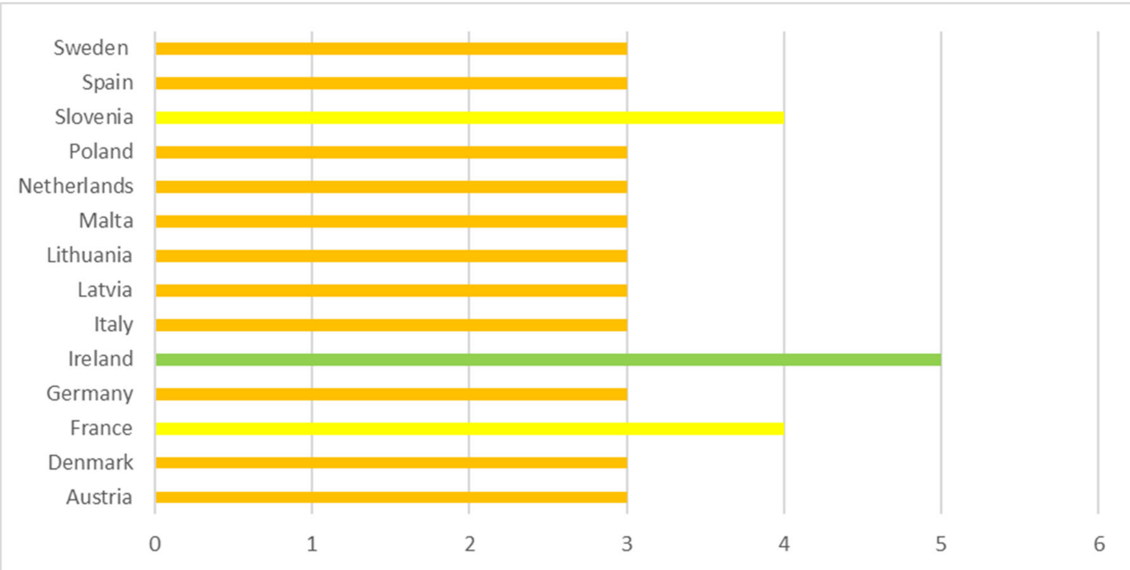


Source: Own elaboration

The best performing country is Ireland with a score of 77, which qualifies it for the EE label B. Thereby, it is the only country among the 14 countries to receive this label and thus, stands out with its EE performance. The second-best country on the ranking is France, which follows with a significant distance and a score 68.6 out of 100. This means, both countries are among the countries with a C-label for their EE performance. In total, 6 out of the 14 MS are classified as countries with an EE label of C. The distance among the 6 countries with a C rating is relatively small with the respective scores ranging from 62.9 to 68.6. The remaining 7 and thus, the majority of the MS follow with a D-label. Among those 7 MS are both countries from warmer climate zones like Italy and Spain, but also northern regions like Sweden. While no country received a A-label, it is also noticeable that no country is located among the bottom half the scale with a E, F, or G label for its EE performance.

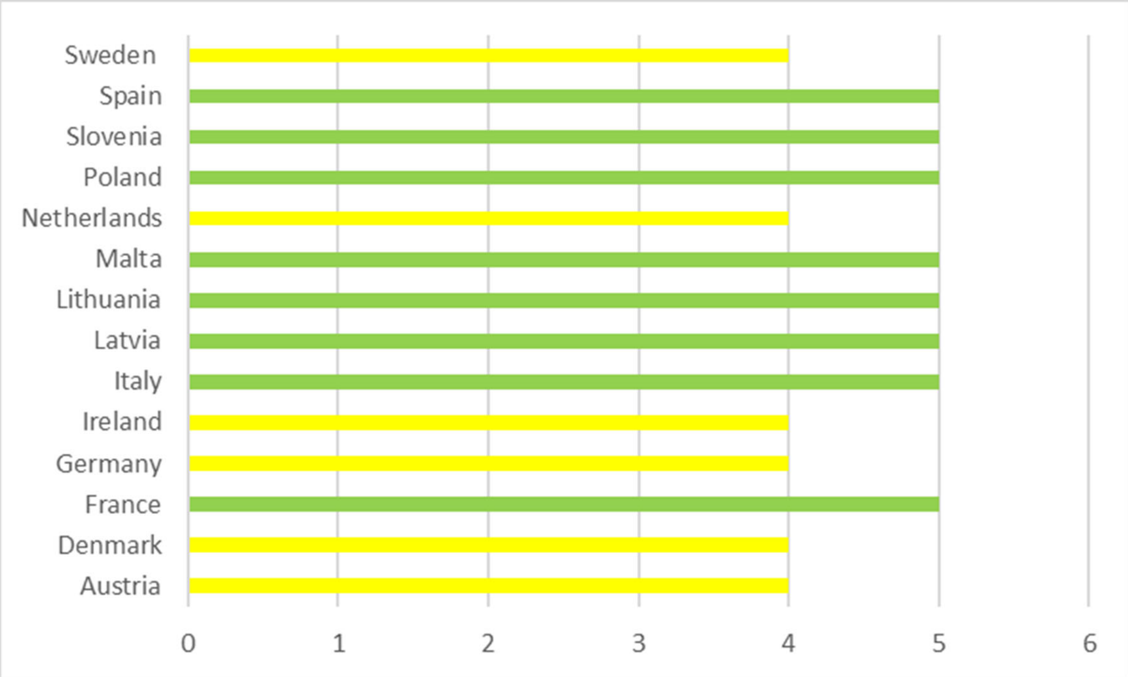
While the results, which were presented for each channel in the chapters 6 to 8, already provide a detailed insight into the performance of the MS in the respective dimensions, figure 19–21 summarize the results with same EE rating system as applied to the overall results. The presentation shows that according to the traditional measurement approach of the EE1 Gap, with a C-rating Ireland are on the same level as the majority of countries. Instead, states like Poland, Malta and Latvia seem to hold the leading positions with respect to their EE performance. This ranking changes as soon as the second dimension is considered as well. In Figure 20, Ireland sets itself apart from the other MS. The third dimension supports the leading position of Ireland, in which an EE label of A is only allocated to Ireland, Denmark and France. The opposite to Ireland constitutes Malta, which in the first dimension is among the top performers, belongs to the average in the second dimension and receives the worst rating in the benchmarking process. However, countries like Latvia and Lithuania shows that some countries hold similar rankings across all dimensions. Both in the first- and third-dimension Latvia and Lithuania receive green coloured labels and perform above average. In this second dimension they are among the average, but as only two countries differ from the E rating, it does not impact their overall ranking compared to the other countries.

Figure 19: EE rating score regarding political effort



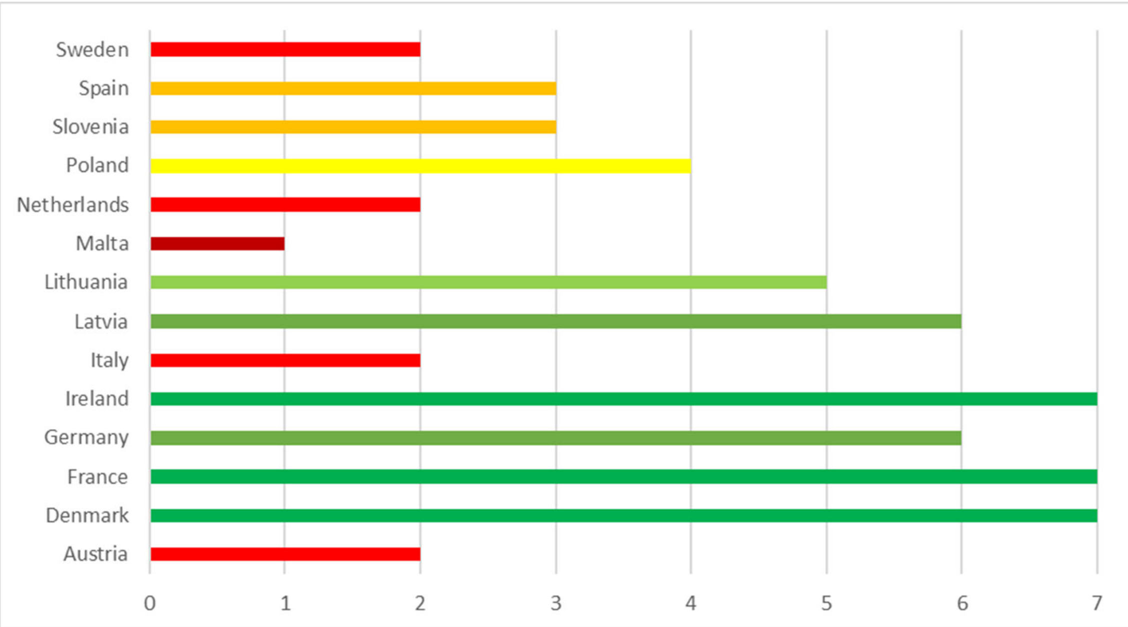
Source: Own elaboration

Figure 20: EE rating from a technological perspective



Source: Own elaboration

Figure 21: EE rating score for Benchmarking



Source: Own elaboration

9.3 Sensitivity Analysis

The dependency of the results on the weighting scheme of the three dimensions are tested through a sensitivity analysis. Table 5 shows the different score and label each country reached depending on the weighting scheme. For this analysis, three different weighting schemes were chosen. Option I describes the actual formula, which was used to assess the EE1 Gap across the EU. Option II also assigns equal weights to dimension I and II of the indicator but puts a lower weight on dimension III compared to the original equation. Option III excludes dimension III completely to evaluate how the inclusion of a relative ranking impacts the overall results.

- Option I: $I_j = \frac{2}{5} * I_{1,j}^* + \frac{2}{5} * I_{2,j}^* + \frac{1}{5} * I_{3,j}^* \qquad j = 1,2, \dots \dots ,14$
- Option II: $I_j = \frac{3}{7} * I_{1,j}^* + \frac{3}{7} * I_{2,j}^* + \frac{1}{7} * I_{3,j}^* \qquad j = 1,2, \dots \dots ,14$
- Option III: $I_j = \frac{1}{2} * I_{1,j}^* + \frac{1}{2} * I_{2,j}^* + 0 * I_{3,j}^* \qquad j = 1,2, \dots \dots ,14$

Table 5: Sensitivity Analysis of the Results

Country	**Option I**		**Option II**		**Option III**	
	Score	Label	Score	Label	Score	Label
Austria	51,43	D	53,06	D	57,14	D
Denmark	65,71	C	63,27	C	57,14	D
France	68,57	C	63,27	C	57,14	D
Germany	62,86	C	61,22	C	57,14	D
Ireland	77,14	B	75,51	B	71,43	C
Italy	51,43	D	53,06	D	57,14	C
Latvia	64,54	C	67,35	C	64,29	C
Lithuania	65,71	C	65,31	C	64,29	C
Malta	54,29	D	57,14	D	64,29	C
Netherlands	51,43	D	53,06	D	57,14	D
Poland	62,86	C	63,27	C	64,29	C
Slovenia	65,71	C	67,35	C	71,43	C
Spain	54,29	D	55,10	D	57,14	D
Sweden	51,43	D	53,06	D	57,14	D

Source: Own elaboration

Two lessons can be learned from the sensitivity analysis. Firstly, the difference between Option I and Option II is statistically not significant. This is demonstrated by the EE labels, which are kept unchanged for the MS across both options. A t-test for the two options confirms this with a p-value of 0.72. Table 6 summarizes the results of the t-test.

Table 6: Two-sided t-test for different weighting schemes

	Option I	Option II
Mean	60,6122449	60,787172
Variance	66,78627495	48,1713206
Observation	14	14
Pearson correlation	0,985648425	
Hypothetical difference in mean values	0	
Degrees of freedom (df)	13	
t-statistic	-0,369059466	
P(T<=t) two-sided	0,718024621	
Critical t-value with two-sided t-test	2,160368656	

Source: Own elaboration

Similar results deliver the t-test for Option I and III. However, in this case the individual EE labels of the countries change, even though overall the EE labels still predominantly range between C and D. MS like Austria, Denmark and France have a D-rating instead of C and others like Italy, Malta and Lithuania improved from a D label to a C-rating. The sensitivity analysis shows that the inclusion of benchmarking in form the third dimension impacts the distribution of the EE labels across the different MS, but due to the weighting scheme of the indicator it has no significant impact on the overall results for the EU.

Table 7: Two-sided t-test for different weighting schemes

	Option I	Option III
Mean	60,6122449	61,2244898
Variance	66,7862749	29,154519
Observation	14	14
Pearson correlation	0,65054291	
Hypothetical difference in mean values	0	
Degrees of freedom (df)	13	
t-statistic	-0,3690595	
P(T<=t) two-sided	0,71802462	
Critical t-value with tow sided t-test	2,16036866	

10 Discussion

10.1 EE1 Gap in the EU

As outlined in the previous chapter, no MS reached an EE-label of A. This implies that all 14 countries continue to underinvest in EE and thus, are not able to close the EE1 Gap with their current and planned energy measures until 2030.

On one hand, these results are in accordance with the findings of previous literature. As stated in the introduction, there are disagreements about the size of the Gap, but they predominantly agree on the general existence of the EE1 Gap and the existence of barriers, which might impede the uptake of EE technologies. Regarding the EE1 Gap specifically in the EU, only few studies have committed to examine the actual existence of an EE1 Gap across the MS and thereby, mostly focused on specific sectors. For instance, Ó Broin et al. (2015) estimated, that the EE1 Gap in the Swedish residential sector ranges between 14 to 19 percent by 2030 (Ó Broin et al. 2015). In electricity-intensive industries across Sweden the EE1 Gap is even higher and amounts to 35-38 percent (Paramonova et al. 2015, p. 481). Other studies focus more on barriers and evaluate their role in the uptake EE products. In Spain, the hidden costs in the case of electric vehicles and the issue of bounded rationality and principal agent-problems were identified as the most relevant causes for the slow adoption of the EE technologies (Ayala et al. 2021, pp. 10–11). Among Latvian manufacturing companies both imperfect information and high investment costs present the most influential obstacles to EE investments. Further organizational barriers like the low status of energy efficiency, complex decision-making chains and lack of internal control slow down or prevent EE improvement within the companies (Kubule et al. 2019, p. 5). These studies support the assumption that partly due to the influential role of barriers in the uptake of EE technologies, the MS might not be able to close the EE1 Gap by 2030.

On the other hand, the results are surprising considering the emphasis, which is put on EE on the political sphere. The EE1 principle was specifically introduced to solve the issue of underinvestment in EE and thus, to close any possible EE Gaps. Its application constitutes a requirement for the design of the NECP, which encompasses all energy policies and measures until 2030. Therefore, it could be expected that through a successful implementation of the EE1 principle the EE1 Gaps are closed, or at least narrowed by 2030. However, the results imply that by 2030 across all 14 MS the adaption of EE technologies still occurs at a sub-optimal level, which leads to the continuous existence of an EE1 Gap by 2030. A closer look at the compliance rate of the MS with the EE1 principle through channel II of the indicator, shows that actually no MS fully complies with the principle and as a logical consequence the appearance of EE1 Gaps across the EU are not a surprise after all. The interviews, which were conducted in context of channel II, suggest that one reason for deficiencies in the implementation of EE1 is not a lack of willingness, but rather due to a lack of understanding the principle. While there are clear definitions on the EE1 principle, a lack of guidelines for its practical application are missing. Thus, a future provision of clear and structured guidelines on the application of the EE1 principle and on how to close the EE1 Gap might present an effective tool for the MS to narrow the Gap.

10.2 Lessons Learned

Apart from providing an answer to the research question on the potential existence of EE1 Gaps across the EU, the indicator allows to derive some lessons on the underlying reasons of the EE1 Gap in the different countries. This is due to the fact that the indicator is based on multiple dimensions and covers different perspective on EE. This makes the indicator also more insightful compared to the traditional assessment approach to the EE1 Gap since in this case only the technological aspects of EE are examined.

As described in the results, Ireland stands out from the 14 MS as being the only country with a B-label. This means, that by 2030 the EE1 Gap continues to prevail in Ireland, but the untapped EE potentials are smaller compared to the other MS. Particularly prevalent of Irelands EE performance was the fact that it surpassed the second-best country by 10 percentage points. This raises the question how the role and the treatment of EE differs in Ireland to generate those results. A closer look at the benchmarking in the third dimension implies that the strength of Ireland lies in their EE policies. In 2020 the EE level is relatively low with only the Netherlands and Malta showing a lower level of EE. However, through the combination of the highest annual improvement rate in EE and a comprehensive as well as effective set of EE policies, Ireland offsets its current deficiencies in the EE level and thereby, puts itself in the leading position regarding the benchmarking process by 2030. Apart from a sectoral strength in the household and service sector, no direct implication can be drawn on the drivers of the steep technical EE improvements based on the indicator (ODYSSEE-MURE 2020b). However, through the second dimension on the political effort, lessons can be learned about the political strength of Ireland. Table 8 summarize the score the

MS received for each of the 13 criteria. As stated previously, a score of 2 represents a full compliance with the criteria and 0 a failure of compliance.

Table 8: An assessment of the EE1 principle across the NECPs

Category	**Criteria**	AT	DE	DK	ES	FR	**IE**	IT	LT	LV	MT	NL	PL	SE	SI
Policymaking-process	Comparison of supply and demand	2	2	1	2	2	2	2	1	1	2	1	2	1	2
	Cost-benefit analysis	0	0	0	0	1	2	0	1	0	1	1	1	2	2
	Discount rates	2	1	1	0	1	2	0	0	1	0	2	0	1	1
	MBs	0	1	1	1	1	1	1	1	1	1	0	1	1	0
	Economic efficiency potentials	0	1	1	1	1	2	1	1	0	1	1	1	1	1
Removal of barriers	Prevention of distorted markets	0	0	0	1	2	0	1	1	1	0	1	0	0	1
	Access to information	1	2	1	2	1	2	1	1	1	2	1	1	1	1
	Access to capital	1	2	1	1	1	1	1	1	1	1	1	1	1	2
	Risk and certainty	0	1	1	0	1	1	1	1	1	0	0	0	1	1
Challenges	Energy poverty	2	0	0	2	2	2	1	1	1	2	0	1	0	2
	Sufficiency	1	0	1	1	0	1	0	0	0	1	0	0	1	0
Regional and local level	Region and local level	1	1	1	1	1	1	1	2	1	1	2	1	1	1
Monitoring	Monitoring	1	1	2	1	1	1	1	1	2	1	2	2	1	1

Source: Own elaboration

The table shows the Ireland excels in regard to the treatment of EE in the policy-making process. Since this category contains five criteria, the maximum score a country can receive are 10 points. Ireland has a score of 9, which is a significant difference to the second-best score of 6 by France and Slovenia. This indicates that Ireland is the only country in this study, which actually treats EE equally to other resources in its political decision-making processes. Through official guidelines on how to assess EE – cost-benefit analysis, societal discount rates etc. – Ireland ensures that the full value of EE opportunities is taken into account. Additionally, the interviews revealed that Ireland is unique in terms of comparing the impact of their existing and planned measures with the EE potentials. Thereby, they go beyond assessing the economic potentials, but also include behavioral aspect of consumers and companies in the target setting and actively aim to achieve the full exploitation of the economic EE potentials and hence, the closure of the EE1 Gap.

In contrast, the other countries consider economic EE potentials mainly to raise their awareness on sectors and policy areas with high EE potentials, but they not actively aim for the full exploitation of the potentials and thus, closure of the EE1 Gap. In those countries, EE rather seems to be a tool to achieve certain goals like CO2 reduction, but it is not fully viewed yet as a desirable goal on its own. A failure to take the full value of EE opportunities into account and to compare it on equal terms with other resources, leads to undervaluation of EE in decision and policymaking process. Consequently, economic EE opportunities might get overlooked and potentials remain untapped. This becomes evident considering the low scores countries such as Austria, Italy and Malta received in the policy-making process. All three countries receive a D-rating for the EE1 Gap and located at the bottom of the country ranking. Therefore, to ensure that countries actually exploit the existing EE potentials and close the EE1 Gap, countries should make this a target. If countries continue to treat EE more as tool and not as a goal and resource on its own, EE1 Gaps are likely to remain across the EU. Thereby, taking the full value of EE into account, will help stakeholder to detect economic opportunities and improve the political feasibility of EE measures.

10.3 Comparison of the Methodologies

The innovative aspect of this paper was the development of a novel approach to assess the EE1 Gap. The necessity for this development originates from the multiple measurement and modeling errors, which are often associated with the common assessment methodologies, and thus, lead to biased results. The traditional assessment approach was extended through two additional dimensions in order to include the different aspects of and perspective on EE in the assessment. Overall, a direct comparison between the results of the two methods is challenging due to the different output units. The traditional EE1 Gap assessment is conducted with bottom-up engineering studies and evaluates the gap in terms of ktoe or percentage. The indicator approach considers the technological aspect, but together with two further dimensions delivers information on the EE1 Gap in form of different EE labels, whereby every label below A implies deficiencies and thus, the existence of an EE1 Gap. The classification into seven different EE labels allows to differentiate the extent of deficiencies and thus, the size of the EE1 Gap in different countries. However, a specific EE label cannot be assigned a specific size of the gap. Therefore, in the following, the results are not compared by their absolute results, but in relation to the ranking each country holds within the two assessments. Table 9 displays the rankings of the 14 MS and how their ranking changes with the application of the composite indicator developed in this paper compared to the common EE Gap assessment. The data for the ranking of the countries according to the traditional assessment method equals the data used for channel I of the composite indicator.

Table 9: Country ranking according to different methods

Country	Ranking: EE1 Gap	Ranking: EE labels	Difference
Poland	1	7	↓
Malta	2	9	↓
Latvia	3	2	↑
Lithuania	4	3	↑
Slovenia	5	6	↓
Spain	6	10	↓
France	7	3	↑
Italy	8	11	↓
Austria	9	11	↓
Sweden	10	11	↓
Netherlands	11	11	→
Denmark	12	3	↑
Ireland	13	1	↑
Germany	14	7	↑

Source: Own elaboration

The table shows that only the Netherlands holds the same position in both rankings. However, within the composite indicator four countries share the last position and hence, four countries are assigned rank 11. Therefore, it cannot be clearly determined if the position of the Netherlands remains the same across the methodologies. Overall, most countries experience changes to their ranking, whereby the ranking of seven MS decreases and of six MS increases. For the most part, those changes are limited to small alterations to the position. For instance, Lithuania, Latvia, Sweden and Slovenia only move one place and Austria two places on the ranking.

However, there are also outliers with Ireland moving 12 places and Denmark 9 places. Both countries are positioned on the bottom with rank 12 and 13 for the EE1 Gap assessment with the traditional bottom-up approach. According to the composite indicator Ireland is the best performing country and Denmark holds the third place together with France and Lithuania. A closer look at the performance of Ireland in the three individual dimensions reveals, that the current EE level in

Ireland is one of the lowest in the EU, but in regard to the EE trend, policies and the degree of compliance with the EE1 principle Ireland is in the lead compared to the other 13 MS. Since the underlying assumptions of the modeling approach in the first dimension, which is used for the traditional gap assessment, are unknown, it cannot be assessed why the EE level of Ireland is forecasted to remain that low relative to the other MS considering their advantages in EE policies and positive trend in EE.

Nevertheless, the movements in ranking imply that the inclusion of additional dimensions to assess the EE1 Gap has an impact but presents no contradiction to the common measurement approach since for most countries the change in ranking was below 3 positions. On the other hand, outliers like Ireland and Denmark suggest that the two methods seem to value aspects like the current level of EE or EE policies to a different extent, which leads discrepancies in the forecast about the EE1 Gap in the future. However, due the limited scope of this paper, it was not possible to gather the background information necessary on the modeling approach of channel II to establish the drivers of the partly differing rankings.

10.4 Limitations and Future Application

Before drawing an overall conclusion on the EE1 Gap across the MS, the framework of the indicator approach should be taken into account as it comes with some limitations. First of all, the three dimensions come with some limitations.

In the first channel the first potential shortcoming stems from the weighting scheme of the individual indicators. Although the weights are allocated to the best of knowledge and the resources available, some assumptions might be affected by subjective judgement. Second of all, data sources were limited to the NECPs, the ODYSSEE-MURE database as well as interviews, which were conducted with 1 to 4 stakeholders per country. These sources can be considered to be sufficient for the acquirement of necessary information about the policies and measures, which are in place to remove market barriers and combat the challenges to EE. Since this information is formally documented, subjectivity presents no concern in this context. In contrast, the assessment of the EE1 principle in general policy- and decision making requires insights about the policy-making process, which are not necessarily formally and publicly documented. While the interview partners had a comprehensive understanding of the policy-making processes in the respective countries, the small number of interview partners per country might introduce some subjectivity to the assessment.

In the second channel the economic EE potentials are compared with the realized EE investment by 2030. The calculations of economic EE potentials are susceptible to measurement and modeling errors and thus, often over or underestimate the potentials. Similar errors can occur in the forecast of energy consumption due to forecast errors like the misjudgement of trends and behavior as well as the failure to anticipate the introduction of new technologies or change in prices. Due to reliance on external data for the potentials and the energy consumption forecast, it difficult to assess the modeling approach and the underlying assumptions. Therefore, without further research into the data and modelling approach of those scenarios, no valid statement can made about potential upward or downward bias of the scenarios.

However, those potential shortcomings do not interfere with the purpose of this paper. The aim was to develop an indicator to measure the existence of a possible EE1 Gap and to apply it to the European context. Since the measurement errors of the second dimension were known beforehand, the decision was made to not solely rely on this channel to assess the EE1 Gap. Instead, two further channels were added in order to get a more holistic approach and for them to offset the potential modeling errors. The result is a single indicator, which reflects the weighted average of the three dimensions. In contrast to many previous studies on the EE1 Gap, the outcome of the indicator is not a precise number on the size of the gap, but rather an EE label as they are commonly used to rate electrical appliances with respect to their level of EE. According to the current state of knowledge, this constitutes a novel approach to the assessment of the EE1 Gap. In general, information on the exact size of the gap allow to derive information on the costs of closing the gap or the additional emissions caused by the failure to close the gap. However, since statements on the size of gap have been considered with caution due to existing challenges of estimating the economic EE potential, the validity of the implications on cost and environmental aspects are limited as well. The EE labels allow for some extent of bias in the estimations of the economic EE potentials, as it uses two further sources of information to generate the overall assessment. A further advantage lies in the simple and straight forward design of the rating system. It is already a common tool in the field of EE and without a lot of background information the performance of a country can easily be classified. For instance, it can quickly be assessed that France with an EE label C is already on a good path, but improvements still have to be made in order for them to fully exploit the EE potentials. In contrast, the statement that France has an EE1 Gap of 15 percent, makes it difficult to evaluate without prior knowledge if 15 percent implies a lot of deficiencies or if this is considered an acceptable gap.

Due to this simple and straightforward design the application of the indicator is not limited to experts and researchers but allows every interested individual to easily review the EE1 Gap of countries without the necessity of prior knowledge on EE issues. A further target group are politicians and stakeholders involved in the policy process. The first dimension measures the EE1 Gap in form of political effort as a proxy. This dimension evaluates different policies and different aspects of the policy-making process. Therefore, in case of an EE1 Gap, the indicator already points the stakeholder to the areas, in which policymaker can still improve to close the EE1 Gap.

While the bottom-up assessment in this indicator only present one out three perspectives on the EE Gap, the modelling in this dimension should further be improved. For instance, as described above, in Ireland behavioral aspects are already included in modelling of economic EE potentials and hence, generate more realistic scenarios of the economic EE potentials. Another research gap presents the quantification of the role of policymaking on the EE1 Gap. The example of Ireland showed that treatment of EE in the policymaking process can have significant impact on the EE1 Gap. However, based on this paper only assumption can be made about this relationship. The quantification of the relationship between EE policymaking and the EE1 Gap, could provide valuable insight on the understanding of the EE1 Gap and on how the reduce it.

11 Conclusion

The intention of the paper was to provide an answer on the question about the potential existence of an EE1 Gap across the EU. To assess the potential existence of the EE1 Gaps, bottom-models are usually applied. However, this approach has been subject to criticism. The challenge of including hidden costs and unexpected events as well as to correctly map the heterogeneity of human behavior, presents a risk to the validity of those estimations. Furthermore, the dependence of those calculations on the definition of an optimal level of EE, underlying assumption and the application of discount rates make it difficult to compare different assessments. For those reasons, many economists argue that bottom-up model often over- or underestimate the true size of EE1 Gap. To avoid the modeling and measurement errors, which are associated with the traditional assessment method, a novel approach was developed in this paper to answer the question on the potential occurrence of EE1 Gaps across the EU.

For this purpose, a composite indicator was established. The indicator consists of three dimensions, which all reveal untapped EE potentials from a different perspective. Since regulations and policies play an essential role in overcoming the barriers to EE investments and closing the EE1 Gap, political effort was chosen as the first dimension of the composite indicator. In this context, the target is not the implementation of a certain number of policies or measures, but rather the creation of a political and investment environment, which allows and even promotes the exploitation of EE potentials. To assess this, I took advantage of the recently introduced EE1 principle in the EU, which requires the MS to create such an environment and thereby, solve the problem of underinvestment in EE across the EU. The idea behind the EE1 principle is that a full compliance with EE1 principle would enable the MS to exploit the full potential of EE and thus, close the EE1 Gap. Therefore, the compliance rate with the EE1 principle constitutes the first dimensions.

In the second dimension the EE1 Gap is assessed through the classical bottom-up approach. An external study was used to extract the necessary data on the economic EE potential in 2030 and the forecast for the energy consumption by 2030. To assess the EE1 gap, the absolute gap was put in relation to the total energy consumption, to generate the relative EE1 gap.

Benchmarking the countries efforts against each other was chosen as the third dimension. Benchmarking has proofed to be an effective tool to assess untapped

EE potentials in the industrial sector. Furthermore, this dimension avoids the challenge of determining an optimal scenario by comparing the performance of one country to the best performing one. The performance of countries was compared in three different categories: level, trend, and policies. The overall performance of the county was summarized in a combined indicator, which provides a holistic view on the state of EE in the different MS.

While the results of each dimension already generate a first impression on the potential existence and the extent of the EE1 Gap, the three dimensions are merged into a single indicator. The advantage of the composite indicator instead of relying on a single channel is that it provides a more holistic view on the EE1 Gap. Furthermore, taking the average of three source of information on the EE1 Gap allows to offset potential biases, which are associated with bottom-up assessments. The output of the composite indicator is a rating system from A to G such as it is commonly used for EE level of appliances in the EU. In this context, A reflects a very good level of EE and a non-existence of the EE1 Gap, while a rating of G implies significant deficiencies in performance of countries and a substantial EE1 Gap within the countries.

The operationalization of the novel indicator-based approach to the EE1 Gap, was tested in this paper with its application to 14 MS. Among those MS no country received an A-rating, which implies that an EE1 Gap continues to exist in all countries by 2030. Only Ireland is assigned a B label, which means that in comparison to the other MS the extent of the EE1 Gap is the smallest in Ireland. The majority of MS have a C-label, which reflects that EE already presents an issue of importance in this country, but further steps are necessary in order to close the EE1 Gap and exploit the EE potentials. A D-rating is the worst EE label among the 14 MS and was assigned to 6 of them.

In conclusions, it can be assessed that an alternative assessment method to EE1 Gap was developed. Its applicability across different countries was tested and it generated the data necessary to answer the research question of this paper. However, it has to be noted that the output of the composite indicator in form an EE label differs from the common assessment results, which evaluate the EE1 Gap by its size in ktoe or percentage. The rating system in form of EE label was selected, since so far, the current data available as well as the different modeling approaches failed to make precise and reliable ex-ante forecasts. For this reason, a completely different approach was chosen, instead of aiming to construct another bottom-model as an improved version to previous one, but still containing significant biases. The idea was to apply the EE label system, which is already established to assess appliances, to the assessment of countries. The advantage of this evaluation method is that this rating system is already established and commonly used to assess EE performance. Beside observers being familiar with this rating system, the design is simple and straightforward. It allows for an easy interpretation with deep background knowledge and to compare the performance of countries with each other.

The results of this assessment imply that all 14 MS are still affected by an EE1 Gap in 2030. However, those results should not consider as a prediction. Instead, the results serve as indication for policymakers and stakeholders that the current and planned measures until 2030 are insufficient to close the EE1 Gap. Therefore, the results are an impetus for more measures and action in order for the EE potential to be exploited the and the societies to be able to enjoy the MBs associated the EE.

Another challenge to the success the E1 principle is presented by Energy sufficiency. Energy sufficiency relates to changes in consumption patterns that help to remain within the ecological carrying capacity of the earth, whereby aspects of utility of consumption change. Some of those behavior changes and new trends support the E1st principle, while others have a counteracting effect. Examples include lifestyle choice like the number of TVs per household, or the principle of a shared economy.

1. Are measures included in the NECP, which ensure that the consumption changes due to sufficiency choices positively impact the implementation of the E1st principle?

A) **Existence of a regulatory framework for regional and local entities to implement the E1st principle**

The aim of the E1st principle is not only to be applied on the national level in policymaking, but also local and regional entities as well as all participants on the energy market.

2. How is the E1st principle incorporated on the local and regional level? Are there ambitions to introduce the E1st principle in local policymaking e.g. on a voluntary basis, through training of local policymakers?

B) **Monitoring and verification process**

3. What monitoring and verification mechanisms are applied at the national level? Are ex-ante and ex-post evaluations applied?

The question relates both to the E1st principle, but also to the monitoring of efficiency policies and trends in general. In this context, we are particularly interest if one single method is used like bottom-up evaluation or a combination of different approaches (beyond Art.7 EED reporting).

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