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How to estimate energy savings and other gains from application of the Energy Efficiency First Principle

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ABSTRACT

The Energy Efficiency First principle (EE1st principle) was defined in the 2018 EU governance regulation, and further elaborated in the 2023 recast of the Energy Efficiency Directive, which specifies concrete requirements for Member States in its articles 3 and 27. The application of the EE1st principle requires the identification of alternative cost-efficient energy efficiency measures optimising energy demand and supply. These measures must still achieve the objectives of the relevant sectoral policy, planning, and/or major investment decisions.

In this paper, we present a methodology for estimating cost-efficient potential energy savings and other energy efficiency gains, which may particularly stem from the modification of load profiles to better match energy supply and demand.

The overarching methodology differentiates between the energy sector and the energy end-use sectors.

For the energy end-use sectors, the methodology focuses on estimating energy savings potentials. The energy end-use sectors included in the study were: transportation, industry, buildings, ICT services, water and wastewater management, and agriculture. A simplified methodology was applied to estimate the EU-wide energy savings potential for these energy end-use sectors.

For the energy sector - particularly in the electricity sector - the methodology incorporates additional steps to estimate the impact of energy efficiency on the load profile from energy savings, demand-side response and storage. These steps require a dynamic methodological approach, based on forecasting and modelling.

We also discuss the proposed methodology's limitations and future research options to improve the assessment of the potentials of the EE1st principle in policy, planning and major investment decisions.

Introduction

Recent European Union (EU) legislation has introduced and defined the Energy Efficiency First principle (EE1st principle) as a requirement for the assessment and development of decisions in policy, planning, and investment decisions in both the energy sector and all energy end-use sectors.

The core of the EE1st principle is an economic comparison of default infrastructure options in energy supply to alternative energy efficiency solutions on a level playing field. Alternative energy efficiency solutions may aim at both reducing energy demand and at optimizing load profiles. Therefore, application of the EE1st principle may yield energy benefits either in the form of energy savings, or of a better match of the load profiles of energy supply and demand. The latter will also be called 'other energy efficiency gains' for this paper. In addition, further multiple impacts of energy efficiency (IEA, 2014; Thema et al., 2018) may provide other gains. EU legislation also requires these to be included into the economic comparison under the EE1st principle.

This paper aims to develop and discuss methods for estimating the energy savings and other energy efficiency gains from application of the EE1st principle. It is based on a study performed for the European Commission in the context of developing guidance to the EU Member States on how to apply the principle, however, it aims to discuss the wider application of the methodology.

Therefore, this article is a methodological paper. Hence, its results are 1) the methods developed for estimating the energy savings and other energy efficiency gains, and 2) an application for estimating energy savings potentials in energy end-use sectors, with the transport sector as an example.

The next section will provide more background on the EE1st principle and its relation to similar concepts, from whose application we may learn for the methodology. The methodology section is quite brief, since the results of this article are mainly methods. Therefore, the results section will present the principles and methods for assessing energy savings and other energy efficiency gains for both the energy sector and for the energy end-use sectors in general, followed by an application example for the EU's transport sector, and an overview of results for six energy end-use sectors. A discussion of the strengths and limitations of the methods and of the comparability of sectoral results follows, accompanied by considerations on the relationship between the EE1st principle and the future rounds of national energy and climate plans (NECPs) of the EU Member States. Some conclusions and perspectives on further research needs will round off the paper.

Background

The EE1st principle was defined in 2018 in the EU's Governance Regulation (EU, 2018), and the 2023 recast of the Energy Efficiency Directive (EED) (EU, 2023) holds further concrete requirements for Member States in its articles 3 and 27.

The official EU definition (article 2 (18) of the Governance Regulation; EU, 2018) reads: 'energy efficiency first' means taking utmost account in energy planning, and in policy and investment decisions, of alternative cost-efficient energy efficiency 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 decisions'.

Therefore, the EE1st principle gives energy efficiency measures the status of a resource for reaching the objectives of policy decisions at a level playing field to default infrastructure options, provided that a benefit-cost analysis proves their cost-efficiency relative to these default infrastructure options, and provided that they can be relied upon to achieve those same objectives. In that case, energy efficiency measures should even be given priority over the default infrastructure options, although the legal formulation does not clearly state this.

As Mandel et al. (2022) observed, the above legal definition contains at least three important aspects that need further clarification: the objectives of decisions, the resource options available both on the energy

efficiency side and on the energy infrastructure side, and the actual decision rule. The source offers some suggestions for clarification (Mandel et al., 2022).

It is also important to note that the EE1st principle shows significant similarity to the principles of Integrated Resource Planning or Least-Cost Planning developed in the USA and other regions in the 1980ies (e.g., Hirst&Goldman, 1991; Swisher et al., 1997; Wuppertal Institute et al., 2000; Neme&Sedano, 2012; Pató et al., 2020). A major difference, however, is that the EE1st principle covers not only planning and investment decisions, but also policy decisions. In addition, it covers all forms of energy and all energy end-use sectors, as well as a wider range of impacts (Mandel et al., 2022).

Therefore, particularly for planning and major investment decisions in the energy sector, methods to estimate energy savings and other energy efficiency gains that were developed in the USA and elsewhere in an Integrated Resource Planning context (e.g., Swisher et al., 1997; U.S. EPA, 2008) may also inspire the application of the EE1st principle in such cases.

Methods to assess energy efficiency gains in the energy sector must focus not only on estimating energy savings through an increase in energy efficiency, but also on other energy efficiency gains leading to a better match of the load profiles of energy supply and demand. Due to the inherent challenges of balancing supply and demand in real time, the electricity sector is the most complex case for managing energy. Therefore, we analysed the methodology in detail for the electricity sector as a model example, and will briefly discuss its application for other grid-bound subsectors.

Both energy efficiency solutions in energy end-use sectors and in the energy sector itself, such as more energy-efficient transformation (e.g., more energy-efficient power plants) and reduction of grid losses, will directly lead to energy savings. These can be quantified using the wealth of methods developed during the last decades (e.g., U.S. EPA, 2008; Wuppertal Institute et al., 2009; Proceedings of the International Energy Program Evaluation Conferences and the Energy Evaluation Europe Conferences).

However, energy efficiency gains in the energy sector are broader than energy savings and often indirect. The estimation of other energy efficiency gains achievable for the energy system through many energy efficiency solutions is more intricate. Taking the electricity sector, examples of alternative energy efficiency solutions include reductions in peak power, changes in load profiles and demand-side response (i.e., load shift) (Swisher et al., 1997; European Commission, 2021).

Therefore, the methodology has to account for a reduction or modification of loads. For example: Incentivising the use of demand response and installing the hardware allowing for its use will enable consumers to shift loads from hours with little generation from renewable energies (high prices) to hours with high renewable energy electricity generation and usually lower prices. This will save primary energy (e.g., natural gas) that has not been burned in thermal power plants and, possibly, also reduce the curtailment of electricity generated with renewable energies.

Energy savings achieved in the energy end-use sectors will also have indirect impact on load profiles. A heat pump's annual electricity consumption will, in general, be higher when it is installed in a building with a low energy performance rating compared to a well-insulated building. Whether heat pumps are mainly added to energy-efficient or less energy-efficient buildings will, on a large scale, have different implications for the need to add generation capacity and extend the grid. The extent, to which generation capacity has to be added or grids have to be extended, leads to different implications for future electricity prices.

While these impacts are marginal from the perspective of the individual building owner, and therefore, likely not included in their investment appraisal, from the policymakers' perspective, these impacts are highly important and to be taken into account when giving guidance on regulating the performance standards of buildings.

Cost-benefit analysis (CBA) including multiple impacts (or, as the EED refers to them, wider benefits) has also gained increased attention in recent years (e.g., Thema et al., 2018). A tool has been developed and published at micatool.eu, which can be used by EU Member States and other actors to estimate quantitative or even monetised values for such impacts.

Methodology

Methods used to for the development of the estimation methods

The main method applied for the development of the estimation methods and their methodological framework was desk research for data and literature, and the evaluation of the relevant data (e.g., from Eurostat) and literature on the EE1st principle, energy efficiency solutions and their potentials, methods of energy planning in the EU, etc.

The methodologies were discussed with experts on the EE1st principle and sectoral stakeholders in an online workshop to obtain insights in their applicability and to receive suggestions for potential improvements.

Overarching principles for the development of methods

Our approach to developing a methodology to estimate energy savings and other energy efficiency gains revolves around a set of overarching principles. Some of these cater to the specific requirements that are due to the context of the EU and its Member States, as well as EU legislation. The overarching aim was to enable the Member States to fulfil their legal requirements in a pragmatic, yet as consistent as possible way.

1. Ensuring EU-level consistency and standardised data by utilising publicly available, standardised data and delineations, leveraging EU data sources and reports, and complementing gaps with the latest research. The use of Eurostat data also ensures data accessibility for Member States and satisfies the need for a consistent methodology for all Member States. This approach enables Member States to obtain reasonable estimates of energy consumption by sectors as a starting point, while allowing flexibility for Member States to improve the accuracy of their national and regional calculations based on their own data availabilities.
2. Ensuring data accessibility and ease of calculation, we aim to satisfy the need for providing a consistent and pragmatic methodology for all Member States in obtaining reasonable estimates of energy savings and other energy efficiency gains as well. Therefore, the analysis of energy efficiency potentials was based on the results of EU-funded projects, such as Enefirst or sEEnergies, that assessed the EE1st principle for different sectors, which had aimed to perform a cost-effectiveness assessment including multiple impacts (e.g., Abid et al., 2021; Böck et al., 2022; Hummel et al., 2023; Johannsen et al., 2023). For the energy sector and the energy efficiency gains from changes in load profiles, the scenarios developed for the European Resource Adequacy Assessment (ERAA) and the Ten-Year Network Development Plans (TYNDP) were taken as a starting point.
3. Producing a comparable – yet flexible – methodological design that is fit to accommodate the diverse contexts of EU Member States, recognising variations in data availability and sectoral characteristics at the national level. The methodology must enable Member States to use national or regional data with greater granularity where this is available to them, by providing methodological flexibility to incorporate these sources of data. Notwithstanding, where national data is not available for Member States, the methodology must provide a fallback option to the overarching method.
4. Conducting an assessment of methodological limitations, accompanied with guidance on incorporating more accurate information where available to enhance the accuracy of the estimations.
5. For assessing cost-effectiveness, a societal perspective on costs and benefits (CPUC, 2001; U.S. EPA, 2008; Wuppertal Institute et al, 2009) should be taken, and multiple impacts should be taken into account as far as possible.

6. Further, the inclusion of scenarios with varying energy savings percentages for the alternative energy efficiency solutions analysed offers a range of potential outcomes, accounting for uncertainties and providing a more nuanced understanding of the solution's potential benefits.

Results: Principles and methods for assessing energy savings and other energy efficiency gains

This section presents the principles and methods for assessing energy savings and other energy efficiency gains for both the energy sector and for the energy end-use sectors in general, followed by an application example for the EU's transport sector, and an overview of results for six energy end-use sectors.

Energy sector

The methodology for the electricity sector uses the European Resource Adequacy Assessment (ERAA) as a starting point, to be consistent with established methodologies and develop them further. The ERAA is performed by the Transmission System Operators (TSOs) and includes the analyses of the adequacy of power generation, demand side response (DSR) and storage to meet electricity demand. It also models potential network congestion at the TSO level. The input data and assumptions for ERAA are based on scenarios for future development of demand that the TSOs in Member States provide. In most cases, these assumptions are taken from scenarios developed for the National Energy and Climate Plans (NECPs), and therefore include certain levels of energy efficiency improvements. Some of the Member States have already provided scenarios consistent with the EU's energy efficiency policy targets for 2030 according to articles 4 and 8 of the EED (EU, 2023). Nevertheless, the development of future demand is an exogenous input and the question remains to what extent the energy efficiency improvements considered in the scenarios are optimal in the sense of the EE1st principle. Given the upstream implications on losses (in other words, 'the energy consumption of the energy system') and costs within the energy system, it is not obvious whether this assumed level of energy efficiency improvements is optimal, too low (or too high) from the perspective of sectoral cost-efficient energy efficiency potentials, as well as of costs in all sectors together (i.e., the system level costs when minimising them in all sectors simultaneously). Such an optimisation considering all feedbacks between sectors is complex and, consequently, costly, but nevertheless the best approach.

For the gas and heat supply sectors, the methodology can be applied in a similar and simplified form (seasonal instead of daily load profiles; see below for detail).

Overarching methodology

In Figure 1, we present an overview of the methodology for the energy sector, taking the electricity sector as an example and the corresponding supply adequacy and network planning processes as the basis.

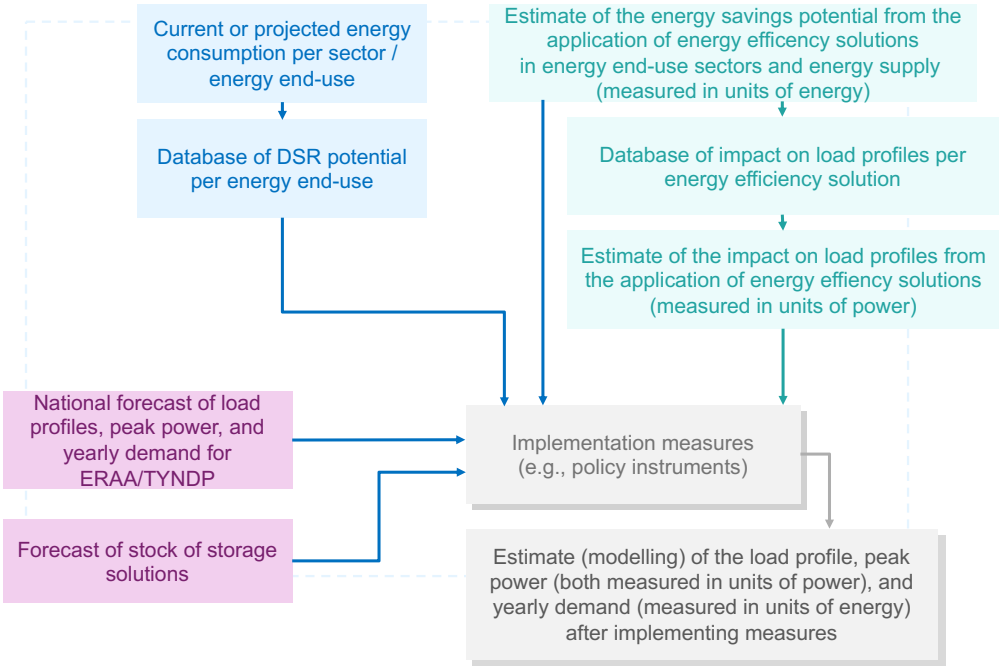

Figure 1. Overarching methodology for the energy sector (example: electricity)

The methodology addresses two major areas:

1. The impact on load profiles, peak load, and yearly demand from the implementation of energy savings in the energy end-use sectors (upper right side of Figure 1), and
2. the additional impact on load profiles, peak load, and yearly demand from DSR and energy storage (left side of Figure 1).

More detailed methods to assess these impacts will be presented in the following.

The impact on load profiles, peak load, and yearly demand from the implementation of energy savings in the energy end-use sectors and energy supply

The ERAA includes a demand forecast, either national, or by ENTSO-E using its demand forecast model (DFM) (ENTSO-E, 2023b). This shall be based on the "national objectives, targets and contributions, and other projections contained in the NECPs", which shall include DSR and energy efficiency measures (ACER, 2020). Scenario assumptions shall also align with the latest NECP-based TYNDP scenario (ACER, 2020).

If the energy consumption and savings targets according to Articles 4 and 8 of the EED in the NECPs are already in line with results of an application of the EE1st principle, and if the demand forecast for the ERAA is based on the energy consumption target from the NECP, the basis for the first step (the reduction in load curve and yearly energy demand resulting from the cost-effective energy savings) will have been correctly laid according to the EE1st principle.

However, the national Article 4 target is set in terms of the final and primary energy demand overall, not only for electricity; and this is the same for the Article 8 target. In addition, not all Member States based their demand forecast on the NECP alone. According to ENTSO-E (2023a), "Most TSOs have submitted data that are primarily driven by the NECP and the FF55. Primary drivers for demand forecasts and profiles in PEMMDB 3.5 included NECP, TSO/DSO studies, political targets, Fit-for-55, national energy strategies, connection requests and independent research institutions. These drivers considered factors such as sector coupling, electrification, Power-to-X, line gas phase-out, GDP growth, and increasing electrification in various sectors."

The first step in the methodology for this area of analysis is, therefore, to assess the remaining cost-effective energy savings potential in energy end-use sectors after implementation of the measures included in the NECPs; and how much of this can be implemented through additional measures. The methodology for

suggested for the energy end-use sectors below may be useful for this. Further energy savings will directly reduce the yearly demand as shown in Figure 1, but also have an impact on the load profile and peak power. Assessing these load impacts is the second step.

In addition to the energy end-use sectors, there are also energy efficiency solutions in the energy sector, such as more efficient power plants and reduction of network losses. The latter will also achieve energy savings in yearly demand and reduce peak power in the system, which has an impact on the ERAA. The former will save primary energy but not influence the balance between supply and demand. Still, both should be included in the analysis of cost-effective potentials for energy savings and other energy efficiency gains in the context of the EE1st principle.

The simplest, but least accurate, way to estimate the impact of energy savings on load is the generic method, i.e., estimating the % reduction of the load profile at all times to be the same % as the energy savings in annual demand. More effort will be needed, but accuracy will be higher, to estimate an end-use or solution-specific load profile that is to be deducted from the total load profile. In either case, the estimate will be implemented for a bidding zone and both sides of a network congestion point.

The additional impact on load profiles, peak load, and yearly demand from DSR and energy storage

This second area of the methodology has two steps:

Step 1 assesses the size of the cost-effective potential of explicit DSR and implicit price sensitive electric vehicles (EVs), heat pumps (HPs), and out-of-market batteries (oomBs). This is addressed in the ERAA in principle (ENTSO-E, 2023b). It involves estimating:

1. The DSR potential by sector and energy end use based on the sectoral and end-use energy consumption (see methodologies for end-use sectors) and a database of respective DSR potentials. This is shown in the upper left side of Figure 1.
2. A forecast of the stock of storage solutions. These should include EVs, HPs, and oomBs, but also other types of storage (e.g., heat storage in district heating systems that allows flexible use of CHP power plants and large-scale heat pumps). This is shown in the lower left side of Figure 1.

In the future, due to the recent revision of the electricity markets regulation 2019/942, Member States will be obligated to estimate the needs for flexibility for at least the next 5 to 10 years and update these reports every two years (Art. 19c of the trilogue compromise text). The European Union Agency for the Cooperation of Energy Regulators (ACER) shall issue a report analysing them and providing recommendations on issues of cross-border relevance. Furthermore, according to Art. 19d, Member States will establish one single indicative objective at national level for 'non-fossil' flexibility allowing for different types of resources, with a focus on the specific contributions by DSR and energy storage. These objectives should also be set following the EE1st principle.

For all of these flexibility resources of DSR and storage, the last subtask in Step 1 is to design measures for their implementation and estimate, how much of the potential can be implemented through the measures.

Step 2 will model the impact on load profiles, peak power, and yearly demand, using the models set up for the ERAA and incorporating the impact of the additional energy savings in the energy end-use sectors plus all the changes from DSR and storage prepared in Step1. This is shown as the grey box on the lower right end of Figure 1. In the ERAA methodology, so far, larger scale 'in-the-market' batteries, explicit DSR capacities, and electrolysers, as an important element of sector coupling, are price-sensitive and are explicitly modelled, while the 'out-of-market' batteries and other 'implicit DSR' (EVs and heat pumps) are exogenously included in the demand profiles based on information provided by TSOs (e.g. typical consumption patterns for household batteries). This means that the amount of capacity available for flexibility is estimated by TSOs based on the total installed energy and load capacity and an estimated share of flexible owners/users. This amount of flexible capacity is then included in the modelling using a time-window and load-shifting approach, which is simplified but appears to be a plausible approach. In the future, however, the amount of flexible EVs, HPs, and oomBs to be included in the modelling would be determined by the Member States' single

indicative objectives at national level for 'non-fossil' flexibility according to the revised electricity markets regulation, while the modelling may take a similar approach as for the ERAA 2023.

This step will most likely involve several iterations of model runs to find the best system efficiency and cost-optimal result, including sector coupling, according to the EE1st principle. These iterations may also involve going back to the energy savings in end-use sectors, considering an increase in the amount of savings from solutions with desirable impacts on the load profiles, or may modify the amount of sector coupling.

The same methodology could also be applied using the demand projections for the TYNDP scenarios as the basis when applying the methodology for the TYNDP process. The TYNDP process is performed in an integrated way for the electricity and gas sectors by ENTSO-E and ENTSO-G. Therefore, the application of the EE1st principle would be best integrated in the joint planning of both sectors. On the gas side, primarily the impact of additional energy savings in the energy end-use sectors will be relevant, but also modifications to peak loads and load profiles through DSR and storage on the gas side. In the future, the emerging hydrogen network and supply could be integrated too. On the gas side, the methodology can also be applied to the processes regarding the summer/winter outlooks and reviews, as well as security of supply simulations.

Performing this methodology at the national or bidding zone level will also help to inform policy-makers in their decision making on other initiatives and processes, such as:

- drafting the next NECPs or their periodic updates,
- the development of a capacity mechanism, and
- national transmission network planning.

For regional (sub-national) planning, and for concrete investment decisions, special modelling exercises are likely to be needed. For example, if necessary, Member States will need to develop and apply a specific methodology for planning and investment processes at the distribution system level. The same is true for heat supply and its networks, which is usually organised at the local level.

Energy-end-use sectors

This section summarises the overarching approach for developing sectoral methodologies to estimate the energy savings potential for several energy end-use sectors.

Steps of the overarching methodology

In Figure 2, we present an overview of the overarching methodology for the energy end-use sectors.

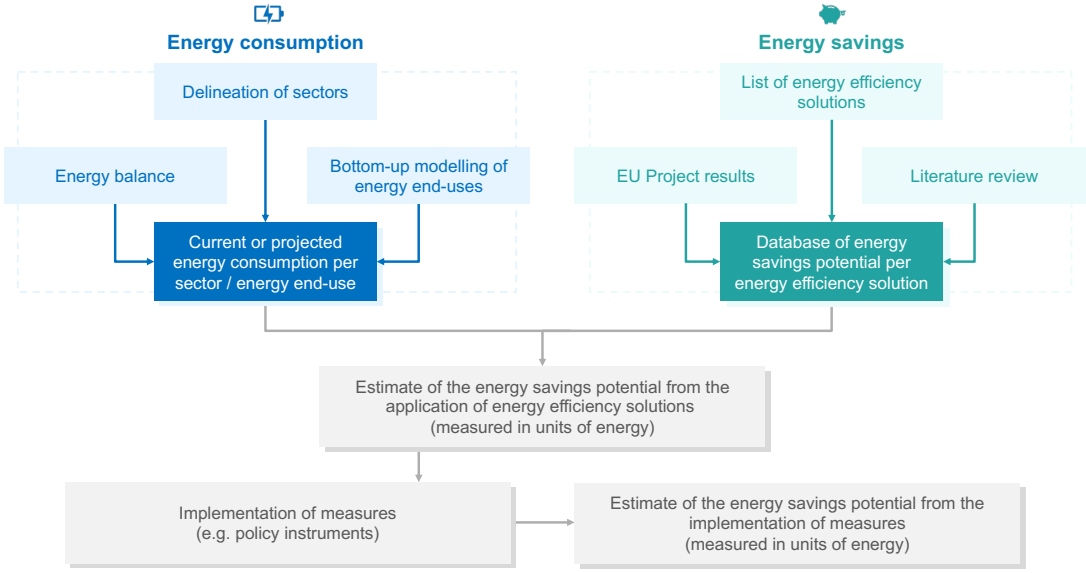

Figure 2. Overarching methodology for energy end-use sectors

The overarching methodology includes three specific steps.

Step 1. Estimation of the energy consumption for end-use sectors

Our approach aims at prioritising consistency at the EU level by utilising standardised Eurostat sector delineations, ensuring uniformity of the outputs of the implementation of the methodology across Member States. Additionally, where feasible, the method prioritises drawing on Eurostat data from energy balances on the energy consumption by sector and, where available, sub-sectors or end uses.

Where Eurostat data does not allow for sector delineation and a quantification of sectoral energy consumption, we have complemented methodologies and data sources from the scientific literature and other publications from European or international organisations. The methodology then requires bottom-up modelling for the separation of sectoral energy consumption to end-uses or sub-sectors. Additional methods and data sources are outlined in the upcoming study report for the European Commission. The result of this first step is the current energy consumption per sector and end use, see Figure 2.

In a simplified approach, this may be taken as the basis for estimating the energy savings potentials in step 2. However, utilising only current energy consumption as the foundation for estimating potential energy savings has its limitations. This is a constraint deemed appropriate if the objective is only to identify the sectors with the highest energy savings potentials, as in the case of our study conducted for the European Commission. Using this static approach may also be sufficient for most investment decisions.

However, for policy and planning decisions, Member States are likely to obtain more accurate results by adding a forecast of future energy consumption by sector and end use as the basis for estimating the energy savings potential. This forecast should include the impacts of current energy efficiency policies. It will also be needed for the energy sector methodology, as presented above.

Step 2. Estimation of the energy savings potential in energy end-use sectors

As presented on the right side of Figure 2, this step starts with a list of energy efficiency solutions that enable energy savings in specific end uses or sub-sectors. Based on an extensive search of literature and on the results of the sectoral Horizon projects on the application of the EE1st principle, the study compiled a database of best available figures for the percentage of energy savings possible for each solution.

As we present in Figure 3, the methodology will first multiply the energy demand per sub-sector, or per end use, with the potential energy savings from the solution addressing the sub-sector or end use to estimate the solutions-specific potential. In the second sub-step, the solutions-specific potentials will be summed up to estimate the total energy savings potential of all solutions. However, as interdependencies may exist between different solutions, they should be considered and if relevant and possible, eliminated in developing the sectoral methodologies.

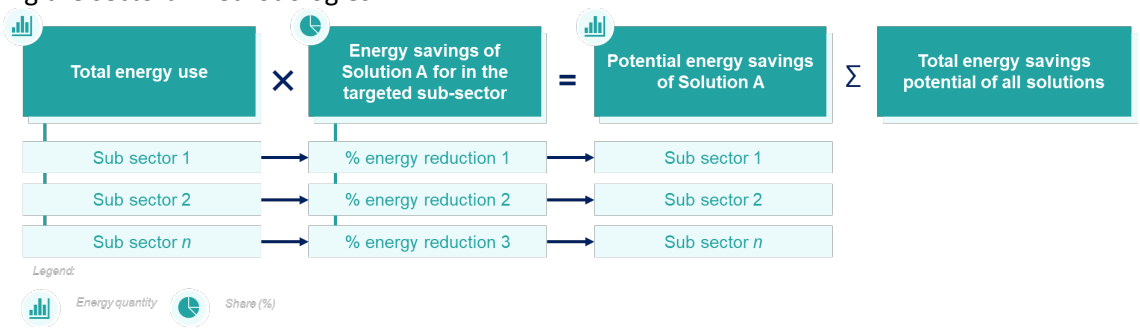

Figure 3. Overarching methodology for estimating energy savings potential in energy end-use sectors

Selection of energy efficiency solutions:

Using the identified delineations within each energy end-use sector and its subsequent solutions, the methodology conducts a review of the scientific literature and past and current projects that have assessed the cost, benefits and saving potentials of applying the EE1st principle. The goal of this review is to derive

values for quantifying the energy savings potential for the respective energy efficiency solutions in the energy end-use sectors.

Data on the energy savings potential of energy efficiency solutions and the EE1st principle:

According to the EE1st principle, a cost-benefit analysis (CBA) should be conducted on the energy efficiency solutions to estimate the share of the technical energy savings potential, which is also cost-effective. Only this part of the potential would be weighed against the default infrastructure options. This CBA should be done using a societal perspective, i.e., with the technical lifetime of the solutions and with a societal interest rate as input data. In addition to the direct energy and cost savings, the multiple impacts should be taken into consideration. If these can be monetised, the process becomes straightforward, as the value of the multiple impacts can be added to the benefits or costs, depending on their value. If this is not possible, the value of the impacts in other units or in qualitative terms must be considered as factors that could influence the decision towards or against implementing the energy efficiency solution, particularly if the monetisable costs and benefits are roughly equal, e.g., differing by up to 20%. If Member States apply the EE1st principle and the corresponding CBA, they are advised to use available up-to-date literature and tools on multiple impacts, such as the micatool.eu.

However, in the available literature on energy savings potentials, it is not always clear if data presented for the energy savings potentials refer to technical potential, cost-effective potential based on direct costs and benefits, or to a potential based on the EE1st CBA principles discussed above. Even if the data sources were aiming for a full CBA, the concrete assumptions regarding investments, lifetimes, or interest rates may differ. This introduces a limitation, which will be discussed below.

Step 3. Policies and measures, and their impact

How much of the energy savings potential could be implemented? There are numerous market and practical barriers that hinder the implementation of this potential. Therefore, policies and measures are needed to address the barriers and harness at least a part of the potential. However, the adequate combinations of policy instruments and other measures are highly context-specific. Therefore, situations and conditions vary too widely to allow for any meaningful estimate for the % of the economic energy savings potential that could be implemented by a certain instrument or policy package for the EU as a whole, using the literature available today as the basis.

When Member States implement the methodology including this third step, they will need to perform ex-ante and ex-post evaluations on the energy savings and other impacts, costs, and benefits of implementing policies and measures, as they are – or should already be – doing in the process of preparing the NECPs. A vast body of evaluation literature is available to support this, including the sources mentioned in the background section.

Example application: the Transport Sector

The EU's Energy Efficiency Directive (EED) acknowledges the significant impact of the transport sector, which is responsible for more than 30% of the Union's energy consumption. The EED also acknowledges that this sector presents unique challenges for tapping into potential energy savings (Recital 13). The following example presents the results of the simplified analysis carried out in the study for the European Commission to demonstrate the application of the methods. It is simplified in three aspects: 1) it is based on current energy consumption, not on forecasting; 2) it only includes steps 1 and 2 of the overarching methodology to derive the overall energy savings potential, but not the analysis of the potential impacts of policies and measures to be performed in step 3; and it does not take into account that a part of the potential is already covered in the current NECPs of Member States, nor estimate the size of that part of the potential.

Energy consumption by end-use

Sector delineation and approach:

Defining and delineating the transport sector's energy consumption is relatively straightforward, as it encompasses the energy use associated with the intentional movement of humans or goods. In our approach to the transport sector, we primarily build on the sector delineation outlined in the Eurostat energy balance (Eurostat, 2024). This data source distinguishes between energy consumption for rail transport, road transport, domestic aviation and domestic navigation. In this analysis, therefore, the transportation sector includes domestic (within an EU Member State) aviation and navigation, but excludes international and intra-EU (between Member States) aviation or navigation, since these are not included in Eurostat's energy consumption data. In addition, the energy balance includes energy consumption for pipeline transport under the transport sector, which we consider to be part of the energy system in our delineation of sectors.

Results for the energy consumption by end-use:

In 2022 – the latest year for which an energy balance was published by Eurostat – we estimated that the transport sector consumed more than 3,200 TWh of final energy (see Table 2.1). Furthermore, we were able to differentiate the energy consumption shown by transport mode according to function (passenger transport or freight transport) and vehicle type. This differentiation is based on the results of the Integrated Database of the European Energy System (IDEES), developed by the European Commission's Joint Research Centre (JRC, 2024).

Table 1. Energy consumption of the transport sector in the EU by transport mode, function and vehicle-type

Transport mode	Function	Vehicle Type	Energy consumption [TWh]
Rail	Passenger	Metro and tram, urban light rail	4.5
Rail	Passenger	Conventional passenger trains	35.5
Rail	Passenger	High speed passenger trains	7.0
Rail	Freight	Rail transport	12.5
Road	Passenger	Powered 2-wheelers	39.9
Road	Passenger	Passenger cars	1,792.4
Road	Passenger	Motor coaches, buses, trolley buses	152.8
Road	Freight	Light duty vehicles	354.2
Road	Freight	Heavy duty vehicles	713.5
Domestic Aviation	Passenger	Domestic	62.0
Domestic Aviation	Freight	Domestic	5.5
Domestic Navigation	Freight	Domestic coastal shipping	36.7
Domestic Navigation	Freight	Inland waterways	11.1
Not elsewhere specified	--	--	6.6
Total transport			3,234.2

Source: Eurostat (2024); JRC (2024)

Energy Efficiency Solutions

The list of energy efficiency solutions applicable in the transport sector (Table 2.2) was selected based on the European Commission Recommendation 2021/1749 (European Commission, 2021) on the EE1st principle, as well as desk research on energy efficiency solutions studied in European projects related to the EE1st principle and discussed in other scientific literature (cf. Table 1 for the sources in detail). Table 1 shows that road transport is by far the largest energy consumer within the transport sector. Private cars account for 55% of the sector's total energy consumption, while light and heavy-duty vehicles for freight transport

account for another 33%. Consequently, the focus of the energy efficiency solutions considered here is on activities relating to these vehicle types. Nevertheless, it should be noted that the list of energy efficiency solutions presented in Table 2 is not exhaustive.

Table 2. Energy Efficiency Solutions for the Transport Sector

Solution	Description	Target	Solution's energy savings potential	Source
Urban / spatial planning (e.g., densification, superblocks)	Reducing energy consumption by avoiding travel	Mainly passenger transport	59% (comprehensive approach) 13% (superblock concepts in cities)	Abid et al. (2021), Elle et al (2022), Berger & Mischkowski (2024).
Public transportation (e.g., mass transit, on-demand services)	Enables modal shift from road to rail and/or shift to other more energy efficient vehicle types	Road/Rail Passenger transport	29-33%[1]	Nobis (2016)
Cycling and pedestrian infrastructure (e.g., bike lanes, bike-sharing systems)	Enables modal shift from energy-balanced modes (road/rail) to non-energy-balanced modes	Road/Rail Passenger transport	9-11%[2]	Nobis (2016)
Transport demand management (e.g., road pricing)	Increases incentives for using more sustainable modes of transportation or decreasing the transport volume	Road/ Passenger and freight transport	NA	
Mobility management (e.g., car-sharing programs)	Reduces the number of ways travelled by car	Road/ Passenger transport	2-7% (carsharing) 11-28% (carpooling, increase in car occupancy rate)	Nicholas et al. (2021), Pucheanu et al (2020)
Electrification of transport (e.g., electric vehicles)	Reducing energy consumption through using more energy-efficient engines (e.g., electric motors)	Passenger and freight transport	48% (Strategy for heavy electrification) 64% (combined electrification and comprehensive urban planning approach)	Kany (2021), Abid et al. (2021)
Incentivising the purchase of smaller, low-weight vehicles	Lighter vehicles need less input of energy to provide the same level of service	Passenger transport	13%	Winkler et al. (2023).

Solution	Description	Target	Solution's energy savings potential	Source
Shifting freight to other modes of transportation than road and systemic improvements in road freight	Domestic navigation and rail transport is often more energy-efficient than transport by road	Freight transport	7% (Böck, shifting only) 60% (i.e. systemic improvements)	Böck et al. (2022), Böck (2023), IEA (2017)

Notes:
[1] Nobis (2016) estimates the energy consumption implications of expanding the public transport system based on the Swiss model and simultaneously promoting cycling based on the Dutch model in Germany. A breakdown by public transport and cycling is not provided in the study, and therefore, an estimation is provided here.
[2] See above

Resulting energy savings potential for the transport sector

Table 2 demonstrates the substantial energy savings potential for the transport sector. All of the solutions presented contribute to this in a significant manner. However, the solutions and their effects on energy consumption cannot be clearly distinguished from one another. There is a degree of overlap and mutual influence between the various solutions, making it challenging to ascertain their individual impact. For example, the described solutions for energy-efficient spatial planning include measures to support a shift to public transport, walking and cycling, and the scenarios for electrification of the vehicle fleet include approaches to promote the use of lightweight vehicles and increased use of shared vehicles. For this reason, the results presented in the literature can only provide a rough estimate of the savings potential. In order to obtain a solution-focused estimate of the potential savings, these must be significantly revised downwards.

The overall approach follows a hierarchical procedure: The first step is to avoid transportation through urban/spatial planning. The second step is to shift traffic to public transport, cycling and walking, mobility management (if leading to a modal shift). The third step is to improve energy efficiency of transportation through mobility management (using car-sharing/pooling) and electrification.

The 'CLEVER' study (Bourgeois, 2023) can be consulted to determine the overall savings potential of the solutions discussed here. In the "CLEVER" scenario, the total energy consumption reduction in the transport sector is estimated at approximately 70% by 2050. The range of solutions encompass all of the approaches previously described.

Based on the assumption that the solutions presented can save a total of approximately 70% of the energy consumption, and considering the results presented in the literature above, the potential savings shown in Table 3 can be estimated. The interactions between urban/spatial planning, public transportation, cycling and pedestrian infrastructure, and transport demand management have been taken into consideration by revising the individual potential data presented in Table 2 above, down to the values included in Table 3, based on our expertise. For transport demand management, we have concluded that it is included in the previous three solutions. Similarly, electrification is only applied after reducing transport demand through the previous solutions in the hierarchy, so the remaining potential is estimated to be 20% of the total current energy consumption, including more efficient, e.g., low-weight vehicles. Altogether, the total energy savings potential for passenger transport is estimated at 80%. For freight transport, it is 55%. The weighted average for the transport sector is 67%.

Table 3. Resulting energy savings potential for the transport sector

Solution	Target	Assumption: energy savings potential	Energy savings potential [TWh/yr]
Urban / spatial planning (e.g., densification, superblocks)	Road / Mainly passenger Transport	20%	397.0
Public transportation (e.g., mass transit, on-demand services)	Road/ Passenger transport	15%	297.8
Cycling and pedestrian infrastructure (e.g., bike lanes, bike-sharing systems)	Road/ Passenger transport	10%	198.5
Transport demand management (e.g., road pricing)	Road/ Passenger and freight transport	Included in other solutions	
Mobility management (e.g., car-sharing programs)	Road/ Passenger transport	15%	297.8
Electrification of transport (e.g., electric vehicles)	Road/ Passenger transport	20%	397.0
Incentivising the purchase of smaller, low-weight vehicles	Road/ Passenger transport	included in "electrification of transport"	
Shifting freight to other modes of transportation than road	Road/ Freight transport	5%	53.4
Systemic improvements in road freight (incl. electrification)	Road/ Freight transport	50%	533.8
Total		67 % (weighted)	2,175.4

Source: authors' own calculations

There may be further potentials related to international or intra-EU aviation or navigation, but due to a lack of energy consumption data, it is not possible to quantify them in this analysis.

Overview of sectoral results

Based on the sectoral methodologies and results developed in the study for the European Commission, the six end-use sectors analysed can be ranked according to their energy savings potential. Figure 4 presents the ranking by the absolute potential of final energy savings.

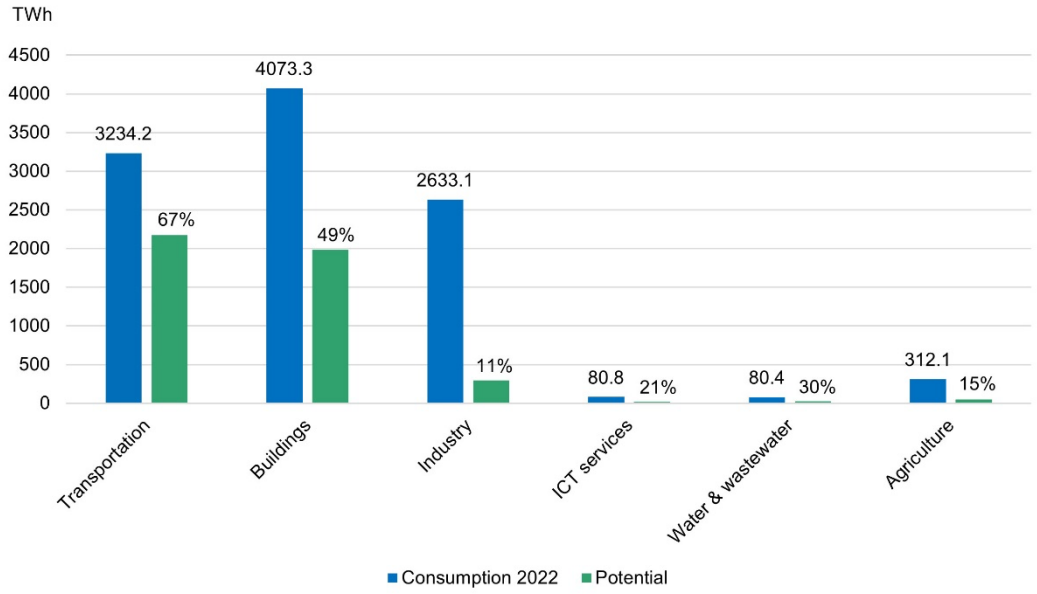

Figure 4. Energy end-use sectors and their energy savings potential

Source: authors' own calculations

Assessing these results, there are two sectors that clearly stand out with their energy savings potential: transportation and buildings. However, in the next section, a discussion is needed about the extent to which the analysis performed here is comparable between the sectors and in line with the EE1st principle. Particularly the assessment result of the percentage of energy savings potential for industry sector appears to be quite low compared to the other sectors.

Discussion

Throughout the presentation of results, several points have emerged that are worth discussing. These are covered below.

Strengths and limitations of the approaches

Strengths and limitations applying to all sectors

Strengths:

The objectives in developing this methodology were to provide a pragmatic, comparable, yet flexible set of methods and steps to assess cost-efficient energy savings potentials and other energy efficiency gains. The use of Eurostat data with minimal sectoral adjustments both reduces efforts and supports comparability in the first step on the estimation of current sectoral energy consumption. The possibility to either use current consumption or a forecast as the basis provides flexibility and represents another strength. In addition, suggesting the use of results on energy savings potentials by sector and Member State from EU-funded projects – which have aimed to perform an assessment based on a CBA in line with the EE1st principle – is a pragmatic approach that should reduce effort and support a minimum level of comparability between Member States for each sector. As we will see below, the comparability between sectors may, however, be limited.

Limitations:

The simplest form of the methodology is based on a static analysis regarding the sectoral energy consumptions as well as the potential of energy efficiency solutions, which enables calculating energy efficiency savings within a particular time frame. One primary justification for this approach is the feasibility

developing a static methodology, making it a more practical and realistic choice when resources are limited. Given the availability of data, a static approach provides a snapshot of the current energy consumption and potential at a given time. However, it cannot account for various other factors significantly impacting energy savings potential. Therefore, it is also essential to acknowledge the limitations of the static perspective as compared to a dynamic analysis. The methodology will need to be advanced to incorporate modelling of scenarios for future changes in GDP and other drivers of energy consumption, the development of new energy efficient technologies, the implementation of renewable energy sources and electrification in many energy end-use sectors, as well as continuous policy and market developments, if there is the need to account for current dynamic trends and to provide a fully accurate reflection of future energy consumption and energy savings potential. This is, e.g., necessary for the development of future NECPs.

In its simplest form, the methodology suggests a "best available estimate of savings" approach, leveraging the potential savings outlined in the above-mentioned Commission Recommendation and the academic literature. In this approach, a further limitation is the lack of a case-specific analysis of direct and multiple costs and benefits, which would be needed to put the energy efficiency solutions on a level playing field with the default infrastructure options, as required by the EE1st principle. Still, the methodology may be able to outline to Member States how, in principle, energy savings potential solutions can be applied and quantified, and point to which solutions are (in principle) most suitable to achieve energy savings in their respective energy end-use sectors.

Finally, it is also important to note that the energy efficiency solutions provided for each sector in our analysis are non-exhaustive. Therefore, it should not be assumed that the total energy savings can be derived solely from this list. The energy efficiency solutions provide several feasible examples, which have been proven to be effective by academic research, but their implementation does not necessarily capture the entirety of possible energy savings potential in the each of the respective sectors. Thus, depending on the purpose, the methods should be supplemented with dynamic modelling, further CBA, and policy evaluation to capture the full potential opportunities for the implementation of the EE1st principle.

Specific strengths and limitations for the energy sector

Strengths:

The methodology for the estimation of the potential for energy savings and other energy efficiency gains for the energy sector builds on the established ERAA and TYNDP methodology and tools. It also builds on results of sectoral analysis of energy consumption and energy savings potential performed in an EE1st context.

Limitations:

- In their energy efficiency and renewable energy dimensions, the NECPs are already based on forecasting demand, renewable energy capacities, and the impact of energy efficiency policies. In the past, the link between NECPs and ERAA/TYNDP was not always adequate, but in the future, they should be made consistent with each other and the EE1st principle.

  As mentioned above, the demand forecast for the ERAA or TYNDP 2023 is mostly based on the NECPs and additional modelling. Therefore, the distinction between the impact of policies and measures that are already included in NECPs or existing modelling of the demand for the ERAA, and policies and measures defined for an additional EE1st scenario may be difficult in practice. It will likely require better transparency and documentation of the assumptions and input data for the existing modelling for both NECP and ERAA/TYNDP.

  This problem should be resolved in the future by basing the demand modelling of both NECPs and ERAA/TYNDP on the EE1st principle. Particularly, better transparency on the link between the CBA, the policies and measures assessed for and included in the scenarios modelled for these policy and planning processes, and the assumptions for their contribution to the achievement of targets is something needed for the future NECPs and their interim updates. And this should also inform the ERAA and TYNDP.

- The methodology is applicable at the national and bidding zone level, but disaggregated input data, forecasts, and modelling will be needed for application at other subnational levels.

Relationship between the EE1st principle and the NECPs

In the NECPs, Member States must adopt energy saving targets related to Articles 4 and 8 of the EED. According to Article 4 , the targets for final and primary energy consumption in 2030 are indicative at the Member State level but are guided by a formula based on the overall EU headline targets. The targets for energy savings resulting from policies and measures under to Article 8 are set as fixed percentages for the years up to 2030. Therefore, these overall targets cannot be changed by an analysis according to the EE1st principle at the national level. In principle, as the decision on the EED and its targets was based on an extensive impact assessment including modelling of cost-effectiveness of energy scenarios, they are informed by an analysis similar to the EE1st principle.

The analysis of policies and measures by Member States will aim to prove how to attain the targets and whether achieving the targets cost-effective. This analysis should be based on a CBA according to the EE1st principle. Application of the EE1st principle may inform future recasts of the EED and the setting of corresponding targets for subsequent years, e.g., 2040.

More importantly, however, the EED Article 4 and 8 targets are set at the overall national level but not for each sector. The application of the EE1st principle can support the allocation of these targets to sectors, sub-sectors, end uses, and corresponding energy efficiency solutions. It should, therefore, also be applied in the scenarios to model future demand, the amount of energy savings by sector available and needed for target achievement, and the impact of measures, which Member States develop as the basis for their NECPs. Moreover, the EE1st principle serves to ensure that energy efficiency solutions and potentials are properly considered in planning, policy, and major investment decisions in the energy end-use sectors, on an equal footing with default infrastructure options. In doing so, application of the EE1st principle will also support attainment of the national targets by implementing more of the energy savings potential in practice.

Comparability of results between the sectors

As Figure 4 shows, the percentage of energy savings potentials that we identified based on available literature varies widely between the energy end-use sectors. Such discrepancies may arise due to the following factors:

1. Completeness of the energy efficiency solutions analysed
2. Extent to which overlaps between energy efficiency solutions have been taken into account when estimating the overall energy savings potential in a sector
3. Character of the potential found in the literature: technical or cost-effective? And if cost-effective, taking which perspective (private investor or societal), and including multiple impacts or not?
4. Conservativeness of the savings estimates – even between estimates of technical or cost-effective energy savings potentials, respectively, there can be a significant deviation between different sources in the literature.

1) Completeness of the energy efficiency solutions analysed

In principle, the analysis has aimed to include all major direct energy efficiency solutions that are identified and analysed in the literature. There may be indirect solutions as well as other solutions, which could add further energy savings. The indirect solutions may include material efficiency and circular economy in industry, which will reduce the demand for basic materials, and hence the energy demand needed to produce them; reducing water losses on the demand side; and reducing food waste. It is a question of interpretation, whether these should be included in an analysis of the potentials of applying the EE1st

principle. Material efficiency and circular economy in industry have been mentioned in the European Commission Recommendation 2021/1749 (European Commission, 2021), while the other two have not.

2) Due consideration of overlaps
All our sectoral analysis has given due consideration of overlaps.

3) and 4) Character and conservativeness of the potentials included
Unfortunately, the character and conservativeness of the potentials found in the literature and subsequently used in the analysis appears to differ between sectors, cf. Table 4.

Table 4. Character and conservativeness of the energy savings potentials included in the analysis

Sector	Character of energy savings potential	Conservativeness of energy savings potential
Transportation	Partly technical, partly cost-effective/EE1st analysis	Aiming for completeness
Buildings	EE1st scenario analysis or other cost-effective	Somewhat conservative; scenario ends in 2050, further building shell renovation and corresponding energy savings possible afterwards
Industry	Cost-effective	Very conservative
Information and communications technology services	Cost-effective	Somewhat conservative
Water and wastewater	Partly technical, partly cost-effective/EE1st analysis.	Conservative
Agriculture	Partly technical, partly cost-effective/EE1st analysis	Conservative

Source: own assessment of sources used

To control our results, we may, e.g., consider those of the modelling performed for the 2050 climate-neutrality strategy of the EU (European Commission, 2018). 2050 is far enough in the future from 2018 to include most of the reinvestment cycles for different energy efficiency solutions. According to this source, the total reductions in final energy use in the most ambitious scenario, 1.5°LIFE, is 50% in transportation, which would yield 1,617 TWh of energy savings using our findings on base year energy consumption; 41% in buildings, yielding 1,670 TWh of energy savings; and 31% in industry, yielding an estimate of 816 TWh. Although this analysis was not performed according to the EE1st principle, it may be more consistent between sectors, since the sectoral energy savings data in % are closer to each other than in our analysis.

Conclusions

In this paper, we have presented a suggestion for methodologies to support implementation of the EE1st principle in EU Member States by assessing cost-efficient energy savings potentials and other energy efficiency gains using a pragmatic and comparable, yet flexible set of methods and steps. These methods differentiate between the energy end-use sectors and the energy sector. In the former, the objective is to estimate energy savings. In the energy sector, other energy efficiency gains, particularly to improve the

match between load profiles of demand and supply, are added. The steps include an estimation of the current energy consumption by sectors and end uses, the analysis of cost-effective energy efficiency potentials, and of the impact (and cost-effectiveness) of policies and measures.

While the estimation of the current energy consumption by sectors and end uses can be based on official statistics and a consistent source from JRC, and therefore appears quite reliable, the literature on energy savings potentials is far less coherent and consistent. This particularly concerns the character of the potentials – whether they are technical or cost-effective potentials; and if the latter, from a private actor's or a societal perspective, and including multiple impacts or not – and the degree, to which the estimated potentials are conservatively low or ambitiously high. In some cases, one study estimates higher cost-effective potential than another one presents technical potentials, although theoretically, the cost-effective potential can never be higher than the technical one.

Nevertheless, we have suggested to use Horizon projects such as Enefirst or sEEnergies as much as possible as the basis available in the short term for solution-specific energy savings potentials, because these projects were aiming to support the operationalisation of the EE1st principle by assessing solutions and energy savings potentials based on a CBA corresponding to the principle, and consistently between Member States.

However, we strongly suggest that Member States will need further analysis to evaluate the economic viability of energy efficiency solutions in both the energy sector and respective energy end-use sectors. Without such an analysis, the costs and investments needed per solution are unclear, hence, the economic impact cannot be fully assessed according to the EE1st principle, including multiple impacts. Such a full assessment is the first precondition for giving energy efficiency solutions priority over default energy infrastructures in policy, planning, and major investment decisions.

In addition, we strongly advise to aim for more harmonised principles for the CBA method and its input parameters, along the lines discussed above.

Furthermore, more clarity and reliability will be required regarding the impact of policies and measures. For energy efficiency solutions to be given priority over default energy infrastructures, their impact on energy savings and load profiles needs to be similarly reliable to, e.g., power plants or LNG terminals. There is a vast evaluation literature of energy efficiency policies and measures, but to date no systematic approach to derive average figures of achievable shares of the cost-effective energy savings potential related to end uses and energy efficiency solutions. Therefore, we propose to establish a repository of ex-post evaluation results in the EU or possibly worldwide.

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