Analysis to support the implementation of the Energy Efficiency First principle in decision-making

Final report

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OVERVIEW

This report presents the results of Task 1, 2 and 3 of the project "Assistance with the analysis to support the implementation of the Efficiency First Principle (EEF principle) in decision-making" by the consortium of Ecorys, Fraunhofer ISI and Wuppertal Institute, for the European Commission, DG ENER. The objective of the study, which ran from April 2020 to October 2020, was to:

1) Develop a decision tool to apply the EEF principle by national/local authorities and by the Commission
(Task 1)

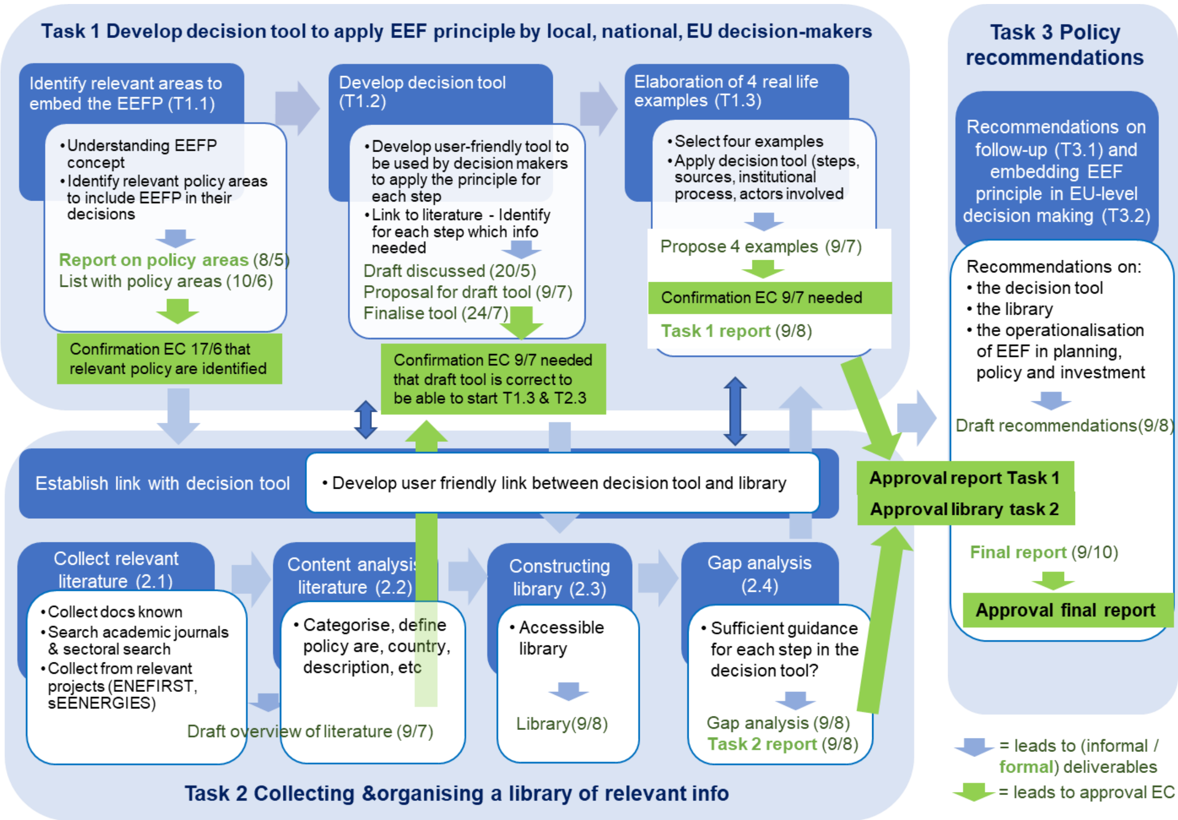
2) Collect and organise a library of relevant information (Task 2)

3) Provide policy recommendations (Task 3)

The **general objective** of the proposed assignment is to provide **practical contributions and clear guidance for operationalising and implementing the Energy Efficiency First Principle in the EU**. This is to be done by means of facilitating decision-making of EU, national and local level actors involved in planning, policy-making and investment decisions.

The **specific objectives** can be narrowed down to: (1) **Designing, developing and testing a user-friendly EEF decision-making tool** to be used by EU, national and local authorities; (2) identifying, consolidating and effectively **presenting all information which could be relevant/useful when applying the decision-making tool** and (3) **providing guidance and policy recommendations** for the future development and operationalisation of the energy efficiency first principle. Figure 1 provides an overview of the different tasks and activities and the linkages between them, as well as the relevant data. Both formal and informal deliverables have been included to detail the process.

Figure 1 Overview of the subtasks, their results and interrelations



1. OBJECTIVE

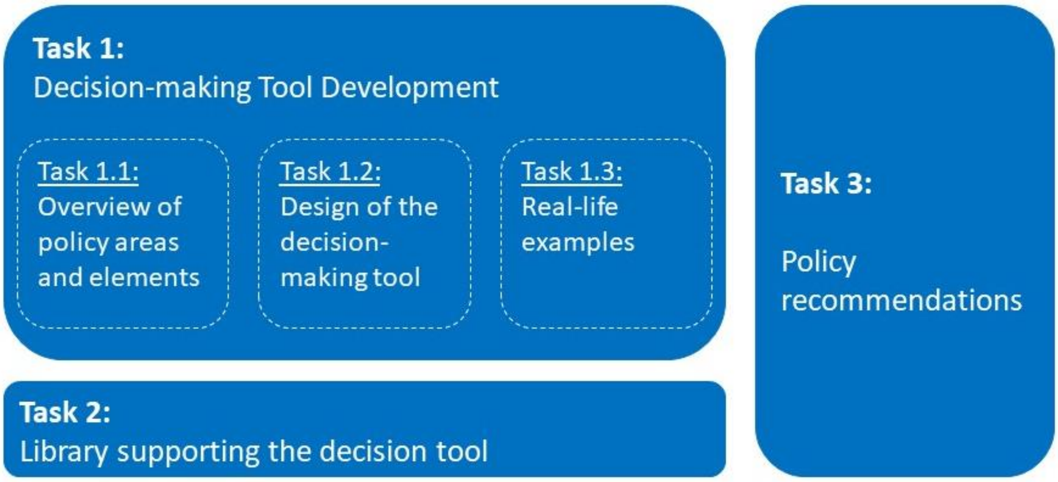
Energy efficiency (first) is one of the central pillars of the EU's long-term strategy [1] and is termed its first fuel. Yet, in real-world planning, it is a fuel that is still far too often overlooked as compared to supply-side options. In order to prioritise energy efficiency options when they are more beneficial than supply-side options, a more thorough discussion, understanding, and guidance is needed in which policy areas and at which decision-making steps the Energy Efficiency First (EEF) principle can and should be applied. This project aims to deliver a hands-on approach to do so.

To consequently implement the EEF principle in all steps of the decision-making process, it is necessary to value the benefits of energy efficiency (EE) against the supply-side options. Hereby, in a first step, it needs to be assessed whether energy efficiency is an alternative to an energy supply option at all. If yes, in the second step all the costs of the two options have to be considered in an encompassing manner. This goes beyond the mere direct economic costs necessary to implement the various options. Particularly the literature shows that the EE options are often performing better than the supply-side options when taking multiple impacts (such as environmental or employment impacts) and benefits over the lifetime of the projects into account, because EE options often have the advantage that they have smaller operating costs than supply-side options. Often decision-makers are trained to very specific considerations when deciding for a certain option. From recent studies, it is known that these considerations might systematically undervalue the advantages of EE options. In order to do justice to the EEF principle it is, therefore, necessary to widen the spectrum of indicators, which evaluate the best option.

The EEF principle can be applied both in policy-making, in planning processes, and for concrete investment decisions. It is not only applicable to energy-related processes and decisions, but also to other sectors, including transport, water, digitalization, or all kinds of natural resources.

This report consists of following tasks as shown in Figure 2.

Figure 2 Three tasks in the report



Task 1 is to develop a decision-making tool, which enables the policymakers and regulatory authorities to apply the EEF principle in practice. For this purpose, three subtasks are included. First, in Chapter 2, Task 1.1 opens the discussion by identifying key policy areas and elements or types of investment and planning processes therein, which are of particular relevance when implementing the EEF principle. Then, in Chapter 3, Task 1.2 develops a tool to guide the decision-maker through various steps and the corresponding extended spectrum of indicators. The tool makes it explicit to the policymakers and regulatory authorities, at which steps, which aspects should be considered, to allow for an encompassing analysis of the options, and do justice to the EEF principle. Finally, in Chapter 4, Task 1.3 further illustrates, tests, and refines the tool based on four real-life examples. To support the decision -making tool developed in Task 1, Task 2 establishes a library of relevant literature from academic journals and other relevant reports, and provides gap analysis for the application areas of EEF principle. Finally, based on Task 1 and Task 2, policy recommendations are provided in Task 3.

2. OVERVIEW OF POLICY AREAS AND ELEMENTS

2.1. Approach

Efficiency First (EEF) is a concept that applies across many areas of energy policymaking, planning, and investment. As part of the amendments and recasts to multiple established legislation in the Clean Energy for All Europeans (CE4ALL) package, EEF now has a prominent standing in Europe's energy and climate policy framework. While these legislations certainly support the implementation of EEF in different policy areas, the provision needs to be strengthened in many instances to make sure that investments are made wherever efficiency is more cost-effective or valuable than equivalent supply-side resources. At the same time, there are policy areas that, so far, do not at all feature explicit consideration of the EEF principle.

This section introduces the approach to identify and screen the relevant policies which provide opportunities for embedding the EEF principle to achieve a least-cost portfolio of energy resources to meet consumers' needs as well as the EU's objectives for integration, the security of supply, competitiveness, and sustainability. For the sake of conceptual clarity, a distinction is made between **policy areas** and **policy elements**. Policy areas are understood as general topics in energy policymaking and investment, including, for example, the *market design* area which is also one of the five general dimensions of the Energy Union [2]. Given its broad scope, the term policy area does not allow for pointing out single decision-makers or distinct EEF implementation options. Therefore, we hereinafter refer to *policy elements* as building blocks of a given policy area, which feature a limited range of decision-makers and existing legislation, investment schemes, and planning processes. This distinction allows for a more tangible screening of existing and conceivable EEF applications.

Policy areas and policy elements therein are identified through a **review of established literature**. This work is guided by completed and ongoing research projects on the EEF principle in EU decision-making, including ENEFIRST, sEEnergies, ODYSSEE-MURE, and COMBI. Besides, non-established policy areas and elements are also covered that, so far, have been less in the focus of established literature on EEF – including digitalisation, water, and transportation.

Table 1 Analytical framework for the screening of policy elements

Policy element: (title) [...]			
Major decision-makers			
☐ Policymaker	☐ Regulation authority	☐ Energy suppliers	☐ Network operator
☐ Consumers	☐ DSM service provider	☐ Other	
Relevance			
low	medium	high	
Description [...]			

Each policy area is screened according to a uniform **analytical framework** (Table 1). The top section provides a short outline of the policy element and its overall relevance and linkage to the EEF. Next, the **major decision-makers** (or actors) related to the given policy element are indicated via checkboxes (☑/☐). Following the unbundled design of the internal markets for electricity and gas, market actors are distinguished into policymakers, regulatory authorities, energy suppliers, network operators, consumers, DSM service providers, and others. Note that this checklist is by no means exhaustive. Instead of pointing out every category of decision-maker involved in the different policy elements, it allows an overall appraisal of interdependencies in the decision-making across different policy areas and elements, and also corresponds to the design of the tool. The further introduction for each decision-maker will be provided in Section 3 in detail.

Subsequently, the overall **relevance** of the policy element concerning EEF is indicated. Note that this is only a rough qualitative appraisal and not based on any detailed indicator logic. Relevance can refer to savings of greenhouse gas emissions, energy use, or costs that are conceivable if the policy element is to thoroughly embed EEF.

A comprehensive overview of the policy element is given in the **description** section. For each policy element, to varying extents, this section elaborates on the following points: (i) rationale for embedding EEF in this policy element; (ii) quantitative data on greenhouse gas, energy, or cost-saving potentials; (iii) role of major decision-makers; (iv) major EU legislation, investment schemes and planning processes within the element; (v) gaps in the existing legislation concerning the extensive application of EEF.

Overall, this analytical framework allows for a consistent, yet detailed screening of policy areas and elements relevant for practically embedding the EEF principle. The following sections in this chapter present an overview of the policy areas (chapter 2.2) and the analysis for different policy elements therein (chapter 2.3).

2.2. Outline of policy areas

The screening of established literature revealed a total of 7 relevant policy areas. These are energy markets, energy supply and energy system integration, energy demand, governance, digitalisation, transport, and water. Within these policy areas, 18 policy elements have been identified. In the following, a more detailed outline of the policy areas is provided.

Energy markets: Energy market integration is a key component of European energy policy. To shape competitive markets that maximise consumer welfare and provide energy services at least cost, the Internal Electricity and Gas Directives have introduced various measures to liberalize and better integrate the markets. As part of the recent Clean Energy for All Europeans package (CE4ALL Package) [1], the legislative framework for the electricity market has entered a new phase with the adoption of the recast Directive (2019/944) and Regulation (2019/943) on the internal market for electricity (Electricity Directive and Electricity Regulation) [3][1] While these legal provisions certainly recognise the important role of demand-side resources in markets, demand response and end-use efficiency still do not compete on truly equal footing with supply-side resources in different markets. To reap the benefits of well-functioning markets and to benefit consumers from the least costs in line with the notion of Energy Efficiency First, the internal market requires further strengthening. The following sections screen distinct policy elements where market rules can and should embed the EEF principle:

- **Market access for demand-side resources:** Remove regulatory barriers to enable demand-side resources to participate, for example, in the electricity markets and district heating systems;
- **Transmission and distribution network planning:** Require regulated DSOs and TSOs to target the most cost-effective portfolio of demand and supply resources in network development;
- **Network tariff design:** Create dynamic tariffs and reduce fixed charges to motivate consumers to procure demand response and other demand-side resources to reduce network costs.

Energy supply and energy system integration: Decarbonizing the economy is one of the five dimensions of the Energy Union. Concerning energy supply, this means a significant shift away from fossil fuels to renewable energy sources (RES). With fossil electricity and heat generators increasingly being decommissioned, renewable generators take their place – along with the need for capital-intensive infrastructures such as transmission and distribution networks, large-scale storage facilities, and hydrogen infrastructure. This transition occurs in parallel with developments on the demand-side of the energy system. Besides end-use

[1] With regard to energy markets, the CE4ALL Package also includes the ACER Regulation (2019/942) that provides for the competencies of the European Agency for the Cooperation of Energy Regulators (ACER) as well as the Risk-preparedness Regulation (2019/941) that stipulates Member States to develop national crisis scenarios for electricity supply.

efficiency, decarbonizing the building and transport sectors essentially require electrification to provide heating and cooling as well as motive power. Embedding the EEF principle in this setting comes down to only investing in supply-side energy infrastructures (generation/transmission/distribution/storage of electricity/heat/gas) and *behind-the-meter* supply technologies (e.g. heat pump in buildings) whenever demand-side resources (end-use efficiency, demand response, distributed resources) are not available or more expensive. Note that this does not mean the withholding of renewable capacity deployment but rather a transparent competition between decarbonized supply options and demand-side resources [4]. The major legislative action in this policy area is the recast Renewable Energy Directive (RED) (2018/2001), which provides the EU with a framework for the funding of renewable energy. Building upon the idea of EEF, it formulates the target of raising the share of renewable energy to at least 32 percent in final energy consumption. This figure may be raised further to comply with an enhanced Greenhouse Gas emission target of 55% reduction compared to 1990, as proposed recently by the EU Commission. Within this policy area, four policy elements are screened in detail:

- **Integrated district heating/cooling planning:** Require the use of cost-benefit analysis in the planning of regional district heating networks to identify the most cost-effective heat supply options and to assess these against reducing heat demand through energy efficiency in buildings and processes;
- **Power generation planning:** Consider demand-side resources when evaluating investment needs for generation capacity for cost-effectiveness at the system level;
- **Hydrogen infrastructure:** Provide cost-optimal deployment of hydrogen infrastructures and alternative end-use efficiency measures through market design and regulation;
- **Energy storage**: Evaluate the trade-off between utility-scale and behind-the-meter storage facilities vs. adoption of energy-efficient appliances/equipment and demand response schemes.

Energy demand: Demand-side resources that are balanced against large supply-side infrastructures are at the core of the EEF principle. However, the concept of EEF can be taken one step further by also evaluating technology trade-offs within the demand sectors of the energy systems, i.e. households, services, industry, and transportation. Buildings, for example, can be substantially upgraded and renovated by better thermal insulation or by replacing an outdated heating system with a more efficient one. Both measures essentially are evaluated "behind-the-meter" by the consumer, yet the trade-off between saving energy and producing energy persists.[2] While the topic of market barriers to efficiency measures has a prominent standing in scientific literature (see, for example [5,6]), this policy area sheds light on two policy elements under particular consideration of the EEF principle:

- **Public procurement rules:** Require or encourage the procurement of energy-efficient goods and services in the public sector, based on integrated cost-benefit assessments;
- **Efficient manufacture, use, and disposal of industry materials**: Strengthen material efficiency and energy-efficient technologies as counterparts to the production of materials and energy supply.

Governance: Overarching governance frameworks that layout how climate and energy targets are planned to be met (on national as well as on European level) are crucial to enable the Member States to pursue strategies that allow them to reach the short-, mid- and long-term targets of the national states as well as of the EU as a whole. If these governance frameworks and strategies are well defined, they will serve as a guiding principle for the design of national policies that affect emission and energy goals. These overarching frameworks are crucial to avoid that policies are not synchronized or that in total they are not sufficient to reach the actual targets. As part of CE4ALL Package [1] all of these strategies, reaching the energy efficiency target as one of the EU's 2030 energy and climate targets is an important goal. However, measuring the efficiency improvements is more complicated than for example measuring the share of renewable energies, because improvements have to be measured against (counterfactual) baseline developments. Therefore, energy efficiency targets have often been formulated as energy consumption targets. The following overarching governance

[2] Note that the Energy Performance in Buildings Directive (EPBD) (2010/31/EU, 2018/844) defines methodologies to determine cost-optimal building renovation standards.

frameworks that currently exist under EU law are discussed in this report; prospectively, further reporting obligations could be discussed additionally:

- **Security of supply planning for trans-European infrastructures:** Substitute or defer supply infrastructure investments through energy efficiency and demand response in long-term cross-border energy security planning;
- **Preparation of National Energy and Climate Plans (NECPs):** Require Member States to develop mid-term strategies under explicit consideration of the EEF principle;
- **National and European long-term strategies:** Enshrine EEF as a guiding principle for long-term planning towards EU-wide climate neutrality in 2050. Next to the national level long-term strategies, this concerns in particular the recent proposal by the European Commission on establishing the framework for achieving climate neutrality (European Climate Law).

Digitalisation is one of the mega-trends that will shape our future. At the current stage, the effect of digitalisation on energy demand comes with a promise as well as a challenge. Digitalisation has the potential to enable our future, sustainable energy system, for example through smart grids, smart meters, connected devices, and demand-side management systems, which enable amongst others to account for the fluctuation of renewable energies [7]. At the same time digitalisation allows us to drastically increase data collection, data storage, and data processing. These processes themselves need major amounts of energy and enable new business models, such as autonomous driving, which run risks of further increasing energy demand [8]. Thus, at the current point in time, decision-makers have to be aware of this dualism of digitalisation as an enabler for the sustainable energy transition as well as digitalisation as a driver for further increasing energy demand. Energy efficiency improvements play a major important role to restrain the energy demand of the currently drastically increasing demand for digital services [9]. To fully incorporate the Energy Efficiency First principle into decision-making in the policy area of digitalisation, three areas of investment decisions are crucial: (i) investments in digitalisation related infrastructure, including data centres and 5G RAN, (ii) the transfer to more efficient ICT appliances as well as more efficient software (e.g. exploiting of edge computing options) and (iii) energy efficiency investments in technology and infrastructures in the sectors, which are not accounted in the first two areas, but which are necessary to exploit the full saving potentials that arise through digitalisation and energy efficiency (e.g. technology that allows production on demand). In the following overview, we will have a closer look at the first area, which is inherent to digitalisation and respective infrastructure. The following sections screen distinct policy elements where digitalisation can and should embed the EEF principle:

- **Construction of data centres:** Promote the diffusion of energy-efficient facilities, waste heat reuse, and adoption of self-use renewable generation systems;
- **Deployment of 5G networks:** Consider the EEF principle in the design, construction, and utilisation of 5G network infrastructure, and promote the use of behind-the-meter battery storage for demand response.

Transportation: The transportation sector is a category of companies that provide services to move people or goods, as well as public and private transportation infrastructure. It is responsible for around a quarter of the European Union (EU) Greenhouse Gas (GHG) emissions, making it the second biggest GHG emitting sector energy efficiency measure could be understood as an improvement of the ratio between the mobility service needed and the amount of energy needed for this (Thomas et al 2003). The first policy framework at the EU level here was a Transport White Paper [12], regulations, and directives have been developed since (as elaborated in the sections below). Most recently, the European Green Deal reiterated the need for deeply transformative policies for clean energy in the transport sector, explaining that to achieve climate neutrality, a 90% reduction in transport emissions is needed by 2050 [11]. Three (often overlapping) policy elements where policy decisions and market rules can and should embed the EEF principle:

- **Policy decisions in energy efficiency of passenger vehicles:** Decisions must be taken to ensure these vehicles are designed and used in a way that is as energy efficient as possible, meaning that minimal energy is used in any particular journey;
- **Investment decisions in local transport planning and management:** Harness the EEF principle through assessment of the energy efficiency of different modes of transport, digital technologies, joint undertakings, and sustainable urban mobility plans (SUMPSs) but also

energy- and cost-optimised national road and rail network planning and operation in the planning and management of urban and long-range mobility;
- **Policy decisions in Energy efficiency in the transport of goods:** Encouraging to decide the transport means based on efficiency and emission reduction potential/options for the transport of goods as well as cost-effectiveness.

Water: The water sector and energy efficiency are strongly linked. Water is used for the energy sector producing fuels, cooling thermal power plants, and generating electricity in hydropower plants. Conversely, the water system needs energy for collecting, pumping, treating, and desalinating water. The EU has set ambitious decarbonisation goals for the future, which could be very difficult to achieve if the water system becomes too stressed. A switch to a low carbon energy system will have to be managed with care since some low carbon energy systems (e.g. many bioenergy systems) could use water more intensively than the systems they replace The EEF principle can be relevant for water usage by industry, agriculture, and consumers. When decision-makers have to focus on the energy efficiency of measures that can be taken in the collection, pumping, treatment, desalinating water. The Energy Efficiency Directive (2018/2002) is already stimulating energy savings through regulations on billing or consumption of heating, cooling, and domestic hot water (Art. 9). The application of the Energy Efficiency First principle can be strengthened for the use and management of energy and water, bearing in mind the fundamental difference between energy and water: that energy can be renewable, but water resources are finite. Opportunities in both systems can be maximised, increasing energy efficiency in the water sector, using the water system to add flexibility to the power system, extracting more energy from water, and reducing the water footprint of the energy industries [13]. Within this policy area, one policy element is screened in detail:

- **Water treatment:** Assess and identify methods to increase energy efficiency by reducing leakage in the system as well as optimise operational energy in the pumping, the treatment, and sludging of water.

2.3. In-depth screening of policy elements

The following sections provide a detailed screening of policy elements in the policy areas introduced above, that can and should embed the EEF principle to the extent possible.

2.3.1. Energy markets

Policy element: Market access for demand-side resources

The participation of demand response and other demand-side resources reduces the amount of electricity (or heat) and capacity procured and, in the long-term, avoids unnecessary investment on the supply side. This also benefits consumers by lowering clearing prices and allows for a larger share of variable renewables to be accommodated. The access and participation of demand-side resources are thus an important application of the EEF principle in terms of establishing a level playing field. However, especially for the electricity system, its application across all relevant markets (e.g., wholesale, balancing, capacity) is an ongoing process. Ensuring that demand response and other demand-side resources can access relevant power markets and compete on an equal footing with generation is an important application of EEF.

Major decision-makers

☑ Policymaker ☑ Regulation authority ☑ Energy suppliers ☑ Network operator
☑ Consumers ☑ DSM service provider ☑ Other

Relevance

low	medium	**high**

Description

In the capacity markets, energy efficiency and demand response (DR) can reduce the need for expanding generation resources and sometimes transmission and distribution capacities too. With the advancement of variable renewable generation, the need for flexibility in the power system increases. To ensure system reliability and cost-effectiveness, DR and other demand resources play an important role through participation in power markets – ranging from short-term spot markets to long-term capacity markets. International experience shows that allowing energy efficiency and demand response to bid against the generation in power markets lowers clearing prices and thereby the total costs paid by customers for the same level of reliability and quality of service. For example, in North America's largest power market PJM, savings resulting from the participation of demand response and energy efficiency in capacity auctions were at $9.35 billion for the delivery year 2017/2018 [14] However, in Europe, the extent to which demand response customers and their aggregators can access all relevant markets is limited. Reaching a cost-optimal portfolio of resources in line with the EEF principle requires ongoing removal of regulatory barriers in the EU's regulatory framework and Member States' transposition. The provisions set out in the new Directive (2019/943) and Regulation (2019/944) on the internal electricity market provide a new framework for integrating demand-side resources in power markets. A general principle outlined in Article 3(f) of the Electricity Regulation is that market rules shall deliver appropriate investment incentives for generation, storage, energy efficiency, and demand response to ensure the security of supply, meaning that all resources must participate on equal footing in the market. Article 22.1 of the Regulation reconfirms that demand resources need to be treated equally with the supply side in capacity markets, requiring that they "(h) be open to the participation of all resources that are capable of providing the required technical performance, including energy storage and demand-side management". With regards to aggregators, who bundle flexibility of numerous consumers and selling it as a single unit in the market, the Electricity Directive improves their status by setting fundamental rules about market access and data exchange between market participants engaged in aggregation. Article 17.3 of the directive grants market access for independent aggregators without consent from other market participants.Overall, the new Electricity Directive and Regulation confirms the standing of demand resources and its aggregators, particularly in capacity markets. This enables and requires Member States to design markets as level playing fields for all resources, for example by setting auction rules in a manner that allows for equal participation of demand resources. While capacity markets are considered second-best solutions for the long-term provision of reliability [3], it is an important step forward in moving towards energy-only markets. While the Member States now need to transpose the provisions, the European Commission will need to monitor the Member States' progress on market opening to demand-side resources, and, where necessary, enforce and further develop these provisions.

Policy element: Transmission and distribution network planning

While the integration of the European Energy markets is advancing, the transmission and distribution (T&D) infrastructures remain regulated monopolies that require regulatory oversight to ensure reliability and fair pricing. Just as the liberalized energy markets, these regulated sectors equally need to open up to demand-side resources in their network development planning. However, while wholesale markets essentially require stringent market rules to take explicit account of demand-side resources (see *Market access for demand-side resources*), T&D network planning is subject to traditional monopoly regulation. In this context, regulators can use utility remuneration and performance incentives to stimulate T&D utilities to use demand resources to supplant the need for electricity and natural gas infrastructure investments.

Major decision-makers

☑ Policymaker ☑ Regulation authority ☐ Energy suppliers ☑ Network operator
☐ Consumers ☑ DSM service provider ☐ Other

Relevance

low	medium	**high**

Description

There is substantial evidence, especially from the United States, that demand-side resources can be a cost-effective alternative to traditional T&D infrastructure investments. For example, New York's utility ConEdison deferred 40 MW of network upgrades and saved $75 million through locally-targeted end-use efficiency and other demand-side investments [15]. To deliver on this, there must be rules in place requiring and rewarding DSOs and TSOs to plan for and invest in the most cost-effective portfolio of demand- and supply-side resources, and providing national regulators with an active role for monitoring and enforcement [14]. As with market access, the EU has already taken steps to address energy efficiency and other demand resources in T&D sector regulation. In general terms, Art. 15.4 of the Energy Efficiency Directive (EED) (2012/27/EU) and its recent amendment (2018/2002) calls on the Member States to remove incentives in T&D tariffs that are detrimental to the overall efficiency (including energy efficiency) electricity system. The Member States shall also ensure that "that network operators are incentivized to improve efficiency in infrastructure design and operation". While these provisions are important to address incentives adverse to efficiency, they so far do not apply to the natural gas sector. Under the recast Electricity Directive (2019/944) (Art. 32), Member States must design a regulatory framework for DSOs that, among other things consider energy efficiency measures that may supplant the need to upgrade or replace electricity capacity and that support the efficient and secure operation of the distribution system. According to Article 18.8 of the recast Electricity Regulation (2019/943), National Regulatory Authorities (NRAs) shall introduce performance targets for DSOs and recognize innovative measures to raise efficiencies of their networks, including energy efficiency. Together, these provisions introduce a framework for incentive-based regulation, which can be a strong driver for investment in unconventional resources, including energy efficiency [16]. As for electricity TSOs, Article 51.3 of the Electricity Directive requires them to "fully take into account the potential of the use of demand response, energy storage facilities or other resources as an alternative to system expansion" in the preparation of Ten-Year Network Development Plans (TYNDP). Overall, these legal provisions provide a robust framework for considering energy efficiency and other demand-side resources in T&D planning. However, addressing the full potential of efficiency in deferring T&D investments requires further strengthening of existing provisions to drive regulatory reform. If T&D network operators are not subject to energy efficiency obligation schemes according to Art. 7 EED, they should be required by national regulations to take the effect of energy end-use efficiency programmes and policies of governments or other into account in their network expansion planning. This need for strengthening also includes the establishment of equivalent legal provisions for natural gas TSOs and DSOs. Also, the same principles need to be extended to the development of European T&D projects, notably through the extension of the requirement for a least-cost investment standard led by efficiency Trans-European Energy Networks (TEN-E) and Projects of Common Interest (PCIs). T&D network investment is a costly business, so cost-effective measures to reduce peak load in line with the EEF principle will bring substantial benefits to the network company and, eventually, power network tariffs to the consumers [3,17].

Policy element: Network tariff design

Just as transmission and distribution system operators need to be incentivized to procure demand-side resources, network users need incentives for the adoption of demand response, distributed generation, and energy efficiency. Tariff design is an essential component of EEF as it affects price signals and thus investment and behaviour responses on the part of consumers. Tariff design should steer customers to optimise their bill consistent with minimizing system costs. Applied to network charges, this rule implies that consumers should pay for the network in proportion to their actual use and the associated costs. Fixed charges – that are economically inefficient and promote energy use at times of stress on the grid – should be minimized to help embed the EEF principle in network operation [3].

Major decision-makers

☑ Policymaker	☑ Regulation authority	☐ Energy suppliers	☑ Network operator
☑ Consumers	☑ DSM service provider	☐ Other	

Relevance

low	**medium**	high

Description

Network charges are paid by customers to cover the costs for power lines and other network assets. At present, they account for just over a quarter of the electricity bill for the average European household [18]. While demand response and energy efficiency can be important resources to defer network infrastructure investments in line with the EEF principle, the very common fixed or flat rate network charges hardly incentivize customers to procure these resources. In turn, dynamic tariffs are linked to the cost of network use in a given moment and provide an incentive to shift use to less congested periods, thereby avoiding or reducing network expansion needs and lower system costs [3]. While consumers in a few Member States already use dynamic network tariffs, further strengthening of a regulatory framework is needed. A major shortcoming of the new Electricity Market Regulation (2019/943) is that it keeps the reference to fixed costs suggesting that "tariff methodologies shall reflect the fixed costs of transmission [...] and distribution system operators [...] to increase efficiencies, including energy efficiency [...] and to support efficiency investment [...]" (Art. 18.2). While fixed costs do not necessarily have to translate into fixed charges, this reference is easily interpreted as justification for a fixed tariff element. Distribution tariffs as well "may contain network connection capacity elements" (Art. 18.7). Overall, these references contradict the general requirement for network tariffs that they "shall neutrally support overall system efficiency in the long run through price signals to consumers and producers" and "shall not create disincentives for the participation of demand response" among others (Art. 18.1). Concerning the introduction of dynamic tariffs, the regulation only requires NRAs to "consider time-differentiated network tariffs when fixing or approving transmission tariffs and distribution tariffs" (Art. 18.1). In turn, other provisions in the Electricity Market Directive (2019/944) strengthen the position of active consumers. Consumers possessing smart meters can request to conclude a dynamic electricity price contract with at least one supplier and with every supplier that has more than 200,000 final customers (Art. 11.1). It also contains requirements for expedited supplier switching (Art. 12.1) and the entitlement of individual consumers to a smart meter even in the absence of a national rollout (Art. 21) [3]. Overall, establishing a level playing field between demand-side resources and network infrastructure investments requires engaged consumers that incur costs when the grid is used and avoid them when it is not. Fixed network charges are economically inefficient and promote energy use at times of stress on the grid. While more accurate and frequent information on consumption through dynamic tariffs can lead to behavioural change in favour of demand response and other demand-side resources, these provisions are unlikely to lead to a dramatic increase in demand-side resource investments without broader incorporation into markets and regulation [14]. Embedding the EEF principle thus needs to be considered at various decision points in overall energy market design.

2.3.2. Energy supply and energy system integration

Policy element: Integrated district heating/cooling planning

The European Commission considers district heating/cooling (DH) as key infrastructures for achieving ambitious climate targets in the EU heating sector. While DH systems are a flexible heat supply option that can integrate both high-performance and renewable heat generators and waste heat from industrial installations, its infrastructure assets are also highly capital-intensive and prone to long-term lock-in effects. Since DH systems are typically treated as vertically integrated utilities in national regulations, they offer the option to embed EEF through an integrated resource planning approach to identify the most cost-effective heat supply options for a given region and to assess these against reducing heat demand through energy efficiency in buildings and processes as well.

Relevance

low	medium	**high**

Description

In the EU Heating and Cooling Strategy [19], district heating is recognized as a highly flexible and affordable technology option for displacing fossil fuels in heat supply. While DH systems are indeed a highly-efficient heat supply option that can integrate cogeneration, renewable electricity (heat pumps), geothermal and solar thermal energy, waste heat and municipal waste, any local development, or major refurbishment of these systems should be evaluated under an EEF perspective. If end-use efficiency (e.g. thermal refurbishment of buildings) and demand response are more cost-effective, they should be prioritized over the deployment of capital-intensive DH infrastructures. As a general provision, the recast Renewable Energy Directive (RED) (2018/2001) calls on the Member States to ensure that any national authorisation, certification and licensing procedures "applied to plants and associated transmission and distribution networks for the production of electricity, heating or cooling from renewable sources [...] contribute to the implementation of the Energy Efficiency First principle" (Art. 15.1). More specifically, the Energy Efficiency Directive (EED) (2012/27/EU) and its amendment (2018/2002) deal with the promotion of high-efficiency cogeneration – i.e. the simultaneous production of electricity and heat – and efficient district heating and cooling (DHC). The latter explicitly implies the use of waste heat from industrial installations. Member States are required to carry out a comprehensive assessment of the potentials for cogeneration and efficient DHC in their national territory (Art. 14.1). Besides, they must perform a cost-benefit analysis (CBA) to identify the most resource- and cost-efficient solutions to meeting heating and cooling needs from a societal perspective (Art.14.3). Guidelines on the calculation methodology for the CBA are provided in Annex IX of the Directive. It shall consider all relevant supply resources available within the system, including individual heating and cooling units on the demand-side (Annex IX, b). It should also include both socio-economic and environmental costs and benefits, such as health and labour market costs (Annex IX, g). Overall, while this methodology provides a rudimentary application of the least-cost planning idea behind the EEF principle in heat supply planning, it falls short in taking account of the full range of possible resources that can potentially limit or defer investments in heat supply infrastructures. End-use efficiency (building envelope insulation) is not within the required scope of investment options, the same as the emerging use of demand response in district heating networks [20]. In addition to these provisions referring to the comprehensive assessment, Member States need to carry out every five years, the EED also requires a cost-benefit analysis for single heat supply projects. This applies to any thermal generator, industrial installation, or DHC network with a thermal power greater than 20 MW (Art. 14.5). However, the methodological provisions given on single projects (Annex IX, Part 2) are even more rudimentary than for the comprehensive assessment. Member States are explicitly allowed to set guiding principles for this methodology which could lead to a more integrated approach to heat supply planning.

Policy element: Power generation planning

The power generation planning determines the construction of new generation technologies over a planning horizon. Following the EEF principle, policies or programs should be designed to induce energy efficiency improvement on the demand-side, or enhance the demand-response flexibility. Note: This policy element relates to the power generation planning within an EU Member State, under the Internal Market Directive. Its main purpose is also to ensure future security of power supply, by matching the forecasts of demand and supply. The difference to the Policy element "*Security of supply strategic planning"* in chapter 2.3.4 below is that the latter focuses on processes between two or more EU Member States. The difference to the Policy element "*Transmission and distribution network planning"* in chapter 2.3.1 is that the latter focuses on the network, while this one here concerns generation.

Major decision-makers

☑ Policymaker ☑ Regulation authority ☑ Energy suppliers ☑ Network operator
☑ Consumers ☑ DSM service provider ☑ Other

Relevance

low	medium	**high**

Description

The power generation problem focuses on determining the capacity, types, location, and construction time of new generation technologies which are added to the existing power system to meet the demand over a planning horizon. Several aspects are related to the optimisation, including market uncertainties, emission reduction, distributed and renewable generation, energy policies, demand-side programs, etc. In the liberalized EU electricity markets, the government and regulator will do the integrated assessment of demand-side and supply-side options, and may ensure that sufficient capacity is available in the future through auctions for new capacity or other capacity mechanisms. Following the EEF principle, energy efficiency and demand-response programs should be considered in the planning, and should be given priority if they are cost-effective in relation to expanding or renewing power generation capacity. In the context of EEF principle, relevant programs are divided into two main categories: energy efficiency programs (EEPs) and demand-response programs (DRPs).

The EEPs are applied to decrease energy consumption so that the level of service to the end-use consumers remains constant or is improved effectively [21]. By promoting the diffusion of energy-efficient technologies, the load level is reduced, so the technologies are also treated as virtual generating units participating in meeting the demand with megawatt power [22]. For this reason, energy efficiency is being known as the 6th energy source following coal, oil, natural gas, nuclear energy, and also RES. In contrast to EEPs, DRPs focus on changing the behaviour of consumers in response to energy price fluctuations over time or to incentive schemes. DRPs contribute to (1) the reduction of peak electricity demand and the investment in generation and transmission and distribution network, and (2) the stabilisation of the power system and the integration of intermittent renewable generation. There are two categories of DRPs. First is price-based programs, including time-of-use tariffs (TOU), critical peak pricing (CPP), and real-time pricing (RTP). Second is incentive-based programs, including direct load control (DLC), curtailable load (CL), capacity marker program (CAP), and demand-side bidding (DSB). Particularly the latter two are actually instruments to implement the Policy element "Market access for demand-side resources (chapter 2.3.1). Following the spirit of EEF principle, both of EEPs and DRPs play important roles in the generation planning, as well as for the transmission and distribution network expansion.

Policy element: Hydrogen infrastructure
Spurred by rising shares of renewable energies, hydrogen produced from renewable electricity through electrolysis is an approach (re)gaining attention in Europe and around the world. Hydrogen can be used as a feedstock, a fuel or an energy carrier and storage, making it versatile for many possible applications across industry, transport, power and the buildings sector. It can also be used to produce synthetic energy carriers and chemicals (synthetic methane, methanol or ammonia). If produced from surplus or additional green electricity, its key benefit will be that it does not emit CO_2 and almost no air pollution when used. Thus, it offers a solution to decarbonise industrial processes and sectors where reducing carbon emissions is both urgent and hard to achieve [23]. However, the high upfront costs associated with hydrogen infrastructures, as well as the low conversion efficiencies, especially when it comes to synthetic fuels, should be evaluated against alternative demand-side resources according to the EEF principle.
Major decision-makers
☑ Policymaker ☑ Regulation authority ☑ Energy suppliers ☑ Network operator ☑ Consumers ☑ DSM service provider ☐ Other
Relevance
low **medium** high

Description

With declining costs for renewable electricity (in particular from wind power and photovoltaics), interest is growing in electrolytic hydrogen and its various possible applications beyond the power sector: a) as a feedstock it can be input in the chemical industry for the production of ammonia, synthetic fuels and various types of fertiliser, as well as in hard-to-abate iron and steel production; b) as a fuel it can be directly used in the transport and buildings sectors, blended with natural gas in existing natural gas pipelines, or to provide power and heat using fuel cells [24]. While renewable electricity suppliers, engineering firms and governments alike anticipate these potential benefits, currently, the production of renewable hydrogen is still not financially viable and remains a technology under research and development in the EU [25]. In this regard, the European Commission's Hydrogen Strategy [23] vision of how the EU can turn clean hydrogen into a viable solution to decarbonise different sectors over time, targeting the installation of at least 6 GW of renewable hydrogen electrolysers in the EU by 2024 and 40 GW by 2030. According to the Commission, by 2030, this pathway corresponds to significant cumulative investments for hydrogen transport, distribution and storage (€65 billion), electrolyser capacity (€24-42 billion) and for directly connecting solar and wind energy production capacity to the electrolysers to provide the necessary electricity (€220-340 billion) [23]. With regard to the EEF principle, these numbers raise the question whether some of these infrastructure investments could be substituted, or at least deferred, by more cost-effective end-use efficiency and demand response options. Renovated buildings, for instance, have a reduced useful energy demand and would thus need less final energy from hydrogen for heating purposes. Similarly, an industrial sector based on material efficiency and efficient production technologies would need less hydrogen as a feedstock and fuel. Battery electric vehicles need around half as much electricity than hydrogen fuel cell vehicles for the km travelled. While these examples seem intuitive, the range of possible value chains and business models attached to renewable hydrogen complicates the design of distinct policies to enable the EEF principle. Following an integrated planning approach, operators of large-scale hydrogen infrastructures that are conceived under the trans-European networks for energy (TEN-E) and the Ten-Year Network Development Plans (TYNDPs) could be obliged to evaluate cost-effective demand-side resources alongside infrastructure expansion (see also policy element 'Security of supply strategic planning'). An alternative approach to establish a level playing field is to enhance market mechanisms. State-imposed grid fees, taxes, levies and surcharges on hydrogen would need to be properly balanced with other energy carriers – especially electricity and natural gas – to send correct price signals to consumers regarding fuel choice [26]. This approach goes hand in hand with removing market barriers that prevent consumers from adopting cost-effective energy efficiency measures [5]. To conclude, renewable hydrogen can potentially contribute to a resilient and sustainable energy future for the EU. Regardless of its currently less significant role in the energy system, the substantial investments associated with its infrastructures should encourage policymakers today to evaluate regulatory approaches and policy frameworks for prioritising efficiency measures whenever they are more cost-effective than newly built hydrogen electrolysers and networks. Hydrogen and derived synthetic fuels will be needed for climate neutrality but the need for them should be mostly reserved to areas without or with little alternatives such as aircraft fuels (where only biofuels are an alternative for the moment but which have limitations due to sustainability criteria).

Policy element: Energy storage

Adopting energy storage technologies can contribute to the efficiency improvement on the demand-side. Thermal energy storage and battery systems are two most important options. They can increase the consumption rate of renewable energies, and provide demand-response flexibility. As a result, investments in power supply or transmission network can be reduced. Following the spirit of EEF principle, energy storage technologies are playing promising roles in the energy transition process.

Major decision-makers

☑ Policymaker ☑ Regulation authority ☑ Energy suppliers ☑ Network operator
☑ Consumers ☑ DSM service provider ☑ Other

Relevance

low	medium	high

Description

The development of renewable energies, such as solar radiation, ocean waves, wind, and biogas, also demands the development of efficient and sustainable energy storage technologies. Among those technologies, thermal energy storage (TES) and battery systems are two widely used options. TES is a technology that stocks thermal energy by heating or cooling a storage medium so that the stored energy can be used at a later time for heating and cooling applications and power generation. TES systems are used particularly in buildings and in industrial processes. The advantages of using TES in an energy system include a potential increase in overall efficiency, particularly in CHP systems, which however needs to be assessed against the storage losses, and better reliability, and it can lead to better economics, reductions in investment and running costs, and less pollution of the environment, i.e., less carbon dioxide (CO2) emissions. The battery system in the power system is accepted as one of the most important and efficient ways of stabilizing the electricity network.[27]. They can be provided by a range of technologies and can add value in a variety of ways, including smoothing of loads and weather variations, peak clipping, reserve standing, frequency control, etc.[28]. Income comes by (1) charging the battery system when the local electricity value is low and discharging it when the value is high; (2) supplying ancillary services, for example, reactive power, voltage, and frequency control and emergency power during a power outage. In the transport sector, another example is the battery-electric vehicles, which enable electric motors that are more efficient than internal combustion engines. If coupled with renewable power, it can significantly reduce the consumption of oil and gas. The cost and overall efficiency of a battery system is evaluated from a life-cycle perspective, and varies according to its scale, sections included (e.g. power conversion system, storage section, and balance of plant), and kinds of batteries. Taking an example from the review study [29] for a utility-scale lead-acid battery system, the annualized life-cycle cost is 646 €/kW-yr, and the overall efficiency is 0.70-0.90. In summary, from the perspective of EEF principle, energy storage technologies are playing important roles by potentially improving energy efficiency and supporting the demand-response flexibility in the power system. However, storage has energy losses, i.e. the overall efficiency is less than 1. So, using heat or power directly is usually more energy-efficient than to store it first. Only if the heat or power supply gets so much efficient that it saves more than the storage losses, overall efficiency will be improved.

2.3.3. Energy demand

Policy element: Public procurement rules

Public entities are a significant sector for energy efficient goods and services. As an exposed and visible consumer, actions taken by government authorities to improve the efficiency of their facilities and public services can strongly influence its citizens and other consumers. The EU, as well as various Member States have adopted policies that require or encourage the procurement of energy efficient goods and services by public agencies. However, strengthening the EEF in this setting requires a greater degree of commitment towards integrated and cost-benefit-based planning of demand- and supply-side resources.

Major decision-makers

☑ Policymaker ☐ Regulation authority ☐ Energy suppliers ☐ Network operator
☐ Consumers ☐ DSM service provider ☐ Other

Relevance

low	**medium**	high

Description

The public sector represents a strategically important market segment for implementing the EEF principle. Its energy use in government agencies typically corresponds to between 2 and 5 percent of total energy consumption of a given region. In addition, the public sector is a big and visible consumer, with new efficiency measures implemented in public facilities (e.g. schools and universities, public administrative offices, hospitals, public lighting systems, etc.) demonstrating good energy management practices and high-performance technologies towards businesses and the public [30]. Concerning energy use, the prime aim of public procurement should thus be to make economic use of budget funding to cover the procurement needs of the public sector. Established government policies and practices to facilitate energy efficient procurement include labelling schemes for energy efficient products; catalogues containing specific technical standards; energy efficient product preferences; and lists of qualified or certified energy efficient products [30] law sets out minimum harmonised public procurement rules, which govern the way public authorities and certain public utility operators purchase goods, works and services. The three major directives include a) the Directive on public procurement (2014/24/EU); b) the Directive on procurement by entities operating in the water, energy, transport and postal services sectors (2014/25/EU); and c) the Directive on the award of concession contracts (2014/23/EU). In addition, provisions in Art. 6 of the Energy Efficiency Directive (EED) (2012/27/EU, 2018/2002) oblige Member State's public bodies to purchase products, services and buildings with high energy-efficiency performance – subject to additional conditions of cost-effectiveness, economic feasibility, wider sustainability, technical suitability and sufficient competition. Regarding the EEF principle, a major shortfall about these terms is that they are not properly defined, which may cause misinterpretation and disregard of energy efficient investment options. Strengthening EEF could imply to define and measure, for example, 'cost-effectiveness' not only in terms of the up-front price of a product and its operational costs, but also regarding its health impacts, toxicity, employment effects, life-cycle energy use, and other environmental and societal effects [31]. In addition to such legal frameworks, emerging approaches and instruments to give more explicit consideration to EFF include, for example, output- or service-based procurement [30], which technical specifications do not specify technology (e.g. LED lighting), but simply the desired energy service (lighting), and then select the highest net present value (NPV) from bids received. This focus on the energy service could then cover a wide range of resources – including energy efficiency, demand response, as well as competing supply-side resources (e.g. onsite micro-CHP combined with efficient lighting), with the result of selecting the most cost-effective resource option from a societal perspective, i.e. including the aforementioned environmental and societal effects. In conclusion, procurement policies and programs can be an effective way to promote energy efficient products by leveraging a government's purchasing power and influence. As a complement to EU legislation, Member States should be encouraged to describe additional criteria to energy efficiency in public procurement to enable and strengthen the implementation of the EEF principle [30].

Policy element: Efficient manufacture, use, and disposal of industry materials

Industry materials are the building blocks of infrastructure, equipment and goods that enable people and businesses to follow their routines. Energy and feedstocks are critical to the production of materials, such as steel, aluminium, and concrete. As the European economy and population grow, so does demand for materials, which highlights the importance of strategies – in particular material efficiency and energy-efficient technologies – that can foster the sustainable manufacture, use and disposal of these indispensable commodities in line with the EEF principle [32].

Major decision-makers

☑ Policymaker ☑ Regulation authority ☑ Energy suppliers ☑ Network operator
☑ Consumers ☑ DSM service provider ☑ Other

Relevance

low	medium	**high**

Description

The industry sector is the largest energy consumer in the EU, accounting for a third of the total final energy consumption and 20% of the EU's emissions. The most energy-consuming industrial sector is the chemical and petrochemical industry, followed by the paper/pulp and iron/steel sectors [33]. According to the IEA, energy efficiency has to play a strong role in the transformation of the EU industry sector. Compared with a business-as-usual scenario, the EU could save 32 Mtoe (372 TWh) in industry by 2040. Savings would come from cost-effective measures, including energy management systems, minimum efficiency performance standards, and greater electrification, including the use of electric heat pumps among others [34]. Only a few EU provisions set requirements on energy efficiency and corresponding carbon reductions in the industrial sector. The EU ETS applies to industry and electricity, with the manufacturing industry receiving a share of their emissions allowances for free and energy-intensive industry benefitting from a special regime under the carbon leakage list. Since 2013, CO_2 emissions from industrial installations have stalled, while free allowances have almost halved. Thus, the ETS does not seems to have significantly contributed to the decarbonisation of industrial installations [34]. The Energy Efficiency Directive (EED I) (2012/27/EU) required large enterprises to carry out a first energy audit by the end of 2015 and continue to carry out audits every four years. Companies are also encouraged through the EED to put in place and energy management system. In place since 2009, Eco-design measures for industrial pumps, fans and motors also contribute to the improvement of energy efficiency in the industrial sector [34]. For embedding the EEF principle and achieving long-term carbon neutrality, the EU needs to act on the demand side with material efficiency targets. EU efficiency standards could promote designs to reduce the use of energy-intensive materials such as iron and steel, aluminium, cement, and plastic, and foster the substitution of these materials with less energy-intensive ones. This can include using timber, where possible, or waste from one sector for other sector (e.g. using steel blast-furnace slag in cement production and waste from other industries as alternative fuels for cement production). Moreover, the EU needs to improve recycling processes, including the collection of scrap metals and the reuse of cement. With the Circular Economy Action Plan [35] announced under the European Green Deal, these issues are acquiring a new dynamic. In addition to material efficiency, the new EU industrial strategy needs to promote energy-efficient technologies such as electric arc furnaces for steel production while decommissioning inefficient ones, promoting the electrification of processes, as well as recovering waste heat [32,34]. Overall, under ideal circumstances in accordance with the EEF principle, the industry would only produce indispensable commodities that cannot be substituted through cost-effective energy efficiency and material efficiency efforts on the demand side. In addition, for energy use in the industry, companies would invest in efficient production technologies (e.g. motors) whenever they are more cost-effective from a societal perspective than supplying energy. Coordinating the entire industrial sector and achieving this ideal state will require significant planning and policy efforts.

2.3.4. Governance

Policy element: Security of supply strategic planning

Energy security is vital to a well-functioning European economy. Digital technologies, communications infrastructure, and industrial operations all depend on a reliable supply of electricity. Buildings, industry companies and the transport sector cannot operate without a stable supply of natural gas, oil, and other commodities. In this setting, the EEF can play an important role by substituting or deferring long-lived supply-side investments whilst saving energy and costs.

Major decision-makers

☑ Policymaker	☑ Regulation authority	☐ Energy suppliers	☑ Network operator
☑ Consumers	☐ DSM service provider	☐ Other	

Relevance

low	**medium**	high

Description

Energy security is commonly understood as the uninterrupted availability of energy sources at an affordable price. The term has many aspects: long-term energy security mainly deals with timely investments to supply energy in line with economic developments and environmental needs. Short-term energy security focuses on the ability of the energy system to react promptly to sudden changes in the supply-demand balance [36]. Besides the role of demand response for short-term power system operation, the EEF principle has particular relevance for the former aspect of long-term planning for energy security. Selecting a cost-effective portfolio of demand-side resources and supply-side infrastructures is important for maintaining a secure, affordable and sustainable energy supply in Europe. For example, renovating buildings often does not only save costs, but also reduces energy consumption. This benefits electricity security, which is challenged by increasing shares of variable renewable supply. When it comes to gas supply, it reduces Europe's heavy reliance on non-EU supplies that are subject to price fluctuations and geopolitical concerns. To help prevent potential long-term energy supply disruptions, EU legislation is devoted to the expansion and maintenance of cross-border network infrastructures. Regulation (EU) 347/2013 establishes guidelines for trans-European energy networks (TEN-E). These guidelines aim to help the EU identify priority cross-border projects that benefit from expedited permit granting procedures and improved regulatory treatment. In addition, designated Projects of Common Interest (PCIs) gain access to European funding, including almost €6 billion available through the Connecting Europe Facility up to 2020. Overall, neither the TEN-E guidelines nor the PCIs selected explicitly mention energy efficiency and demand response as a consideration, besides peripheral consideration in projects relating to bi-directional metering and communication [17]. Implementation of the EEF principle under the TEN-E guidelines could come as a provision that, in evaluating PCIs, cost-effective demand-side resources must be evaluated alongside supply-side resources in meeting cross-border needs [37] the guidelines call on ENTSO-E and ENTSOG to publish their methodologies for an energy system-wide cost-benefit analysis for PCIs. However, the recently published methodologies [38,39] take into account demand-side resources alongside supply in determining investment needs and instead consider the demand side solely as an exogenous input to scenario projections. In fact, a more ambitious consideration of the EEF principle would be in line with Paragraph 5 of the regulation, encouraging "the rational production, transportation, distribution and use of energy resources, [...] and to contribute to sustainable development and protection of the environment" [40]. Similar to the case of PCIs, national and EU-wide TYNDPs, required under the electricity and gas directives and regulations, should consider the opportunities for demand-side resources to address system needs. Promising approaches and case examples are available in different jurisdictions in the U.S. [15,37]. In conclusion, securing a constant supply of energy is vital for a resilient European economy and society. The EEF principle bears a certain relevance for this policy element as demand-side resources can defer the expansion or reinforcement need for network infrastructures, generation units, and storage facilities. Beginning with trans-European energy networks, such critical projects should take explicit account of reliable and cost-effective demand-side measures (including their multiple benefits and impacts) to achieve a cost-optimal outcome for the European society.

Policy element: Preparation of NECPs
In the context of the National Energy and Climate Plans (NECPs), Member States develop a mid-term strategy for reaching the EU's 2030 energy and climate targets. These plans were introduced under the regulation on the governance of the energy union and climate action ((EU)2018/1999) as part of the CE4ALL Package) [1]. An integral part of these plans are the energy efficiency targets of the countries for 2030, as well as a description of the policies and measures that are planned to reach these targets. Furthermore, the governance regulation sets the framework by obliging the member states to apply the EEF principle before taking energy planning, policy and investment decisions. ((EU)2018/1999 (64)).
Major decision-makers ☑ Policymaker ☐ Regulation authority ☐ Energy suppliers ☐ Network operator ☐ Consumers ☐ DSM service provider ☐ Other
Relevance low **medium** high

Description

The regulation on the governance of the energy union and climate action ((EU)2018/1999) introduces the National Energy and Climate Plans (NECPs). In Article 3 of the regulation, the timeframe for the provision of the NECPs is provided. The first round of final NECPs was supposed to be submitted by the 31st of December 2019 and should cover the time frame from 2021 to 2030. From then onwards the NECPs should be provided every ten years for the following ten-year period (next date is the 1st of January 2029). Article 3 also provides a list of contents that have to be included in the NECPs. Integral parts of these plans are (amongst others) (i) a description of the national targets for each of the five dimensions of the Energy Union; (ii) a description of planned policies and measures to reach these targets; (iii) a description of the current situation on these five dimensions and (iv) an assessment of the impacts of the planned policies and measures. These four parts are supposed to be outlined also for the energy efficiency target, as one of the five dimensions and have to be delivered following Article 7 and Annex IV of the EED (2012/27/EU) as well as with the EPBD (2010/31/EU). Two major challenges currently exist concerning the policies and measures that are proposed in the (draft) NECPs: (i) measuring the progress in energy efficiency is more difficult than for other targets, because they can only be measured against a counterfactual (rather than as actual percentage shares as is for example possible for the renewable energy targets). Furthermore, countries might include policies and measures here, which are not following the EED or the EPBD; (ii) in their assessment of the draft NECPs the Commission [41] has pointed out, that the proposed national measures are by far not sufficient to reach the EU's overall target to reduce primary and final energy consumption by 32.5% until 2030. While energy efficiency is an integral part of the NECPs, the Energy Efficiency First principle is not yet fully integrated. Its high potential in developing a balanced and cost-effective system of targets for reducing GHG emissions, energy efficiency, and renewable energies as well as the other two dimensions of the Energy Union is, therefore, not harnessed to the extent that would be appropriate. Despite the emphasis of the commission that energy efficiency should be understood as the first fuel, a preliminary scanning of the public final NECPs shows, that the consideration of the principle in the plans is very limited. Exceptions can be found in the NECPs of Cyprus, Finland, and Latvia where the principle is at least more explicitly mentioned and explained. Many other countries ban the principle to the footnote. This shows that the Energy Efficiency First principle is not yet ingrained in the policymaking at the national level and might not yet be understood as a guiding principle for decision-making. To properly account for the EEF principle in future NECPs, it would be crucial that member states break down more clearly how the principle is implemented in all decision-making steps and how this will be ensured and monitored. This should include (1) **detailed information of how policy-makers include the EEF principle in their policy making process** (How are options compared? What is considered (e.g. multiple benefits, (economic) efficiency potentials)? How is this ensured at al geographical scales? Is energy efficiency given priority in attaining the other targets, before addressing supply-side actions?); (2) **the removing of barriers for demand-side investment**s (including the prevention of distorted markets, the provision of capital and information and the reduction of risks and uncertainties; (3) **a consideration of societal challenges** (e.g. adequately dealing with energy poverty by applying the EEF principle) and (4) **an advance and running approach for monitoring and verify the mechanisms laid out above**.

Policy element: National and European Long-term Strategies

The regulation on the governance of the energy union and climate action (EU/2018/1999) sets out the requirement and the process for the EU Member States to deliver long-term strategies on how they plan to achieve the greenhouse gas emission reductions needed to meet their commitments under the Paris Agreement and EU objectives. The time perspective of this strategy should be at least 30 years, i.e. should exceed the medium-term perspective of the NECPs by at least 20 years. Since also in the long term, the consistent implementation of the EEF principles is absolutely necessary to achieve very ambitious energy and climate targets by 2050 and beyond. One concrete example is the German „Energy Efficiency Strategy 2050" from December 2019, which complements the National Climate Long-Term Strategy with regard to energy efficiency and the long-term implementation of the EEF principle. Next to the national level also long-term strategies at EU level such as the proposed Climate Law of the EU should include the Energy Efficiency First principle.

Major decision-makers

☑ Policymaker ☐ Regulation authority ☐ Energy suppliers ☐ Network operator
☐ Consumers ☐ DSM service provider ☐ Other

Relevance

low	**medium**	high

Description

In Article 15 of the regulation on the governance of the energy union and climate action (EU/2018/1999), the EU sets out the requirement and the process for the EU Member States to deliver long-term strategies of how they plan to achieve the greenhouse gas emission reductions needed to meet their commitments under the Paris Agreement and EU objectives. The time perspective of this strategy should be at least 30 years. This time horizon is considerably longer than the 10 years plan submitted under the NECPs. However, the national long-term strategies should be consistent with the NECPs for the first period. The EU Member States were required to provide their first long-term strategy in January 2020 and every 10 years thereafter. While energy efficiency is one of the five dimensions of the Energy Union, and thus very present in the NECPs, the long-term strategies focus more generally on the greenhouse gas emission reduction but should contain an estimate of the likely energy consumption by 2050 nevertheless.

The strategies should furthermore include among others the following aspects (see Article 15 Section 4. in EU/2018/1999):

a. Total greenhouse gas emission reductions and enhancements of removals by sinks;
b. Emission reductions and enhancements of removals in individual sectors, including electricity, industry, transport, the heating and cooling, and buildings sector (residential and tertiary), agriculture, waste, and land use, land-use change and forestry (LULUCF);

To include this long-time horizon and to ensure the consistency of the reduction pathways and the underlying policies and measures with the NECPs is crucial. At this long-time horizon of 30 years, the consistent orientation along with the principle of Energy Efficiency First has to provide important guidance for the strategic planning so that lock-in effects on pathways (technologies, measures, policies), that will allow reaching the short-term targets laid out in the NECPs but would not allow reaching the long-term targets in 2050, can be avoided. An analysis of the long-term strategies could gain insides into which extent the Energy Efficiency First principle is already implemented as a guiding principle or if more in this regard has to be done by the national decision-makers. Here too, the Energy Efficiency First principle possesses high potential in developing a balanced and cost-effective system of targets for reducing GHG emissions, energy efficiency, and renewable energies as well as the other two dimensions of the Energy Union. Next to the national level long-term strategies, this concerns in particular also the recent proposal by the European Commission on establishing the framework for achieving climate neutrality (European Climate Law) which should inshrine explicitly the Energy Efficiency First principle.

2.3.5. Digitalisation

Policy element: Construction of data centres

The demand for services provided by data centres is increasing rapidly over the last couple of years. Current studies indicate that fast-improving energy efficiency can keep up with the speed of increasing demand. Following the EEF principle, it is important to evaluate the efficiency of data centres, and improve it, for example, by using automatic cooling optimisation based on AI technologies. The costs of these energy efficiency measures should be compared to the costs of supply-side investments in (local) power generation units, utility-scale storage facilities, and distribution and transmission network assets to achieve a cost-optimal resource mix for covering the energy service of data provision.

Major decision-makers

☑ Policymaker	☐ Regulation authority	☐ Energy suppliers	☐ Network operator
☐ Consumers	☐ DSM service provider	☑ Other	

Relevance

low	medium	high

Description

A data centre is a building, or a group of buildings used to house computer systems and associated components, including telecommunications and storage systems, power supply, cooling systems, and various security devices. It provides support for this increasingly digitalized world, and also consumes substantial amounts of energy, which has doubled over the past decade [9,42,43]. Evaluation and improvement is important for construction of the data centres. Applying the EEF principle in this context comes down to selecting and implementing a portfolio of resources that can deliver the increasingly critical energy service of data transfer at the lowest possible cost from a societal perspective. The central demand-side resource is energy efficiency improvement of data centres in terms of electricity use per unit of data, which will also reduce cooling needs. Cooling equipment and its operation should also be as energy-efficient as possible, e.g. with liquid or free cooling. On the supply side, the costs of improved energy efficiency performance should be considered on a par with conventional investments in power generation and network assets, including local photovoltaic installations and storage facilities, network assets, including local photovoltaic installations and storage facilities. The evaluation of the energy efficiency performance of data centres is related to several aspects, and relevant metrics can be classified into different categories, including the energy consumption by the physical infrastructure, the servers, and the airflow and cooling system [42]. One established metric is the power usage effectiveness (PUE), which was published in 2016 as a global standard (ISO/IEC 30134-2:2016), and adopted by the "Energy Star for Data Centres" program in the US. It is the ratio of the total amount of energy used by a computer data centre facility to the energy delivered to computing equipment. Supplementary views exist about considering more aspects, including the efficiency of the IT equipment and the nature of the electricity used (e.g. share of renewable energy used) [43]. Concerning efficiency improvement technologies, for example, Google has been using AI technologies for automatic optimisation and control for the cooling system in its hyperscale data centres and has deployed smart temperature, lighting and cooling controls to further reduce energy use. Facebook is building its hyperscale data centre in Singapore, and it will run on 100% renewable energy. The cooling system that minimizes water and power consumption is expected to reduce peak water usage by more than 20% in hot, humid climates like Singapore [44]. Besides, waste heat collection and reuse can also contribute to the overall efficiency improvement of data centres. In conclusion, the policymakers need to follow the EEF principle and provide incentives to accelerate the adoption of energy-efficient technologies, as well as the renewable energies for the data centres.

Policy element: Deployment of the 5G network

Compared with earlier generations, the 5G RAN network supports much higher speed with much lower latency, but may also consumes more electricity, especially the macro sites, leading to more investment in the distribution network. Following the EEF principle, it is important to evaluate the efficiency of the 5G network, and improve it based on available technologies, e.g. advanced "sleep" modes and battery systems. Such energy efficiency measures should be executed whenever they are more cost-effective than the construction and operation of power generators, network assets and other supply-side infrastructures.

Major decision-makers

- ☑ Policymaker
- ☐ Regulation authority
- ☐ Energy suppliers
- ☐ Network operator
- ☑ Consumers
- ☐ DSM service provider
- ☐ Other

Relevance

low	**medium**	high

Description

5G is the fifth-generation technology standard for cellular networks, which provides mobile devices wireless internet connection with much higher speed and much lower latency, and also makes it possible for new applications in IoT (Internet of Things) and M2M (Machine to Machine) areas. The RAN of 5G consists of two parts, which are macro sites and small cells. The macro sites provide coverage for wide-area, and the small cells are physically small radio base stations that complement the macro network to improve coverage, add capacity, and support new services and user experiences. However, this higher quality of service also demands a higher density of deployment, which may demand more investment in the energy and/or communications network for larger capacity. This is especially the case for the macro sites, which consume much more electricity than earlier generations. To measure the efficiency of a 5G network, the notion of bit-per-Joule energy efficiency is introduced, which is defined as the amount of information that can be reliably transmitted per Joule of consumed energy [45]. Besides, four groups of approaches for improving the efficiency of a wireless network include (i) resource allocation, (ii) network planning and deployment, (iii) energy harvesting and transfer, (iv) hardware solutions [46]. One example is the advanced "sleep" mode, which selectively turns off one or more devices in the absence of traffic. 5G provides for the configuration of transmission-free time slots in non-traffic conditions, in order to enable activation of more advanced and energy-efficient Sleep Modes [47]. Besides, deploying the macro sites with behind-the-meter battery systems also contribute to the efficiency improvement. They charge when the demand for internet connection service is low and discharges when it is high. This shaves the peak demand of macro sites and can reduce the demand of power generation and transmission investment.

2.3.6. Transport

Policy element: Policy decisions in energy efficiency of passenger vehicles

In the EU, 15% of the total greenhouse gas emissions come from cars and vans [48]. Thus, the efficiency of cars and their engines has been a prominent topic in transport and climate policy discussions over recent decades in the EU. The reason for this is the fact that more efficient car engines do not only consume less energy for the distance which they travel. On top of this, carpooling has become increasingly popular, leading to more passengers being carried for each trip made by a vehicle, thereby enhancing the output of that journey. Policy decisions therefore need to accommodate for and promote the application of the energy efficiency first principle in decisions relating to passenger vehicles.

Major decision-makers

☑ Policymaker ☑ Regulation authority ☑ Energy suppliers ☑ Network operator
☐ Consumers ☑ DSM service provider ☑ Other

Relevance

low	medium	**high**

Description

Given that passenger car ownership is increasing across Europe and people still show preferences in many situations to their private cars [48], policy decisions must be taken to ensure manufacturers produce these vehicles in a way that they are designed and used in a way that is as energy efficient as possible, meaning that minimal energy is used in any particular journey. More specifically, the energy efficiency here can be calculated as is the useful travelled distance of passengers, divided by the total energy put into the transport propulsion means. Benefits can be considered not only in terms of energy savings but better air pollution and financial savings for passengers e.g. distance, of passengers divided by the total energy put into the transport propulsion means. Benefits can be considered not only in terms of energy savings but better air pollution and financial savings for passengers. In terms of promoting the design, manufacturing, and sales of efficient cars, three pieces of EU legislation have been central. The EU's Directive on Revised Clean Vehicles Direct (2019/33/EC), the Regulation on CO2 Emissions for Standards Cars and Vans ((EU) 2019/631), and the revised Directive on car labelling (1999/94/EC). These have not only served to minimize the energy consumption and GHG emissions of the production of new cars but also to provide clear information to consumers to make choices based on the efficiency of the cars. Additionally, the EU has been pushing to enhance car-sharing through various initiatives and research projects, such as the through MOMO and CIVITAS projects. Looking at future, and especially long-term, developments, there is the strategic decision whether to promote relatively efficient combustion engine vehicles (as in the past 15 years) plus synthetic fuels (that have low energy efficiency in production), or battery electric vehicles (that have a high energy efficiency but need new infrastructure), or hydrogen fuel cell vehicles (medium energy efficiency but possibly a way forward for long-range trucks, for which battery-electric technology may not be feasible). The systematic life-cycle analysis needed for the comparative assessment would include both the vehicles and the supply and distribution infrastructure, as well as energy, materials, and costs. And for each type of technology, the EEF principle can be applied separately. Further, the consumer choices and offers by car producers for cars with increasing weight is an issue, as the associated rebound effects run strongly encounter of the Energy Efficiency First principle. Hence, the need for expanding the principle to cover also rebounds (e.g. by explicitly taking the car weight into consideration, not only CO2 emissions, which can be very low for very heavy cars if driven by electricity or hydrogen).

Policy element: Investments in local transport planning and management

Transport planning and management includes the planning of public transport networks, transport services and infrastructure. Strategic and proactive planning by the authorities should address all modes of transportation and can thus enhance a cities' energy efficiency through various avenues. Energy efficiency considerations in local transport planning are usually concerned with the basic policy target of realising a reduction in energy consumption or CO2 emissions. In this regard, the utilisation of the energy efficiency first principle can consider whether digital technologies, joint undertakings, and sustainable urban mobility plans but also national road and rail network planning and operation authorities can take decisions based on energy efficiency considerations to optimise resources for travels that are made.

Major decision-makers

☑ Policymaker ☑ Regulation authority ☑ Energy suppliers ☑ Network operator
☐ Consumers ☑ DSM service provider ☑ Other

Relevance

low	medium	**high**

Description

Proactive and innovative investment decisions need to be taken In local transport planning and management to ensure that the needs of mobility in society are met through energy-efficient means of transport (e.g. rail and other public transport, cycling, and walking) and streamlining the journeys taken. Many journeys that need to be taken (e.g. to work or education) can be reduced or optimised, thereby enhancing the efficiency of the energy used for getting someone or something from A to B (for instance through fully utilising the capacity of certain transportation means in each of their journeys). Various benefits in this regard can be considered on top of the energy efficiency gains, including reducing travel times. Three European initiatives serve as examples to illustrate how the EEF principle has been practically applied in transport management and planning decisions can be carried out to promote energy efficiency. Firstly, Sustainable Urban Mobility Plans have been designed to tackle transport-related problems in urban areas more efficiently and the provisions of clean and efficient transport modes for citizens in cities to complete their work and leisure trips in the city.. This has enabled air traffic management to take operational and technical choices which reduce the length of a journey of a flight, thereby making those routes more fuel-efficient, something which the European Green Deal seeks to further improve. Secondly, the EU's Intelligent Transport Systems has supported digital technical, enabling automated mobility and smart traffic management systems. Through stronger communications, congestion is detected and avoided, reducing the energy use of a journey. Thirdly, the EU's SESAR joint-undertaking which concerns air-traffic management and uses trajectory-based operations' (meaning that aircraft can fly their preferred trajectories without being constrained by airspace configurations). Finally, the TEN-T Regulation ((EU) 1315/2013) addresses the implementation and development of a Europe-wide network. In conclusion, the Energy Efficiency First principle can be utilized by local transport planners and management at all levels to identify how to optimise the energy efficiency of transport means and journeys which must necessarily be made. On a local level, measures often revolve around improvement of public transport and the infrastructure and conditions for cycling and walking, as well as municipal fleet efficiency. Such decisions can be taken in terms of system efficiency (e.g. urban mobility plans and land use plans) or by means of (both public and private) travel efficiency (e.g. modal shifts or car-pooling). However, much more needs to be done to mainstream such initiatives and ensure that they are more broadly used across the board. The real-life example in section 4.4 elaborates on these.

Policy element: Policy decisions on energy efficiency in the transport of goods

Goods (freight) can be transported in different forms. By road, sea (shipping), rail and by air. However, in the EU, road transport accounts for 75% of total freight transport (European Green Deal). Thus, the implementation of the Energy Efficiency First principle can also provide more energy-efficient options for the transport of goods through policy decisions on the extension and integration of European and national energy-efficient transportation grids (e.g. railways and canals) or vehicle-related strategic decisions (e.g. overhead or battery electric drives, hydrogen fuel cells, or efficient combustion engines and synthetic fuels).

Major decision-makers

☑ Policymaker ☑ Regulation authority ☑ Energy suppliers ☑ Network operator
☐ Consumers ☑ DSM service provider ☑ Other

Relevance

low	medium	**high**

Description

The energy efficiency in goods transport is the useful travelled distance of goods divided by the total energy put into the transport propulsion means. In this regard, road transport is often not the most efficient form of transportation and it has been recognized by the European Commission that further actions must be taken to optimise the use of other forms of transportation of goods (EC, 2020). As a result, the EU has been encouraging to decide the transport means based on efficiency and emission reduction potential. The benefits of improving the efficiency of freight come not only in energy and GHG terms but also in terms of cost savings and time efficiency (for business and consumers). Just as for passenger vehicle and transport efficiency, applying the EEF principle will mean performing a systematic comparative assessment of the different technology options from a life-cycle perspective, from NECPs to national transport planning to single road, rail, or waterway investment projects. This also concerns transnational projects. Potentials to achieve the same economic outcomes with less transport of goods should also be included in the assessment. Three particular EU measures/initiatives can be noted in this regard that serves to enable the application of the energy efficiency principle and thereby clean forms for the transport of goods. Firstly, the Shift2Rail joint undertaking has been to deliver, through railway research and innovation, the capabilities to bring about the most sustainable, cost-effective transport mode for Europe and working towards the creation of a Single European Railway Area (SERA). Moreover, the EU has promoted various policies to enhance Europe’s inland waterways, given that inland waterway transport is a competitive alternative to road and rail transport. In particular, it offers an environment-friendly alternative in terms of both energy consumption and noise emissions. Its energy consumption per km/ton of transported goods is approximately 17 % of that of road transport and 50 % of rail transport. Furthermore, in the European Green Deal, it was emphasized that a multimodal transport system could significantly increase the efficiency of the transport system (thus a need to strengthen the combined transport directive). Thus, combining various transport modes throughout a journey could also increase the use of sustainable transport. Furthermore, in road transport, there is the strategic decision whether to promote relatively efficient combustion engine vehicles (as in the past 15 years) plus synthetic fuels (that have low energy efficiency in production), or battery electric vehicles (that have a high energy efficiency but need new infrastructure), possibly combined with overhead power lines for direct electric driving, or hydrogen fuel cell vehicles (medium energy efficiency but possibly a way forward for long-range trucks, for which battery-electric technology may not be feasible). And for each type of technology, the EEF principle can be applied separately.

2.3.7. Water

Policy element: Waste Water treatment

The effective management of waste water treatment can make a significant contribution to energy savings. The focus of water treatment will be primarily urban waste water treatment and industrial waste water treatment. There is a need to assess and identify methods to increase water and energy efficiency by reducing leakage in the waste water treatment system as well as optimise operational energy in the pumping, the treatment, and sludging of water.

Major decision-makers

☑ Policymaker ☑ Regulation authority ☑ Energy suppliers ☑ Network operator
☐ Consumers ☑ DSM service provider ☑ Other

Relevance

low	medium	**high**

Description

In general waste water treatment systems need energy for the waste water pumping and water treatment processes. Energy costs make up a significant share of operation and maintenance costs for water treatment utilities. However, the Urban Waste Water Treatment Directive (Commission, 91/271/EEC) has not yet included a focus on the energy-efficient treatment of urban wastewater. Energy efficiency can be gained in the leakage reduction, the pumping, the treatment, and sludging of water through operational energy optimisation, adoption of energy-efficient technology, or energy generation (KWR 2010.011, Energy Efficiency in the European water industry). Furthermore, a significant amount of energy is used in industrial water circuits. There are several initiatives to improve the energy efficiency of the water sector. The project EnerWater, for example, aims to improve the energy efficiency of the wastewater treatment process. A methodology was developed to assess the performance of wastewater treatment processes in industrial plants, and a labelling system to classify them. The potential savings achievable through this methodology amount to almost 5 GWh/year, over the 44GWh, consumed yearly by the participating plants. This would represent savings of 11%, corresponding to the annual energy consumption of 1.368 households.3 Decision-makers have to look at performance, reliability, and risk, leading to new solutions for integrated non-conventional analysis [49]. The key stakeholders in wastewater treatment for urban waste water treatment facilities include utilities, local authorities, consumers (households and public/private sector). The stakeholders for industrial waste water treatment include industry and local authorities. The Energy Efficiency First principle can be applied by first assessing what the existing energy performance of the wastewater treatment process is and then second by analysing which operational changes can minimise the contribution of process units to energy use on wastewater treatment plants. The operational changes can be in in the **pumping system** (are there leaks in the waste water collection network/ pipelines? Can the pumps or motors be upgraded? Possible to avoid pumping at peak energy times? Possible software improvements?), **water treatment** (is the disinfection equipment efficient? Are there any leaks in the system? Is it possible to improve efficiency of aeration equipment and anaerobic digestion? Is it possible to recycle the water?) and finally in the **power options** (Is it possible to implement cogeneration and other onsite renewable power options (e.g. solar panels, wind turbines, low-head hydro)? Or capture energy from water moving downhill to the treatment plant?). In conclusion, the Energy Efficiency First principle should be embedded in the waste water treatment sector as this could stimulate alternative cost-efficient energy efficiency measures to make waste water treatment more efficient.

[3] https://ec.europa.eu/easme/en/news/energy-efficiency-industrial-water-use.

2.4. Summary

This chapter provided a detailed overview of policy areas and policy elements therein, which hold the potential to embrace the Efficiency First (EEF) principle and to establish a level playing field between demand- and supply-side resources.

In the policy area of **energy markets**, the EEF principle has already found explicit reference in established legislations, including, most notably, the Internal Electricity Market Directive and Regulation. Within the three policy elements identified, the idea of establishing a level playing field between demand- and supply-side resources is realised to varying extents. For example, demand response and other demand-side resources have been strengthened in their access to power markets, but energy efficiency needs to be more explicitly covered in the future. Another example is the consideration of demand-side resources in the planning and development of regulated electricity transmission and distribution networks. These provisions should certainly be expanded to the internal gas market and regulated infrastructures therein. In addition, these EU-level provisions need to be implemented more stringently at the national or subnational levels.

The **energy supply and energy system integration** policy area also already features distinct EEF characteristics. More specifically, the existing provisions in the Renewable Energy Directive already require national authorisation procedures to contribute to the implementation of the EEF principle. In the district heating policy element, the Energy Efficiency Directive does implicitly refer to EEF by requiring comprehensive cost-benefit analyses in Member States' potential analyses as well as in the development or major refurbishment of single district heating projects at a local level. However, the methodology provided on the cost-benefit analyses does not yet require Member States to take full account of the range of demand-side resources available that could potentially limit or defer capital-intensive district heating infrastructures.

Energy demand can be seen as a self-evident component of the EEF principle. However, the policy elements screened under this policy area expand the classic notion of EFF (demand-side resources vs. supply-side infrastructures) by addressing also trade-offs within demand sectors, e.g. buildings renovation vs. upgrade of onsite building heating system. In this regard, more distinct provisions on public procurement could strengthen the adoption of energy efficiency and demand response in public facilities, along with setting good practice examples towards consumers. Another important policy element is the industry sector, in which the promotion of material efficiency and energy efficient technologies can reduce the material and energy input needed for the production of consumer goods. In line with the EEF principle, an integrated cost-benefit perspective plays aa substantial role for both of these policy elements.

In terms of **governance**, the NECPs and long-term strategies provide a comparative reporting structure on the mid- and long-term strategies for the five dimensions of the Energy Union and for reaching the EU's 2030 energy and climate targets. Energy efficiency plays a crucial role in these strategies. While energy efficiency is formally included, current country strategies often struggle with a lack of clarity concerning what can be counted towards the target of energy efficiencies. Furthermore, the EEF principle is only mentioned explicitly in very few NECPs, sometimes banned in the footnote and often not present at all. Therefore, the EEF principle is far from (appearing as) the main guiding principle that it was set out to be by the commission. Following the EEF principle would mean to set the target for achieving cost-effective energy efficiency first and to derive the targets for the other four dimensions of the Energy Union and for climate change mitigation taking the energy efficiency targets into full account.

Developments in **digitalisation** are now at a cross-road when it comes to delivering their potential for a sustainable energy system or unfolding ever growing energy demand. This holds particularly true for the policy elements framing investments in digitalisation related infrastructure analysed here, including data centres and 5G RAN. The overview of these areas shows that digitalisation infrastructure is a prime policy area in which the EEF principle can and should be meaningfully applied.

In the policy area of **transport**, although no sector-specific references have been made to the application of the EEF principle in EU policy/legislation, energy efficiency considerations are clear and prevalent in the actions and policy in this field. Albeit, as part of a broader objective of the reduction of emissions and reducing the usage of fossil fuels, where the sector is included in the Governance Regulation and the EED. Such objectives have been particularly underlined in the European Green Deal, whereby efficiency and energy usage in the transport sector has received reasonable attention. In each of the three policy elements explained above, it was shown that moderating transport needs, supply-side actions to support modal shifts, and vehicle standards based on energy efficiency have significant implications (and attractions) for the energy efficiency and cost-effectiveness of the transport sector as a whole.

For the policy area of **water**, there is a strong link to the energy sector. Water is used in the energy sector and a stronger focus on energy efficient measures in the treatment, distribution and usage of drinking water, urban waste water and water in industry and agriculture energy efficiency would be advisable. There is already some legislation, e.g. the Energy Efficiency Directive (2018/2002, Art. 9) focuses on billing or consumption of heating, cooling and domestic hot water. But other legislation could have stronger focus on the Energy Efficiency First principle, such as the Urban Waste Water Treatment directive (Commission, 91/271/EEC).

In conclusion, there are numerous instances where the EEF principle can be practically applied. The following chapter elaborates on the design of the decision-making tool to support decision makers in evaluating processes for the practical implementation of the principle.

3. DESIGN OF THE DECISION-MAKING TOOL

The spirit of the EEF principle is to consider demand-side options when planning the energy system, designing relevant policies, or making supply-side or network investment decisions. Specifically, the "demand-side options" fall into two categories:

- First are efficiency improvements, which lead to less energy consumption for a given level of energy service demand. This can be choosing the most energy-efficient solution during normal reinvestments, or actively replacing old technologies with more efficient ones, for example, replacing the old boilers of households with heat pumps combined with tanks as thermal storage, or with district heating based on cogeneration or large-scale heat pumps with higher efficiency, or on waste heat. District heating can also be fed by heat from renewable energies;
- Second is demand response, mainly in the electricity system, to reduce the peak demand of electricity and network constraints, by using information and communication technologies to inform decision-making and to enable interaction between technologies and relevant policy instruments (e.g. real-time pricing). With lower peak demand of electricity, the investment for power generation and transmission and distribution networks is reduced.

When facing a specific case of system planning or investment, in both energy and non-energy areas, the EEF principle motivates us to evaluate the utilisation of demand-side options first, i.e. efficiency improvement or demand-response flexibility enhancement. The whole decision-making process may involve several decision-makers. First are the policymakers and regulatory authorities, who define the regulative framework, design the policy instruments, provide market access, and thereby direct the behaviour of other decision-makers. Taking the district heating as an example, the following decision-makers can be involved: First, the system operator who operates the centralized heat generator and distribution network, and provides services for the consumers. Second, the consumers on the demand-side, who make decisions regarding the choice from multiple options of heating systems. Third, other heat providers, who can sell waste heat to the district heating system if additional investment are made. In the end, based on the coordination among all the decision-makers, the EEF principle is applied in this energy system planning case.

The objective of Task 1.2 is to design a tool, to support the coordination among decision-makers when applying the EEF principle, especially for the policymaker and regulatory authorities, assisting them to organize the whole decision-making process, reminding them the common critical steps to consider and the key questions to answer.

The tool is not only designed for the cases in the energy field, but also for other fields where the EEF principle can be applied. Following the identification in Task 1.1, we further categorize the policy elements into three general objectives as shown in Table 2. In practice, each element could correspond to one or several specific EEF principle application cases, where the tool is supposed to provide support.

Table 2 Key EEF principle related policy areas and elements

Policy area	Policy element	Policy design	System planning	Investment
Energy Markets	Market access for demand-side resources	√		
	Transmission and distribution network planning	(√)	√	
	Network tariff design	√		
Energy supply and energy system integration	Integrated district heating/cooling planning		√	
	Power generation planning		√	
	Hydrogen infrastructure	(√)		√
	Energy storage	(√)		√
Energy demand	Public procurement rules	(√)		√
	Sustainability of investments in the industry			√
Governance	Security of supply strategic planning		√	

Policy area	Policy element	Policy design	System planning	Investment
	Preparation of NECPs	√		
	National long-term strategies	√		
Digitalisation	Construction of data centres			√
	Deployment of the 5G network			√
Transport	Energy efficiency of passenger vehicles	√		
	Transport planning and management		√	(√)
	Energy efficiency in the transport of goods		√	(√)
Water	Water treatment		√	

√: primary category: (√): relevant as well

To design the tool in a both detailed enough and flexible manner, a tree structure is applied to represent the decision-making processes in different cases. The tree is located in a matrix with two dimensions. This is the **first part** of the tool.

- The first dimension consists of the core decision-makers involved in an EEF principle application case, including policymakers, regulatory authorities, energy suppliers, network operators, consumers, DSM service providers, and others.
- The second dimension divides the coordination process into four phases: project inception, preparation (design and planning), validation, and implementation.

When applying the matrix to a specific EEF principle application, first the relevant decision-makers are selected on the first dimension from the ones identified above, and then their actions are organized along the four phases. The decision tree for the specific application is then created by adding the connections between the actions in the different phases to indicate the flow direction.

The **second part** of the tool is a set of pre-identified actions of the decision-makers. Furthermore, for the users of this tool, i.e. the policymakers and regulatory authorities, their actions are selected as critical steps in the decision-tree, and attached with a list of pre-defined questions, which are defined to mark the most relevant aspects to consider when applying the EEF principle.

The **third, and final part** of the tool is a library, which consists of 229 scientific references that answer the questions that are defined in the second part. The literature is selected from high-quality journals, including Energy Policy, Energy Efficiency, Energy Economics, Applied Energy and others, and other literature relevant for the subject.

In summary, the tool consists of a combination of the three parts described above. The tool is not designed for any specific EEF principle application case, but to provide the users, policymakers and regulatory authorities, with a constructible decision-tree model that can be adapted to different cases, including system planning, investment, and policy design. The pre-identified decision-makers, their actions, key questions, and the supporting literature serve as a "box of elements", from which the users can choose the useful ones and construct the decision-tree for a specific case. For some cases, for example a policy design case, the decision-makers and phases involved can be limited. While for some other cases, the tool may need necessary extension, e.g. with new phases added, new decision-makers introduced, and new actions defined. However, the flexibility of the tool supports these potential reduction or extension,

A detailed introduction of the three parts is provided in the subsequent sections. Furthermore, an abstract decision-tree example is provided for clarification. In the chapter that follows the abstract decision-tree, the tool will be applied to four real-life examples, with decision-trees designed, questions attached to the critical steps, and literature organized in the library.

3.1. Matrix for the decision-tree

As introduced above, the decision-tree is designed within a matrix with two dimensions: decision-makers and phases. For the first dimension, seven types of decision-makers are pre-identified, including policymakers, regulatory authorities, energy suppliers, network operators, consumers, DSM service providers, and others. Under a specific case, the decision-makers can be a subset of the seven as needed. Particularly in policy-making processes, like the development of NECPs, the relevant decision-makers are only policymakers and regulatory authorities. Other types of actors may need to provide information or comments in stakeholder meetings, but would not take any decisions in such cases. For the second dimension, four phases are selected: project inception, preparation (design and planning), validation, and implementation.

3.1.1. Decision-makers

In the following, the selection of decision-makers is described in detail, drawing upon established definitions in EU legislation (e.g. Electricity Market Directive):

- *'Policymakers'* means (1) major institutions involved in the EU's standard legislative procedure, i.e. European Commission, European Parliament, Council of the European Union; (2) parliaments and administrative departments whose competence extends over the whole territory (NUTS 0) of a Member State; (3) parliaments and administrative departments whose competence extends over the regions (NUTS 1), provinces (NUTS 2) and municipalities (NUTS 3) of a Member State.
- *'Regulatory authorities'* means the public regulatory authorities or agencies designated at the national or regional level to set rules and ensure compliance, oversee the functioning of markets, and control tariffs in regulated market segments;
- *'Energy suppliers'* means the commercial producers of electricity, heat, and other commodities, as well as the legal entities that sell energy (electricity, heat, natural gas) to consumers;
- *'Network operators'* means entities responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution and transmission system in a given area for ensuring the long-term ability of the system to meet demands for electricity, heat, and natural gas;
- *'Consumers'* means the customers in the household, industry, transport, services and agriculture sectors who purchase energy carriers for final use and also invest in energy-using assets of a certain energy efficiency level;
- *'DSM service providers'* means the entities that provide demand-side management service (supporting consumers for both improved energy efficiency and demand response), and can also increase the responding flexibility of consumers, for example, the aggregators in the power system or dedicated energy service companies (ESCOs).
- *'Others'* means miscellaneous decision-makers that are not explicitly covered in this list.

3.1.2. Phases

- *'Project inception'* refers to the phase when the policymakers define the policy targets and the regulatory framework, based on which relevant decision-makers define the goals of their business, and the regulatory authorities check if the goals comply with the targets defined by the policymakers;
- *'Preparation'* refers to the phase when the market or planning entities, including the energy suppliers, network operators, consumers, DSM service providers, and other relevant decision-makers collect necessary information and systematically evaluate their options within a cost-benefit framework, which is defined by the regulatory authorities;
- *'Validation'* refers to the phase when the market or planning entities propose their investment plan after the assessment, and the regulatory authorities check the plan. However, such a phase only exists in the vertically integrated sectors. In the market-based sectors, the entities do not need permits from the regulatory authorities whenmaking investment decisions;
- *'Implementation'* refers to the phase when market entities implement the plans.

3.2. Actions of the decision-makers

To make the tool both flexible and detailed enough, in this section, we identify the most common actions of decision-makers when applying the EEF principle. They do not focus on one specific case. For different application cases, actions could be selected from the list to construct different decision-trees.

The decision-makers are classified into three categories, with "market entities" referring to energy suppliers, network operators, consumers, DSM service providers, and others. Corresponding to the four phases, the actions of the decision-makers are presented in Table 3. For the actions of the policymakers and regulatory authorities, questions are attached to their actions to remind them of important aspects to consider, and the supporting literature is provided in the library, introduced in the next section.

Table 3 Actions of the decision-makers

Phase	Policymakers	Regulatory authorities	Market entities
Inception	(P1) Define policy targets (P2) Define regulatory framework (P3) Policy impact and alternatives analysis	(R1) Define market access rules for energy efficiency or demand-response solutions (R2) Compliance check of business/project goal with policy targets and market access rules	(M1) Define business/project goal
Preparation		(R3) Define CBA method in principle	(M2) Define CBA method for concrete application (M3) Information collection (M4) Energy service demand forecast (M5) Identify other cost and risk (M6) Systematic assessment based on the EEF principle
Validation		(R4) Check the implementation plan and if relevant, approve it	(M7) Propose the implementation plan
Implemen-tation			(M8) Implement the plan, e.g. provide designed service, adopt energy-efficiency technologies, make investment decisions, etc.

3.2.1. Policymakers

The policymakers refer to the institutions at EU, national, or regional level, who direct the application of EEF principle at a macro-level, by defining the policy targets and regulatory framework, i.e. the policy instruments set. Based on these, the regulatory authorities, at national or regional level, will take local conditions and constraints into account and define specific rules for the market entities, ranging from companies from supply-side to DSM service providers and consumers on the demand-side. Three actions of policymakers directing EEF principle application are identified as below.

(P1) Define policy targets

For the cases where the EEF principle can be applied, the policymaker should define the targets, and consider their interactions with energy efficiency objectives. Then, the policymakers should provide the policy targets to the regulatory authorities and relevant market entities for further steps. For this process, the following questions are involved:

a) What policy targets are usually applied under the specific case? What are the potential trade-offs among these targets?

b) How to measure these targets?

(P2) Define regulatory framework

Based on the targets defined in the first step, the policymaker should also define the regulatory framework to support the application of energy efficiency solutions. The key point of this step is to provide incentives to procure demand-side resources by integrating necessary policy instruments. Specifically, incentives need to be provided for the system operator in the vertical integrated systems, or energy suppliers and energy service providers in the maket-based systems, to promote the use of demand-side resources.

Relevant questions include:

a) To achieve the policy targets listed in the first step, what policy instruments can be applied?

b) What are the existing experiences of these policy instruments? What are the obstacles to implementation?

c) For the specific case under consideration, what are the advantages and disadvantages of the policy instruments?

The above two actions of policymakers are considered in the EEF principle applications cases where more decision-makers are involved, e.g. the system planning or investment decision-making cases. However, for cases of policy-making, the policymakers are the main actor involved. Their actions include the first action above (Define policy targets) plus the following:

(P3) Policy impacts and analysis of energy efficient alternatives

Based on the targets defined in the first step, the policymaker should analyse impacts and alternatives that are better for energy efficiency. Relevant questions include:

a) What is the impact of the policy proposed on energy consumption, energy efficiency, GHG emissions, costs, and other social and environmental impacts?

b) Are there energy efficiency actions that could be an alternative to the supply-side actions in an energy system, or the traditional actions in other systems? Are there alternatives to the proposed policy that would achieve the policy’s target but with less negative or more positive impacts on energy efficiency?

3.2.2. Regulatory authorities

Following the policy targets and regulatory framework defined by the policymakers, the regulatory authorities take local conditions and constraints into account, and interact with relevant market entities at a micro-level, by checking their business goals and implementation plan, and by defining more detailed cost-benefit-analysis (CBA) method and necessary rules. Four relevant actions of regulatory authorities are identified as follows.

(R1) Define market access rules for energy efficiency or demand-response solutions

Some energy efficiency or demand response solutions may not be provided by the market entities under current regulation framework. To implement the EEF principle, new players who provide efficiency or demand-response solutions should be introduced to the relevant markets by defining access rules for them. Concerning the energy efficiency solutions, in the case of a district heating system, examples include the system operator and potential waste heat providers. For the demand-response solutions, it could be the DSM service provider (e.g. an aggregator), who improves the flexibility of demand-side, reduces the peak demand, and further reduces the investment for the supply-side or network in the electricity system. For such cases, the regulatory authority should provide the rules that make this possible. Relevant questions include:

- Concerning the case under consideration, are there any other players that can enhance the energy efficiency or demand response flexibility of consumers, or provide energy from waste collection, etc?
- If there are, what are the barriers for them to implement a more energy efficiency solution or access the market?

- How to evaluate the potential contribution from these decision-makers, and are there any costs of letting them in the system?
- How should the responsibilities be shared for the achievement of the main objectives of the project?
- What are the existing experiences of the application of energy efficiency solution in a specific area?

(R2) Compliance check

Based on the policy targets provided by the policymaker, the regulatory authority should check the business/project goals proposed by the market entities. The aim of this process is to ensure that the business/project goals do not conflict with the policy targets defined by the policymakers and the market access rules, and besides, to ensure that there is space for the application of energy-efficiency solutions on the demand-side.

This should be an iterative process at an early stage of the decision making process that should lead to consideration of increasing energy efficiency in the business goals and ensuring that energy efficient solutions could be eligible for a given initiative. In particular, potential demand-side options, should be specifically considered if they could contribute to achieving the business goals. For this process, the regulatory authorities need to answer:

- How to evaluate the contribution of market entities' goals to the policy targets?
- Are there potential conflicts between the business goals and scope of the project with possible incorporation of energy efficiency solutions?

(R3) Define the CBA method

The definition of CBA method can be different when applying the EEF principle in an energy-related case (policy element) or in other cases. Apart from the energy savings, it should also look at wider benefits which may not be easy to quantify or monetize, and the benefit should be evaluated from a societal cost and benefit perspective, beyond the market entity perspective.

For the energy-related cases, when considering regulated sectors, particularly networks, or vertically integrated energy systems, the regulatory authorities should define the CBA method based on the regulatory framework defined by the policymakers, with the consideration of more detailed conditions and constraints for applying the energy efficiency solutions. Then, based on the CBA method, the market entities can systematically assess their investment options. While in the market-based energy systems, the societal CBA method will also be specified by the regulatory authorities but market entities may define the details of the CBA method from their perspective themselves. In both situations, relevant questions include:

- For the specific initiative, what are the available investment options for the market entities on the supply-side and the network?
- What are the options on the demand-side that can improve the energy efficiency or demand-response flexibility, and further reduce the investment on the supply or the network?
- For these options, how to evaluate their cost and benefit from the perspectives of (i) society, (ii) the market actors that implement the energy efficiency plans, and (iii) the final consumer/investor [50,51].
- How to assess the contribution of cost-effective investment options to the policy targets defined by the policymakers?

For the cases in non-energy areas, the evaluation of investment options should also consider their impact on the energy consumption, and see if the more energy-efficient options can be integrated. From the perspective of market entities, as well as the societal cost and benefit perspective, the regulatory authorities or the market entities define the CBA method, based on the regulatory framework defined by the policymakers. Relevant questions include:

- Given the policy targets or business goals, what are the available options, especially the energy efficiency options? What are the impacts on energy consumption of various investment options?
- How to evaluate the cost and benefit of these options, from the perspectives of society, market actors that implement this plan, and the consumers?
- Where to obtain and how to compare the data, if available?

(R4) Implementation plan check

Following the CBA method provided in the earlier step, the regulatory authorities should check the plans proposed by the market entities from the perspective of EEF principle, and see if the available energy efficiency options are taken full advantage of, and the investment on supply-side and network are necessary. This is an iterative process and will lead to improvement until the plan is justified. Relevant questions are the same as for the action "*Define the CBA method*".

3.2.3. Market entities

The "market entities" here include energy suppliers, network operators, consumers, and DSM service providers, or other relevant actors, particularly in non-energy sectors. Under some cases, it also includes some public entities or state agencies, which directly participate in the system operation and are responsible for implementing the EE or DSM programs, for example, as DSM service providers in the power system.

Here we put the actions of these market entities together as a group for two reasons. First, this tool is developed for policymakers and regulatory authorities, so the actions of other decision-makers, i.e. the "market entities", are not the focus of this tool, and are not attached with questions and supporting literature. Second, these market entities belong to different market segments and have different options, but some actions concerning the application of the EEF principle are shared among them. So, the set containing the actions of multiple market entities are listed and introduced as follows.

(M1) Define business/project goal

Under a specific EEF principle case, some market entities need to define their business or project goals based on the policy targets defined by the policymaker. For different market entities in different cases, the emphasis of the goal can be different. Taking the generation companies in the electricity market, the goal is more about maximising the profit, while for the operator of a district heating system, the goal may concern more about the improvement of energy efficiency, and the cost and benefit is evaluated more from a societal perspective.

Then, the goals defined by the market entities will be checked by the regulatory authorities, to see if they are consistent with the policy targets, and if necessary efficiency options can be included in the following stages.

(M2) Define CBA method

When applying the EEF principle in the market-based systems, the societal CBA method will also be specified by the regulatory authorities, but the CBA method from the business perspective may not be defined by the regulatory authorities, but by the market entities themselves, to systematically assess the investment options, based on the regulatory framework defined by the policy maker. The impact of policy instruments promoting energy efficiency measures will be taken into consideration, and the investment on the supply-side or network may be reduced.

(M3) Information collection

For further steps, the market entities need to collect the necessary information. For example, the operator of a district heating system may collect information about the population or number of the dwellings in this area, as well as their location, to forecast the demand of district heating. Besides, it may also collect the information about potential heat providers from other sectors, e.g. industrial companies or data centres. At last, the system operator also needs to collect information about the cost of heat sources and pipelines, thermal insulation of buildings, social benefit of the district heating system (energy saving, pollution reduction, etc.), to systematically evaluate the cost and benefit of the system from the perspective of the EEF principle.

(M4) Energy service demand forecast

For the EEF principle application to cases in the energy field, all the relevant market entities, especially the ones in the supply and network, will forecast the energy service demand. Additionally, for the vertically integrated systems, the task of forecasting could also be upon the regulatory authority. Then in the following steps, based on this forecast of energy service, they will collect information of the available options and evaluate them following the EEF principle in the CBA method defined before. The forecast should also look at possible further reductions in energy demand levels that could affect the viability and cost-benefit assessment of options.

(M5) Identify other cost and risk

To evaluate the cost and benefit of the planning of the system, or investment decision, or a policy design, one also needs to identify other potential costs and risks and consider them. For example, when designing the contract for the consumers, the operator for a district heating system needs to consider the variation of fuel price, environment cost, etc.

(M6) Systematic assessment based on the EEF principle

Based on all the information collected, including cost of various available options, the forecast of energy service, and identified uncertainty and risk, the market entities will systematically assess all the available options based on the EEF principle.

(M7) Propose the implementation plan

The market entities will propose their implementation plans to the regulatory authorities for a check. The plan should indicate how energy efficiency options were assessed, whether they have been discarded or selected and under what conditions they could be implemented. This is an iterative process and will lead to improvement until the plan is justified.

(M8) Implementation

After all the actions above and receiving approval from the regulatory authorities, the market entities will implement their plans at last, including providing the designed service, adopting energy-efficiency technologies, making investment decisions, etc.

3.2.4. Others

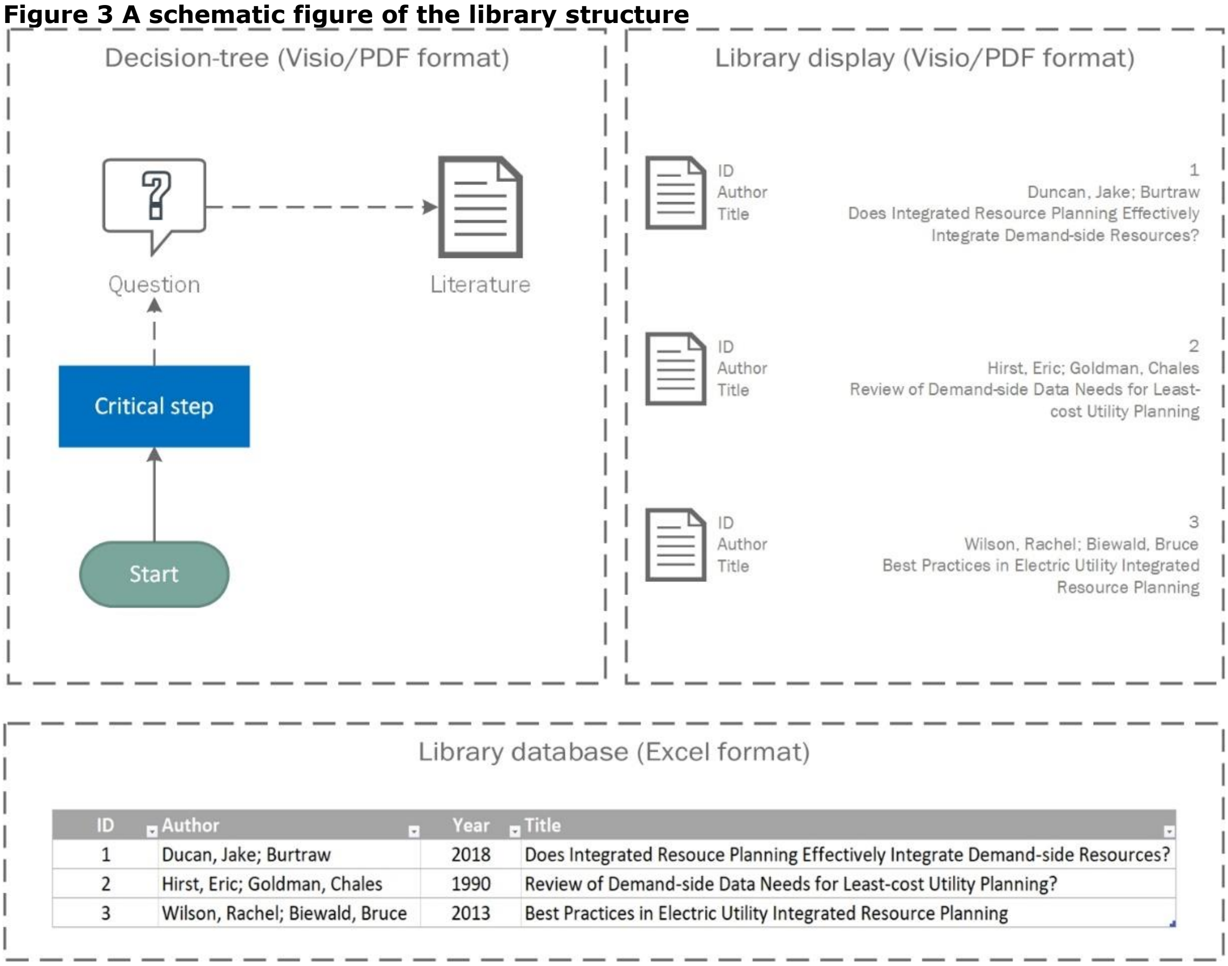
For different planning or investment cases, there might be other market entities involved apart from the ones listed above. For example, when planning the district heating system, waste heat might be collected from industrial sectors and provided to the network and sold. Some sectors might also be potential buyers of electricity generated by the PV systems of consumers. These decision-makers need to be identified case by case, but the actions identified above can also provide reference value.

3.3. Library

As introduced above, for the critical steps in the decision-tree, key questions are attached to remind the policymakers and regulatory authority of important aspects to consider, as listed in Section 3.2.1 and 3.2.2. Then, to answer these questions, this tool provides a library in which papers and reports are organized and linked to the questions. The structure of the library is as shown in Figure 3.

The decision-tree is developed based on the Microsoft Visio software and saved as a PDF file, embedded with links to the library display page and Excel library database.

Figure 3 A schematic figure of the library structure



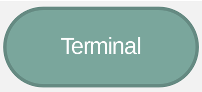
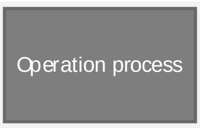
3.4. Decision-tree example

For a specific EEF principle application case, the decision-tree is developed within the matrix of decision-makers and phases, and based on the elements introduced above. In this section, we provide a schematic example for an abstract case for clarification, and four real-life examples will be provided in the next chapter.

3.4.1. Shapes in the decision-tree

Decision trees are an established approach to display information and assist reasoning. In the context of this project and the EEF principle, they are used to visualize complex decision-making processes, to make explicit the structure of decision-makers and their actions, and to gain a shared understanding of these processes. Using the Microsoft Visio software, decision-trees are composed of shapes and flow-lines, with different shapes having different meanings. These mostly correspond to established standards defined by the International Organization for Standardization (ISO 5807/1985) and are outlined in Table 4.

Table 4 Description of shapes used in the decision-making tool

Shape	Description
	Represents the starting or ending point of the decision-tree.
	Indicates some particular operation proceeded by the decision-makers, for example, the policymaker defining its policy target, or the energy supplier collecting information.
	Represents a point where specific checks are made. Lines coming out from the shape indicate different possible situations, i.e. yes or no, leading to different processes.

Shape	Description
	Represent the flow of the sequence and direction of the process.
	Represents information entering or leaving the decision processes, for example, the cost data of demand-side options, or a report on demand- and supply-side costs.

3.4.2. Schematic example

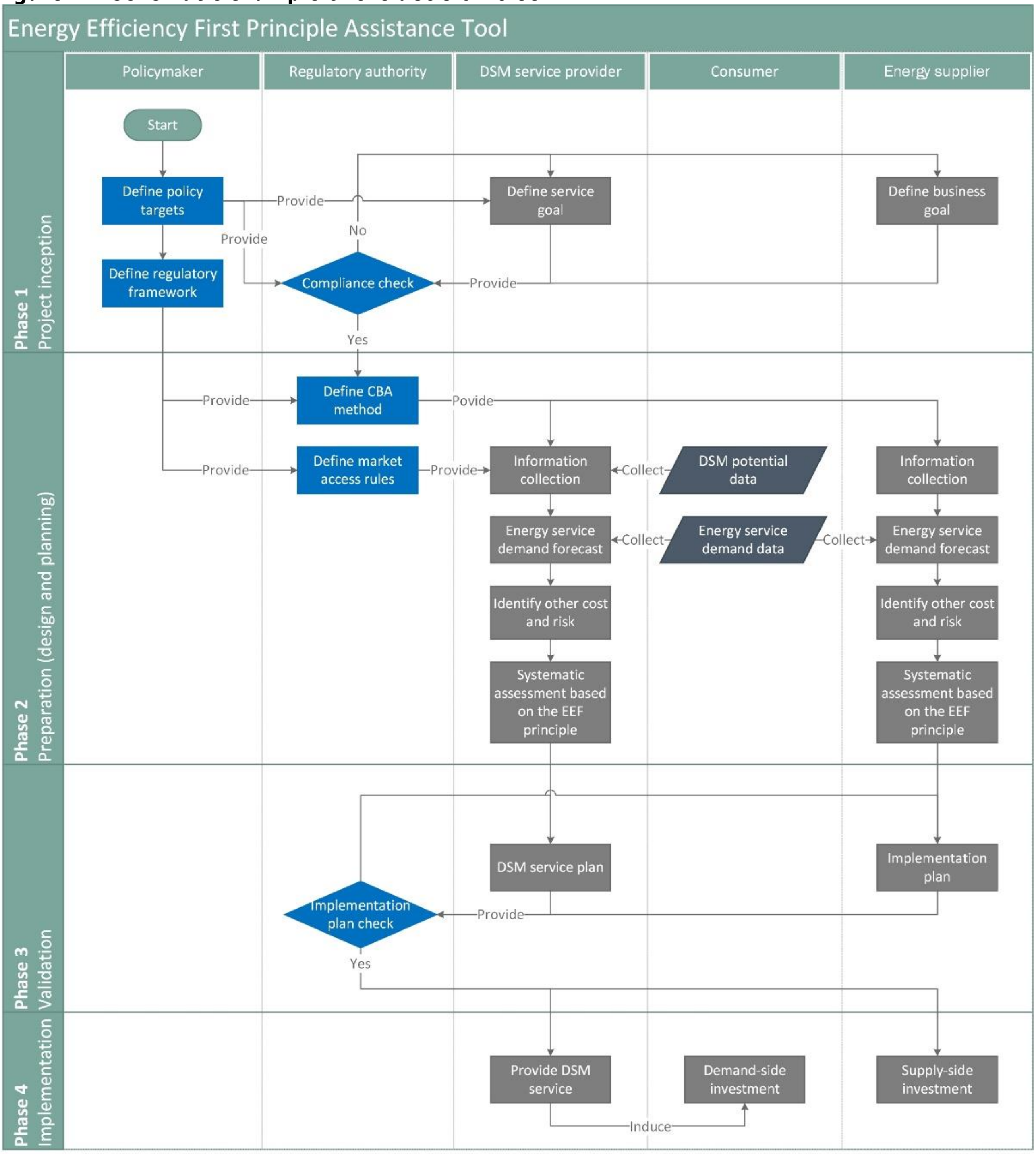
As shown in Figure 4, a schematic decision-tree for an abstract case is provided, with five decision-makers selected: policymaker, regulatory authority, DSM service provider, energy supplier, and consumer. Their actions are organized into four phases as steps in a decision-tree, among which the actions of the users of the tool, policymaker and regulatory authority, are highlighted as blue. Please note that, this schematic decision-tree suits more for the cases where the policymakers, regulatory authorities, and market entities are all relevant. For example, most cases concerning the planning of energy systems, especially the demand- and supply-sides are separate. However, for the other non-energy cases, especially the policy elements from governance area, the decision-makers may not include market entities, and there are not demand- and supply-sides. Then, the decision-tree needs to be simplified, but the actions and questions introduced above still fit.

In the first phase, project inception, the policymaker defines its policy targets and provides them to the regulatory authority, DSM service provider, and energy supplier. Then the two market entities define their goals and provide them to the regulatory authority for a compliance check. When the check is passed, the project proceeds to the next phase, feasibility check.

In the second phase, the regulatory authority will define the CBA method based on the regulatory framework defined by the policymaker in the first phase. This CBA method will be passed to the market entities and guide their further steps. For the DSM service provider, the regulatory authority will also define the market access rules. Then, the market entities will collect information about the options, forecast the energy service demand, identify other cost and risk, and systematically assess the options based on the EEF principle.

In the third phase, implementation plan and check, the market entities propose their implementation plans based on the assessment in the second phase, and the regulatory authority will check their plans based on the CBA method. When passed, the plans will be implemented in the last phase, implementation.

Figure 4 A schematic example of the decision-tree



3.5. Summary

Following the classification of policy areas and elements into different objectives, in this section, we provided a decision-making tool for the application of the EEF principle for the policymakers and regulatory authorities. To make the tool both detailed enough and transferable across different cases in practice, especially for energy system planning and investment decision, the tool is provided as three parts.

- First, a pre-defined matrix of decision-makers and phases, to provide the space for a decision-tree;
- Second, a set of identified actions of the decision-makers and transferable questions attached to the actions of the users of this tool, policymakers and regulatory authorities;
- Third, a library that contains the literature answering the questions.

Based on these three parts, this tool provides the users a hands-on framework to establish decision-trees for different EEF principle cases. When applying this tool to different EEF principle cases in practice, The users could first read through the descriptions of policy areas and elements provided in Chapter 2 and see: (1) if the EEF principle can be applied or already satisfied, and (2) if not satisfied, what options can be introduced. Then, the users could construct a decision-tree based on the framework provided in this chapter, to organize the relevant decision-makers and their actions, supported by the most relevant questions concerning each action and the literature, to promote the application of the EEF measures which are still available.

At last, for specific cases, decision-makers or actions can be defined more specifically then the ones listed in this chapter. Besides, there might also be more decision-makers or actions involved apart from the ones identified above, but following the spirit of EEF principle, this framework is also flexible for potential reduction or extension.

4. REAL-LIFE EXAMPLES

In this section, the decision-making tool is applied to four real-life examples for further illustration and refinement:

- District heating planning;
- Planning for Demand response in the power sector;
- Power transmission and distribution network planning.
- Local Transport Planning.

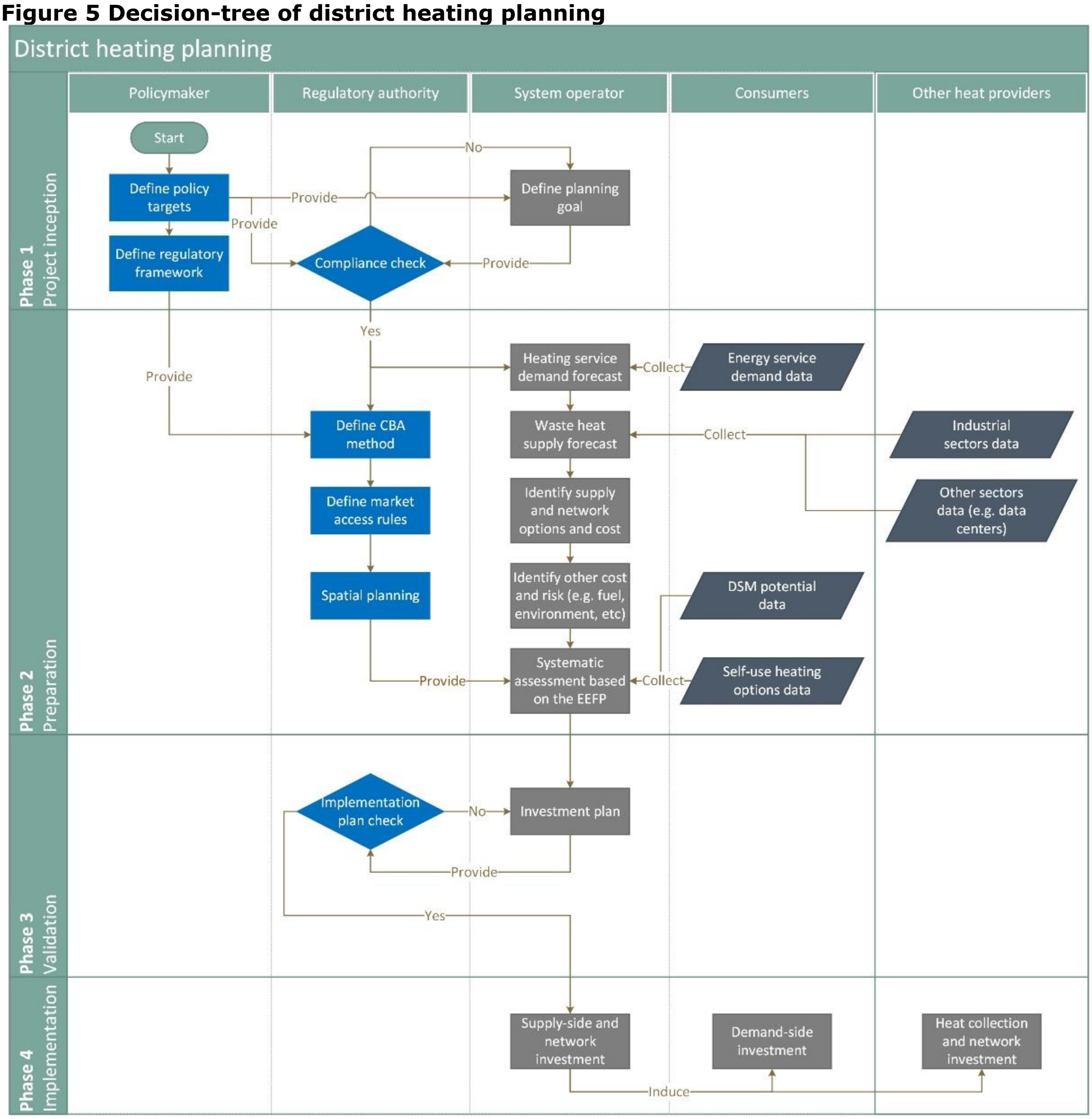
Within the context of the examples, the decision-makers and their actions are more specifically defined based on the structure and elements provided in Chapter 3. For the actions of the users of this tool, policymakers and regulatory authorities, relevant questions are attached, and supporting literature is provided in the library.

4.1. District heating planning

Following the spirit of EEF principle, the analysis of a district heating system should consider three aspects. First, decentral house boilers are replaced by a centralized more energy-efficient heating system or a combined heat and power system. Conversion to energy-efficient district heating is thus an energy efficiency action by itself. Second, it provides flexibility for demand-side management. Based on the information and communications technologies (ICTs), the peak demand of heat can be shaved, then the high pumping cost is reduced, the failure risk of the pipelines from large water velocities is avoided, the demand of production capacity is reduced, and the capacity of the network to connect more buildings is extended. It may also provide flexibility for the electricity sector if heat storage is used to optimise the power generation in a combined heat and power system. Third, however, it is an energy supply system, and energy efficiency in the buildings and production processes supplied with heat from the district heating system should be compared to and assessed against an expansion of the district heating system. Energy saved through energy efficiency with existing customers can be used to serve new consumers.

In most cases, a district heating system is a vertically integrated system, i.e. the system operator is responsible for both heat production and network operation and heat supply, as well as relevant investment decision-making. Besides, a district heating system also supports the connection of other sectors, for example, the industrial sectors which can collect waste heat and sell to the network. The two properties listed above lead to the following selection of the decision-makers in the tool for applying the EEF principle in district heating planning: policymaker, regulatory authority, system operator, consumer, and other heat providers.

Figure 5 Decision-tree of district heating planning



The decision-tree for district heating planning is provided in Figure 5, with seven actions of the policymaker and regulatory authority highlighted in blue. For these critical steps, relevant questions are attached in the following to remind the important questions to consider, and papers or reports are linked for support.

4.1.1. Policymaker

Action 1: Define policy targets and objectives

The policymaker should define the targets (EE or broader) for the planning of the district heating system. Then, provide the targets to the regulatory authority and the system operator for further steps.

Q1: What policy targets are usually applied in the heating sector development, what are the potential trade-offs among these targets, and how can they be measured?

District heating is generally considered a key element for various objectives in energy policy. As pointed out, for example, in the EU Heating and Cooling Strategy [19], district heating should help to reduce energy imports and dependency, to cut costs for households and businesses, and to deliver the EU's greenhouse gas emission reduction goal and meet its commitment under the

Paris Agreement. The trade-offs between these objectives are manifold. Cutting greenhouse gas emissions through a fuel switch in district heating systems is subject to incremental costs that are essentially borne by the end-users and customers of these systems, thus affecting affordability. A fuel switch to scarce resources (e.g. biomass) or such with variable output (e.g. solar thermal) affect the matter of security of supply. Measuring these targets requires a set of dedicated indicators. Greenhouse gas emissions are closely linked to the fuels used in district heating systems and are typically expressed as tonnes of CO_2 equivalents. Closely related is the renewable energy share in energy supply and/or consumption. Economic costs reflect the feasibility of a given district heating system configuration. They can be evaluated from a societal perspective (including external costs and benefits), utility perspective (including the costs incurred by the district heating supplier), or the end-user perspective (determining the costs incurred by the customers). Security of supply can be measured as the reserve capacity required for supplying heat at any point in time required. For example, an additional backup heat-only boiler might need to be installed in a district heating system in case the primary production unit (e.g. solar thermal installation, utility-scale heat pump) cannot supply heat at all times. Note that overall,

while these policy objectives provide a loose framework, there hardly is a dedicated institutional and legal framework for district heating at the supranational EU level. The design and operation of local district heating systems are ultimately determined by the legal provisions in single Member States and, more importantly, by enabling conditions and initiatives steered by local authorities. These local authorities typically are the entity making the decision about the general design of the district heating system (e.g. extent of inclusion of third-party waste heat providers). As such, they can adopt criteria favouring investments in energy efficiency improvements of the system or requirements in addition to the national legal framework.

Title	Author	Year	Description
Germany's Draft of the Integrated National Energy and Climate Plan	Federal Ministry for Economic Affairs and Energy	2020	In Germany's NECP, targets are set for district heating, including renewable generation, GHG intensity, energy consumption, etc.

Action 2: Define regulatory framework

Based on the targets defined in the first step, the policymaker should define the regulatory framework, in which multiple policy instruments can be integrated.

Q2: What policy instruments can be applied for planning the district heating system?

As described in the policy element on *Integrated district heating/cooling planning* in Chapter 2.3.2, there are two major policies on district heating at the EU level. The Energy Efficiency Directive (EED, 2012/27/EU) and its amendment (2018/2002/EU) essentially require Member States to carry out a comprehensive assessment of the potentials for cogeneration and efficient district heating and cooling in their national territory (Art. 14.1). Besides, they must perform a cost-benefit analysis (CBA) to identify the most resource- and cost-efficient solutions to meeting heating and cooling needs from a societal perspective (Art.14.3). However, as described, these provisions do not adequately take end-use efficiency (thermal performance of buildings) and demand response as alternatives to district heating supply infrastructures into account. The provisions on cost-benefit analyses for single district heating projects (Art 14.5) were concluded to be even more rudimentary than for the comprehensive assessment. In addition to the EED, the recast of the Renewable Energy Directive (RED II, Directive 2018/2001/EU) provides the EU with a new framework for the funding of renewable energy. The share of renewable energy in final energy consumption within the EU is to be increased to least 32% by 2030. Specifically, for the heating sector, RED II requires Member States to increase the share of renewable energy they use for heating and cooling by 1.3 percentage points per year from 2021 onwards. These targets are likely to increase the incentives for district heating operators to seek renewable-based heat sources. These two major policies are complemented by various policies in wider field of heating policy. For example, the EU has adopted Eco-design and labelling requirements for space and water heating equipment, banning inefficient boilers from the market and enabling consumers to distinguish the overall efficiency between different alternatives. The Energy Performance in Buildings Directive (EPBD) mandates setting requirements for the energy efficiency of buildings, including the reduction in buildings' thermal energy demand. In terms of finance, the EU provides funding for innovative and smart heating and cooling grids, including the European Regional Development Fund and the Connecting Europe Facility. Overall, besides these provisions at the EU level, Member States have considerable flexibility to implement their own instruments and measures to achieve their individual objectives according to their national circumstances and conditions. The library contains three articles about the application of different measures aimed at promoting energy efficiency in district heating.

Title	Author	Year	Description
Optimisation of a Swedish district heating system with reduced heat demand due to energy efficiency measures in residential buildings	M.Åberg, D.Henning	2011	In this study, a potential HD reduction due to energy efficiency measures in the existing building stock in the Swedish city Linköping is calculated. The impact of HD reduction on heat and electricity production in the Linköping DH system is investigated by using the energy system optimisation model MODEST.
Energy efficiency inside out—what impact does energy efficiency have on indoor climate and district heating?	Sirje Pädam, Agneta Persson, Oskar Kvarnström & Ola Larsson	2019	This research study analyses the relationships between energy supply, energy-efficiency measures, and indoor environment. Heat load duration profiles were applied to analyse the quantitative impact on district heating production of energy-efficiency measures implemented in the multifamily housing stock of three Swedish municipalities.
Towards a decarbonized heating and cooling sector in Europe	Aalborg University Denmark	2019	This report analyses, and where possible quantifies, the potential of energy efficiency and district energy as enablers of the decarbonisation of the European heating and cooling sector and the wider energy system, as well as the role of different technologies to improve the efficiency along the energy value chain.

Q3: What are the existing experience of these policy instruments? What are the obstacles to implementation?

The set of existing EU legislations on district heating and cooling features long-term targets and provisions, and thus stability, which is generally considered an important lever to unlock deployment of efficient district heating and cooling systems and limiting associated investment risk [52]. More specifically, regarding the market access of third party heat providers, a recent evaluation on the recast Renewable Energy Directive [53] concludes that the new provisions will hardly contribute to strengthen the position of third party RES or waste heat generators or to provide additional rights to them. With the new legislation, little will change about the fact that the third-party RES or waste heat generators must seek the consent of the network operator in order to feed its RES or waste heat into the district heating network. At the moment, the Directive leaves important issues unaddressed; for example, who is granted access first and who is remunerated if more than one third party seeks access. Without such a detailed market framework, seeking consent between the third party and the network operator remains the only feasible solution [53]. Overall, research states that local deployment of efficient district heating and cooling systems is not necessarily driven by EU policy, but rather by local energy and environmental objectives. Therefore, EU Directives should support and tap potentials of local initiatives [52]. The library contains two articles with lessons and evidence from existing experience.

Title	Author	Year	Description
Local and Regional State of Play and Policy Recommendations Concerning Sustainable Heating and Cooling: Focusing on EU Level Policy	Committee of the Regions	2016	This report gives (inter alia) the most relevant projects concerning sustainable heating and cooling for local and regional authorities and policy recommendations for future initiatives.
Efficient district heating and cooling systems in the EU - Case studies analysis, replicable key success factors and potential policy implications	Joint Research Centre	2016	This study investigates the key success factors (KSF) enabling to develop high quality, efficient and low-carbon DHC systems, discusses how these KSF can be replicated in the EU and provides a better view on the role and features of these systems, as well as a few potential policy guidelines to support their deployment.

4.1.2. Regulatory authority

Action 1: Compliance check

Based on the policy targets provided by the policymaker, the regulatory authority should check the planning goal proposed by the system operator. This is an iterative process and will lead to further processes until the plan complies with the targets.

Q4: How to evaluate the contribution of a district heating system to the policy targets? Are there potential conflicts between the business goals and the policy targets?

District heating operators have different ownership arrangements, ranging from publicly to privately owned entities or combinations of them. As such, their inherent trade-offs and conflicts between profit maximisation and overarching societal concerns (including the consideration of demand-side resources for the sake of overall societal welfare) need to be addressed differently. For publicly owned district heating systems, national or local authorities have direct influence on the design and configuration of the district heating system. They can thus adopt criteria favouring investments in demand-side resources (e.g. by contracting ESCOs to achieve end-use savings) as counterparts to a larger scaling of the district heating supply system in terms of generation, network, and storage capacity required. Privately owned district heating systems essentially require regulatory oversight to control their performance in considering demand-side resources in their investment and operation decision-making. Besides this realm of investment planning, given the monopolistic structure of the district heating system, regulators also need to exert price control to protect consumers from the operator's market power. Regulatory authorities have different instruments at hand for these purposes. These include: general regulatory oversight (closely supervise all costs and make all investment items subject to regulatory approval; price or revenue caps (set a ceiling that the operator is allowed to pass on to consumers relative to the opportunity costs of alternative demand-side investments); and performance-based regulation (reward the consideration of demand-side resources through financial incentives). Depending on the region-specific jurisdiction, regulatory authorities have quasi-judicial powers, allowing them to establish fines and penalties for non-compliance. Overall, any regulation toward an enhanced consideration of demand-side resources needs to be evaluated in terms of profitability and affordability of the heat supplied, quality of the services offered, service availability and social welfare as a whole.

The library contains four articles about the potential and impact of different types of regulation for district heating.

Title	Author	Year	Description
Regulation of district-heating systems	Matthias Wissner	2014	This article examines the possibility of regulating district-heating systems and the difficulties associated with practical implementation using the example of the German district-heating market.
Policies directed towards heating systems	Naghmeh Altmann-Mavaddat	2018	This contribution addresses the following questions: (a) What are the main trends regarding the heating systems? (b) Are regulatory frameworks effective regarding energy-efficient systems?
Cogeneration and district heating networks: Measures to remove institutional and financial barriers that restrict their joint use in the EU-28	Antonio Colmenar-Santos, Enrique Rosales-Asensio, David Borge-Diez, Francisco Mur-Pérez	2015	This research aims to identify actions that dissipate the institutional and financial barriers that are faced by those energy projects which comprise the joint use of district heating networks and cogeneration in the EU-28.
German Energiewende and the heating market – Impact and limits of policy	Klaas Bauermann	2016	This paper simulates the future German heating market under different policy scenarios to evaluate the impact and limits of recent and conceivable policies.

Action 2: Define the CBA method

Based on the regulatory framework provided by the policymaker, the regulatory authority should define the cost-benefit-analysis (CBA) method for the system operator to systematically assess its investment options, not only from its own economic perspective but also from those of society and the consumer.

Q5: What are the technology alternatives for individual heating supply? How to calculate their cost?

There are numerous system configurations for district heating systems. On the supply side, heat is often provided by large-scale cogeneration plants that run on natural gas, biomass, or waste. Utility-scale heat pumps, solar thermal and geothermal installations and other innovative technologies expand the range of possible supply-side options. Besides heat generation the system then requires local grid infrastructure to supply the heat up to the end-users. Finally, thermal storage units might be added to the system configuration to store heat in times of abundant supply. Overall, in line with the EEF principle, these supply-side assets must be evaluated against alternative demand-side resources, including energy efficiency, energy conservation, load shifting, and other options. A major opportunity for energy efficiency lies in improving the thermal performance of buildings, which reduces the useful energy demand for heating and cooling, and thereby the amount of energy that needs to be generated and transported on the supply side. Energy conservation concerns behaviour changes in terms of reducing energy services. For example, consumers could be encouraged to slightly lower indoor temperatures without compromising perceived comfort. Load shifting can also play a role in district heating systems. Following automated load reduction or price signals, consumers reduce peak demand and thereby increase the load factor of the district heating generators. This allows a lower sizing of the network and thus potential cost savings. Calculating the costs of the various technology options requires detailed indicators. The Levelized Cost of Heating (LCOH) reflects specific costs per unit of heat supplied under different configurations, including costs for capital, fuel, operation and maintenance. To comply with the notion of the EEF principle, additional indicators should be considered that account for the multiple benefits (and costs) of demand-side measures. Deferring supply-side infrastructures is likely to lead to improved air quality and lower health risks. Moreover, local employment effects, resource savings and other indicators should be considered.

The library contains 4 articles about alternative measures.

Title	Author	Year	Description
Efficiency gains in Danish district heating. Is there anything to learn from benchmarking?	Jesper Munksgaard, Lise-Lotte Pade, Peter Fristrup	2005	The aim of this paper is twofold: (1) to investigate the potential for increasing productivity in Danish district heating production and (2) to examine whether benchmarking has a role to play.
Energy efficiency through industrial excess heat recovery—policy impacts	Sarah Broberg Viklund	2015	In this study, interviews were carried out with energy managers to study excess heat utilisation from the industry's perspective. The study seeks to present how excess heat recovery can be promoted or discouraged through policy instruments, and several factors are raised in the paper.
On the benefit of integration of a district heating system with industrial excess heat: An economic and environmental analysis	Gottfried Weinberger, Shahnaz Amiri, Bahram Moshfegh	2017	The present study aims to evaluate economic and environmental effects on the Hofors DH system with jointly operated CHP plant when the nearby steel mill extends the supply of recovered IEH.
Documentation on excess heat potentials of industrial sites including open data file with selected potentials	sEEnergies	2020	This study aims to contribute with the most detailed and the most comprehensive assessment of excess heat potentials available for Europe. More specifically, we aim to analyse the available potential for excess heat from the energy-intensive industries in Europe and assess the suitability for its use in district heating grids.

Q6: How to evaluate the costs and benefits of a district heating system and energy efficiency alternatives?

A cost-based evaluation of district heating systems and alternative demand-side resources implies a detailed comparison of costs and benefits. Here it is important to distinguish to whom these costs and benefits accrue, e.g. to the utility supplying the heat, to customers, or to society as a whole. An established approach to evaluate these different perspectives was standardized by the California Public Utilities Commission (CPUC) [50]. This approach is well suited to estimate the ex-ante value of supply- and demand-side resources in vertically-integrated district heating systems. It includes five cost-effectiveness tests that combine the various costs and benefits in different ways, depending upon which costs and which benefits pertain to different actors involved. For instance, the *Participant test* analyses the costs and benefits experiences by the customers supplied in the district heating system. Their costs include all the direct expenses to purchase, install and operate their heat supply; as well as additional energy efficiency measures. Benefits include the reduction in the customers' energy bills, any financial incentives received, and other non-monetary impacts (e.g. improved indoor air quality. The most significant test, however, should be the *Societal Cost Test* which includes the costs and benefits experiences by all members of society. Its costs include all the costs incurred by the district heating system operator as well as by the customers. Benefits include all the avoided utility costs, plus any other benefits experienced by the customers. The test thus takes explicit account of multiple impacts or externalities occurring in the system. Ideally, the range of impacts considered should be as broad as possible, covering air pollution, macro-economic effects, resource use, energy security, and more. The wider this range of indicators considered, the better a socially optimal district heating system configuration can be determined.

The library contains two articles about benefit-cost-analysis from different actor perspectives in general.

Title	Author	Year	Description
Measuring and reporting energy savings for the ESD – how it can be done.	Wuppertal Institute on behalf of the EMEEES Consortium.	2009	This report contains a chapter 2.10 explaining the basics of different relevant CBA perspectives.
Understanding Cost-Effectiveness of Energy Efficiency Programs: Best Practices, Technical Methods, and Emerging Issues for Policy-Makers.	US Environmental Protection Agency (US EPA). National Action Plan for Energy Efficiency (ed.). Energy and Environmental Economics, Inc. and Regulatory Assistance Project	2008	This guidebook presents considerable detail for CBA of energy efficiency programs, based on the several decades of experience with Integrated resource Planning and EEOS in the USA.

The library contains two articles about system integration measures:

Title	Author	Year	Description
Regional energy system optimisation – Potential for a regional heat market	Magnus Karlsson, Alemayehu Gebremedhin, Sofia Klugman, Dag Henning, Bahram Moshfegh	2009	A region characterized by a high density of energy-intensive processes is used in this study to find the economic potential of connecting three industrial plants and four energy companies, within three local district heating systems, to a regional heat market, in which different operators provide heat to a joint district heating grid. Also, different investment alternatives are studied.
Thermo-economic and environmental analysis of integrating renewable energy sources in a district heating and cooling network	Muhammad Asim, Saad Saleem, Muhammad Imran, Michael K. H. Leung, Syed Asad Hussain, Laura Sisó Miró & Ivette Rodríguez	2019	This paper presents the technical, environmental, and economic evaluation of integrating various combinations of renewable energy sources-based systems in the expansion of a district heating and cooling network of a Technology Park near Barcelona in Spain.

The library also contains four articles about the costs and benefits of different measures for the district heating market:

Title	Author	Year	Description
Renewable energy in district heating and cooling - a sector roadmap for remap	IRENA	2017	This study provides a detailed analysis of the potential of renewable DHC for a broad set of countries, applications, and technologies. It covers both the potential for renewable district heating and the potential for renewable cooling. The objective is to provide a comprehensive evaluation of the cost and benefits of renewable DHC and its potential to help achieve the targets in the Paris Agreement.

Title	Author	Year	Description
Scenario based evaluation of policies addressing the German heating and cooling sector: A bottom-up modelling approach integrating buildings, industry and district heating	Jan Steinbach, Lukas Kranzl, Andreas Muller, Marcus Hummel, Judit Kockat, Felipe Toro, Felix Reitze, Andrea Herbst, Eberhard Jochem, Max Fette, Wolfgang Schulz, Veit Burger	2013	Measures to enhance the energy efficiency of buildings and industrial processes are often considered as a cost-effective opportunity to reduce energy demand and carbon dioxide emissions. This paper presents a variety of scenarios for the German heating and cooling sector up to 2020 using an exploratory modelling approach.
Future use of heat pumps in Swedish district heating systems: Short- and long-term impact of policy instruments and planned investments	Aaron M.Hendricks, John E.Wagner, Timothy A.Volk, David H.Newman, Tristan R.Brown	2016	The economic feasibility of Biomass District Heating (BDH) networks in rural villages are largely unknown. A cost-effective evaluation tool is developed to examine the feasibility of BDH in rural communities using secondary data sources.
Cogeneration and District Heating	Energy Charter Secretariat	2006	This report is produced to assist municipalities in promoting efficient and environmentally beneficial DH and CHP.

Q7: How can automated load control and demand response be put in practice in a district heating system? How can its benefits and costs be evaluated? Are there any existing case studies or assessment studies?

The use of automated load control (demand flexibility) and reactive changes in consumer demand in response to price signals (demand response) is not limited to power systems. Recent experimental research performed on an existing district heating network in Turin (IT) highlights that these measures can achieve a peak reduction in district heating load of about 5% [20]. Demand flexibility and response are thus important demand-side resources for reducing and deferring supply-side generation, network and storage capacities. Their implementation consists in modifying the thermal demand profile of buildings, acting on the settings of the heating system through modification of scheduling or control strategy. Limitations include occupant's perceptions of comfort and indoor temperature that, however, have been observed not to deteriorate significantly in such applications [54]. The costs and benefits of demand flexibility and demand response should be evaluated on a par with supply-side resources, i.e. considering investments (e.g. ICT equipment needed for load shifting in buildings), operation and maintenance costs, as well as a detailed portfolio of non-monetary impacts (e.g. reduced material and resource need for supply-side infrastructures). If demand flexibility is more cost-effective in meeting the energy services of space and water heating, it should be prioritized against the construction or expansion of supply-side assets.

The library contains three articles about alternative demand-side measures´.

Title	Author	Year	Description
Public preferences for district heating system over individual heating system: a view from national energy efficiency	Hyo-Jin Kim, Seul-Ye Lim, Seung-Hoon Yoo	2018	This paper attempts to assess the public preferences for substituting consumption of residential heating produced from an individual heating system with that produced from a district heating system in terms of national energy efficiency. To apply the contingent valuation method, a contingent valuation survey of 1000 households was implemented.

Title	Author	Year	Description
Domestic demand-side response on district heating networks	Trevor Sweetnam, Catalina Spataru, Mark Barrett, Edwin Carter	2018	Results are presented from a field study that deployed demand-shifting technology on a sample of 28 homes connected to a district heating (DH) network in England over the winter of 2015/16. The study aimed to improve the load factor of the participating households.
Demand-side management in district heating networks: A real application	Elisa Guelpa, Ludovica Marincioni, Stefania Deputato, Martina Capone, Stefano Amelio, Enrico Pochettino, Vittorio Verda	2019	This work shows the potential of demand-side management in DH networks in terms of thermal peak shaving. This is done by optimally rescheduling building heating systems. The best rescheduling is evaluated using a simulation tool.

Q8: How can the impact of policy instruments on promoting the development and management of a district system be evaluated?

See articles under Q4.

Action 3: Define market access rules

The regulatory authority should provide the market access rules for the system operator, as well as potential heat producers from other sectors.

Q9: What are the barriers for a heat producer to access the market?

The general issue is that district heating is typically considered an integrated infrastructure, with vertically integrated suppliers constituting a natural monopoly that are responsible for generating and delivering heat to the consumers. The reasons for the monopoly structure is that district heating systems are characterised by large fixed costs and relatively low marginal costs of additional users, so the average total cost falls as the number of customers increases. Erecting a competing district heating system in parallel is thus unattractive; new system operators know that they cannot achieve the same low costs that the monopolist enjoys because; if the second network were to exist, each firm would have a smaller share of the market. As a result, district heating system operators by default have no immediate competitors. In this setting, removing entry barriers comes down to open the value chain stages of production (upstream market) and trade and distribution (downstream market) to free competition. The intermediate stage of the value chain, the network itself, would be preserved as a natural monopoly [53]. However, many EU countries do not yet have dedicated regulation for third party access (e.g. Germany, Sweden, Austria). Here, grid access is negotiated between the parties involved on a completely voluntary basis [55]. Besides these legal barriers, technical and economic barriers often hamper third-party feed-in. Network-bounded heat supply is in fierce competition with numerous other heat generation technologies, such as individual boilers. Any district heating operator thus needs economic security with regard to a consistent feed-in of third parties if they were to enter the market. Ensuring security for both sides (network operator and third-party providers) thus requires fair and reliable framework conditions [53]. In the absence of such regulation that facilitates third party access and waste heat sources remaining unused, district heating systems tend to deviate from a socially optimal system configuration that provides lowest possible costs for heat supply.

There is no literature available specifically about market access barriers.

Q10: What sectors or facilities are potential heat producers for district heating systems (e.g. industrial sectors, data center, etc)? What are the barriers for them to access the market?

Waste heat is generated in almost every industrial process and installation, for example motors, high-temperature metal processing, generation of compressed air, or cooling of warehouses. It is available in large quantities and at different temperature levels. The industrial waste heat potential in the EU is estimated at 300 Terawatt-hours (TWh) per year [53]. Formally, the RED

II defines *waste heat and cold* as "unavoidable heat or cold generated as by-product in industrial or power generation installations, or in the tertiary sector, which would be dissipated unused in air or water without access to a district heating or cooling system" (Art. 2). It is thus considered as waste heat unless it is recovered and reused – for example for the purpose of space and water heating in district heating networks. Other possible applications include cold (sorption chillers that use waste heat to evaporate a refrigerant); internal reuse (waste heat is returned to the production process in which it was generated); and electricity (waste heat converted into electricity to cover company's own electricity consumption) [53]. The exact range of possible applications depends on various factors, including the temperature level of the waste, its distance to demand centres, as well economic and legal considerations.

See references under Q2.

Q11: Are there existing market access rules design for district heating systems?

The recast Renewable Energy Directive (EU) 2018/2001) requires opening of district heating networks for third party renewable energy sources or waste heat generators. However, according to Art. 24 (5) district heating operators can refuse to buy heat from third party RES or waste heat generators if (i) it is not technically feasible; (ii) it will lead to increases heat prices; (iii) the network does not have further capacity due to existing RES and/or waste heat. In addition, according to Art. 24 (6) district heating operators may be exempted from opening-up their networks if (a) their network classifies as *efficient district heating supply* according to Art. 2 EED; (b) it is envisaged that the system will develop into efficient district heating and cooling by the end of 2025; (c) the district heating system has a total rated thermal input below 20 MW. Overall, with this recent legislation, little will change about the fact that third party RES or waste heat providers must seek the consent of the incumbent system operator in order to feed its RES or waste heat into the district heating network [53].

There is no literature available specifically about market access rules.

Action 4: Spatial planning

The regulatory authority should provide spatial planning for the system operator to systematically assess all the options on the supply-side, the network, and the demand-side.

Q12: What are the key objectives and constraints for the spatial planning of the district heating system, and what methods are used?

Strategic spatial planning is important for identifying practical constraints to the construction and expansion of district heating systems and thus their long-term technical and economic viability. Primarily, it is concerned with identifying consumers' heat demand densities as well as their proximity to generation sources – taking account of the fact that thermal energy in district heating networks cannot be distributed across large distances due to energy loss of transportation. This also includes the identification of potential third-party heat providers for waste heat recovery. Borders of land parcels, types of land use, watercourses and natural structures are additional constraints that require scrutiny. Overall, the process of spatial planning should list areas most suitable for district heating through a heat-demand map, identifying key constraints and network development opportunities. Taking into account demand-side resources as alternatives to additional district heating capacity also means engaging with local consumers to evaluate energy efficiency options (e.g. opportunities for thermal refurbishment of existing buildings within the network's service area). This requires substantial coordination between energy specialists, planners and engineers, which could be managed by the regulatory authority itself or other entities commissioned by the network operator, depending on the ownership structure of the district heating system in question.

There is no literature available specifically about spatial planning.

Action 5: Implementation plan check

The regulatory authority should check the plan proposed by the system operator. This is an iterative process and will lead to the real investment until the plan is justified. For the questions and literature relevant, please refer to the action *Define the CBA method*.

4.2. Planning for demand response in the power sector

In the power sector, the demand-side management (DSM) solutions include two parts: energy efficiency and demand response. In the liberalized EU energy markets, there are no vertically integrated utilities anymore, so it is the responsibility of the state to do the EEF principle check, which historically has been called integrated resource planning (IRP) (Wuppertal Institute, 2001). This role of the state should first be adopted in the NECPs (cf. the corresponding policy element in chapter 2.3.4). At the more concrete electricity system planning level, it is included in the Internal Electricity Market Directive, for assessing whether future generation capacities will meet demand forecasts (cf. Policy element "Power generation planning" in chapter 2.3.2), and in the grid expansion planning of the energy regulators together with TSOs (cf. Policy element "*Transmission and distribution network planning*" in chapter 2.3.1). These processes should harness both energy efficiency and demand response, to define the role and amount of both to contribute to matching supply and demand, including the necessary flexibilities. Then, the role of the "DSM service provider" for implementation of DSM is either up to the state (energy agencies, etc.) or to the energy suppliers or grid companies (i.e., inducing energy efficiency and demand response by the consumer e.g. through information and financial support), if there is an EEOS (Art. 7), and both can also involve specialized private DSM service providers.

In summary, the application of the EEF principle concerning DSM in the power sector could indicate multiple situations, with different roles for the central decision-maker, who is generally referred to as "DSM service provider" here:

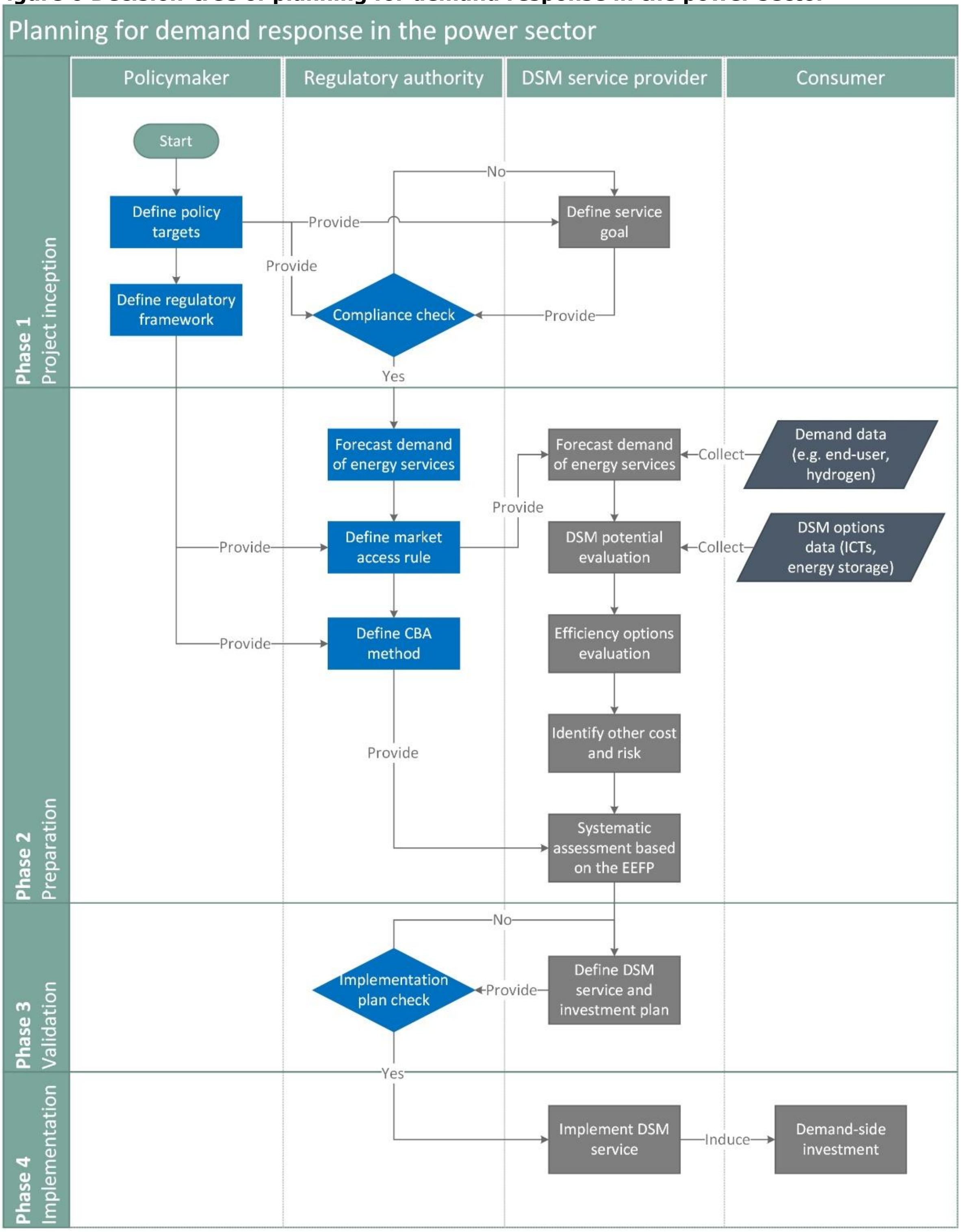
- First, concerning the energy efficiency measures, the DSM service providers refer to state energy agencies, or suppliers/DSOs under the energy efficiency obligation scheme (EEOS). They are responsible for the EEF principle check in practice, under guidance by policymakers and regulators;
- Second, concerning the demand response for the balancing power markets, the DSM service providers refer to large consumers, or aggregators (ESCOs, virtual power plants operators) who could bid in these markets;
- Policymakers and regulators should also open a new market for both demand response and energy efficiency under the upcoming capacity markets due to the revised Internal Electricity Market Directive. Again, aggregators or large consumers could bid in these markets;
- Third, the demand response can also support stabilising the grid, then the DSM service providers include two levels: (1) TSOs and DSOs under supervision of the regulator, offering incentives to the (2) providers of demand response.

The first aspect is included in the NECP area, which is a simple policy-making example, and the third aspect is illustrated in the next real-life example, "*Power transmission and distribution network planning*".

In this example, we will therefore focus on the second aspect and the bidding of demand response in the existing balancing power markets, with the DSM service provider referring to the aggregators specifically, who provide demand-response services to the end-consumers from all sectors. This example can easily be transferred to applying the EEF principle for the upcoming capacity markets, and including energy efficiency. This example, in fact, relates to two policy elements from chapter 2: at the policy and regulation level, to "Power generation planning" in chapter 2.3.2; and at the implementation level, to "Market access for demand-side resources" in chapter 2.3.1.

Based on the development of information and communication technologies (ICTs) and smart measuring and planning devices, demand response is also playing a promising role in the electricity system. Distributed energy resources (DERs) from the industrial, the commercial, and residential end-consumers, can be better controlled and participate in the electricity and ancillary service market as a whole. The DERs include demand-side resources, such as electricity, heat, or cold storage systems, electric vehicles, and interruptible loads, but also distributed generators like solar PV and wind turbines. Following the EEF principle, this improves the grid flexibility, increases the share of renewable electricity that can be integrated in the grid cost-effectively, decreases the generation cost for peak hours, and avoids the over-investment for generation capacity and grid. In this example, the central decision-maker is referred to as the "DSM service provider". The other decision-makers identified in this real-life example include policymaker, regulatory authority, and consumers. The decision-tree is shown in Figure 6.

Figure 6 Decision-tree of planning for demand response in the power sector



For the critical actions of the policymaker and regulatory authority, relevant questions and supporting literature are provided below.

4.2.1. Policymaker

Action 1: Define policy targets

The policymaker should define the targets for the implementation of the demand response planning. Then, provide the targets to the regulatory authority and the DSM service provider for further steps.

Q1: What policy targets are usually applied for demand response planning and how can they be measured?

Demand response management mainly focuses on the electricity consumption of the end-users. As defined by the Electric Power Research Institute (EPRI): DSM is the planning, implementation and monitoring of those utility activities designed to influence customer use of electricity in ways that will produce desired changes in the utility's load shape, i.e. time pattern and magnitude of a utility's load [56]. Facilitated by the energy management technologies and motivated by different kinds of demand respond (DR) programs, the targets of DSM includes (1) the reduction of peak electricity demand the investment need in generation and transmission and distribution network, but this is not directly addressed by the balancing power markets at the transmissions system level. A policy target could be defined as 'to develop x MW of demand response that are prequalified for the balancing power markets'.

Title	Author	Year	Description
Demand response and energy efficiency in the capacity resource procurement: Case studies of forward capacity markets in ISO New England, PJM and Great Britain	Yingqi Liu	2017	This paper compares energy efficiency and demand response. Examination of the process and trends of procuring DR and EE in forward capacity markets, and the design for integration mechanisms. Case studies of ISO New England, PJM, and Great Britain.
Demand-side management and European environmental and energy goals: An optimal complementary approach	Claire Bergaentzlé, Cédric Clastres, Haikel Khalfallah	2014	This paper compares different DSM tools. Demand-side management (DSM) in electricity markets could improve energy efficiency and achieve environmental targets through controlled consumption. This study aims to provide recommendations for the instruments to be used to prompt a demand response to maximise the energy and environmental efficiencies of various countries.
Demand response and energy efficiency roadmap: Maximising preferred resources	California ISO	2013	This document addresses the load reshaping path, the resource sufficiency path, the operations path, and the monitoring path of demand-side resources.

Action 2: Define regulatory framework

Based on the targets defined in the first step, the policymaker should define the regulatory framework for planning the DSM implementation, in which multiple policy instruments can be integrated.

Q2: What policy instruments can be applied for implementing demand-response?

Policy instruments for demand response in general may include two categories: increasing storage options and reducing peak loads. The first one can be accomplished by providing grants for battery adoption, e.g. for battery electric vehicles that can be used as energy storage and which can feed energy back into the grid. The second one can be accomplished by incentivising investments which make loads interruptible or through time-dependent power price programs, or network tariffs, to induce demand-response behaviours. Relevant programs are summarized in Table 5. The very last one, demand-side bidding, is the one enabling direct participation of demand response in balancing markets; the Capacity market program would relate to the upcoming capacity markets. All others may be useful or even needed to create assets and capacities that would participate in the balancing power or capacity markets.

Table 5 Summary of demand-response programs

Price-based programs	Time-of-use tariffs (TOU)	End-users that are charged with a stepped rate structure which intends to reflect the variations of generation cost for different time periods.
	Critical peak pricing (CPP)	Critical peak pricing (CPP) is designed to capture the short-term costs of periods which are critical for the power system. It is triggered by system criteria (e.g. unavailability of reserves, extreme weather conditions that cause unexpected variations in demand, etc.).
	Real-time pricing (RTP)	Real-time pricing (RTP) is a pricing scheme in which the energy price is updated at a very short notice, typically hourly.
Incentive-based programs	Direct load control (DLC)	Direct load control programs engage a large number of small consumers by directly controlling a specific type of their appliances, such as air conditioners (ACs), lighting, water heating, pool pumps, etc.
	Curtailable load (CL)	Curtailable load programs engage medium and large consumers who receive incentives to turn off specific loads. These programs are mandatory, i.e. customers may face penalties in case they fail to respond to a DR event.
	Capacity market program (CAP)	In capacity market programs, customers commit to providing pre-specified load reductions and receive guaranteed payments. When system contingencies arise, they are subject to penalties if they do not curtail when directed.
	Demand-side bidding (DSB)	Demand-side bidding programs provide consumers the opportunity to participate the electricity market by submitting load reduction offers. Large customers may participate in the market directly, while small consumers can participate indirectly through third-party aggregators or load serving entities (LSEs).

The library contains six articles concerning this question.

Title	Author	Year	Description
Demand Side Management in a competitive European market: Who should be responsible for its implementation?	Marcel H Didden, William D D'haeseleer	2003	This paper reviews the current DSM activities and ongoing research from the starting point 'who should be responsible for implementing DSM'.
Incorporating demand-side flexibility, in particular demand response, in electricity markets	European Commission	2013	This working document further explains the importance of demand-side participation, and in particular demand response, and sets out the key elements enabling to make it work more widely in Europe. It outlines what is already being done to put those elements in place and what needs to be done next
Effective Mechanisms to Increase the Use of Demand-Side Resources	RAP	2013	This paper describes a relatively small number (14) of the most effective mechanisms for increasing the use of demand-side resources in the electricity sector. Some of these mechanisms aim at integrating demand-side resources into electricity markets.
Why is demand response not implemented in the EU? Status of demand response and recommendations to allow demand response	Paolo Zancanella, Paolo Bertoldi, Benigna Boza-Kiss	2017	The paper summarizes the status of Member States legislation, market rules, and technical regulations to enable Demand Response. Finally, the paper identifies and proposes regulatory initiatives that would significantly further facilitate DR.

Title	Author	Year	Description
to be fully integrated into energy markets			
Status report on regulatory aspects of demand-side flexibility	Nordic Energy Regulators	2017	The report aims to give a brief overview of some of the potential regulatory changes both in the EU legislation and at the national level, accompanied by an overview of some relevant pilot project and research development which may affect the potential development of demand response in the Nordics.
Time-of-Use Tariffs - Innovation Landscape Brief	IRENA	2019	This brief provides an overview of a key innovation in market design: time-of-use (ToU) tariffs.

Q3: What are the lessons-learned from these policy instrument being implemented?

Currently, the USA takes a leading role in the introduction of DSM. Service providers, and active major companies in the USA include: EnerNOC, Comverge, CPower, and the Enbala Power Networks Company in Canada. Besides, numerous experiments of demand-response programs have also been conducted in different regions in the world, focusing on end-users' behaviour under different DR programs. According to the features of study coverage, DR program and region, a series of studies are listed in Table 6, with main findings provided. In addition, demand response assets are already participating in EU balancing power markets, although the level seems to be small. For example, in Germany in 2018, between 0.5 and 1.0 GW of demand response assets were prequalified for participation in the aFRR and mFRR markets.

Table 6 Existing experiences of DSM programs

Region	Coverage	DR program	Main findings
British Columbia [57]	residential	TOU	The peak of residential energy demand is reduced by 2.6% with a 2:1 peak-to-off-peak price ratio, and by 9.2% with a 12:1 peak-to-off-peak price ratio.
Washington D.C. [58]	residential	RTP CPP	Being different from what is usually expected, there is no "cost of taking action" preventing consumers' response behavior, maybe because the wholesale electricity price is very positively correlated, and the consumers will adjust their behavior for this.
Michigan [59]	residential	CPP	The customers, including low-income participants, do respond to dynamic pricing, and the response to critical peak pricing and peak time rebates are similar.
Houston [60]	industry	TOU	Constrained in ability, the demand response behavior of 20 largest industrial energy consumers in the Houston area are limited.
Mid-Atlantic [61]	residential	CPP	A constant elasticity of substitution model on the SEP pilot hourly consumption, pricing and weather was estimated, indicating that the consumers are incentivized to reduce 33% of their peak demand by the price signal in two consecutive summers.
Chicago [62]	residential	RTP	The consumers significantly respond to the peak electricity price and reduce their demand, but it is not shifted to off-peak periods, which indicates that the real-time pricing program serves as an energy conservation rather than load shifting mechanism.

Region	Coverage	DR program	Main findings
North Carolina [63]	industry	RTP	There is significant response from consumers who can self-generate or with discrete production processes, and it increases with experience.
North Carolina [64]	industry	RTP	The authors showed larger own elasticities than previous studies, complementarity within the potential peak hours and substitution in the late evening. The net benefits are significant and much higher than metering cost.

Apart from the literature listed above, the library also contains two articles concerning this question.

Title	Author	Year	Description
Transferability of demand-side policies between countries	Peter Warren	2017	This paper provides a practical framework for analysing the transferability of demand-side management (DSM) policies. It identifies where policies are transferable at different levels of policy transfer. Tests the framework to determine the transferability of different types of DSM policy across 30 countries and 36 sub-national states. Three levels of policy transfer: direct copying, adaptation and inspiration.
Measures to increase demand side flexibility in the Swedish electricity system	Swedish Energy Markets Inspectorate	2017	This paper proposes a package of measures to increase demand side flexibility in the Swedish electricity system. A large number of possible measures to increase demand side flexibility are identified, and costs/benefits are calculated in packages.

4.2.2. Regulatory authority

Action 1: Compliance check

Based on the policy targets provided by the policymaker, the regulatory authority should check the planning goal proposed by the DSM service provider. This is an iterative process and will lead to further processes until the plan complies with the targets.

Q4: How to evaluate the contribution of the DSM service to the policy targets?

Practically, the contribution of DSM to the policy targets can be evaluated by looking at several indicators. First, we could look at how much peak load is cut or shifted, according to the change of the load curve after the introduction of DSM service. This is the most direct indicator. Second, we can also look at the change of the consumption rate of renewable power, keeping in mind that this rate is influenced by multiple factors. Third, we may also look at some operational indicators, including the diffusion and increase of battery or interruptible loads. The library contains seven articles concerning this question.

Title	Author	Year	Description
Demand side resource operation on the Irish power system with high wind power penetration	A. Keane, A. Tuohy, P. Meibom, E. Denny, D. Flynn, A. Mullane, M. O'Malley	2011	This paper assesses how DSR can aid power system operation. A model for demand side resources is proposed here that captures its key characteristics for commitment and dispatch calculations. The results illustrate that demand side resources can contribute to the efficient, flexible operation of systems with high penetrations of wind by replacing some of the functions of conventional peaking plant.
DSM interactions: What is the impact of appliance energy efficiency measures on the demand response (peak load management)?	S. Yilmaz, A. Rinaldi, M.K. Patel	2020	This paper estimates the impact of energy efficiency measures and policies such as minimum energy performance standards on the peak load by developing a bottom-up model that generates Swiss household hourly electricity demand profiles per appliance based on time use data
Demand-Side Energy Efficiency Technical Support Document	EPA	2015	This report gives a step-by-step explanation of the calculation of the magnitude/timing of savings and assessment of costs for demand-side energy efficiency resources.
Smart choices? An experimental study of smart meters and time-of-use tariffs in Ireland	Cameron A. Belton, Peter D. Lunn	2020	This paper presents an exploratory study that used experimental behavioural science to investigate consumer choice in electricity markets with time-of-use tariffs. A representative sample of consumers (n = 145) were given information about smart meters and time-of-use tariffs. Policy implications include the importance of pre-testing interventions designed to improve consumer decisions.
Explicit and Implicit Demand-Side Flexibility - Complementary Approaches for an Efficient Energy System	SEDC	2016	This paper summarizes various complementary approaches for explicit and implicit demand-side flexibility.
Tools and methods for integrated resource planning. Improving energy efficiency and protecting the environment	Swisher, J.N.; Martino Jannuzzi, G. de; Redlinger, R.Y.	1997	This book provides a systematic introduction for energy efficiency, end-use analysis, demand-side management (DSM), and integrated resource planning (IRP), and also addresses energy efficiency programs and IRP, exploring their application in the electricity sector.
National Action Plan for Energy Efficiency. Understanding Cost-Effectiveness of Energy Efficiency Programs: Best Practices, Technical Methods, and Emerging Issues for Policy-Makers	EPA	2008	This paper reviews the issues and approaches involved in considering and adopting cost-effectiveness tests for energy efficiency, including discussing each perspective represented by the five standard cost-effectiveness tests and clarifying key terms.

Action 2: Forecast demand of energy service

The regulatory authority should forecast the consumers' demand of electricity, as well as the load profile, for further planning the DSM implementation.

Q5: How to forecast the consumers' demand of electricity, as well as the load profile?

Forecasting the electricity demand and load curve based on historical data is an important task for the regulatory authority to plan the implementation of DSM service. There are mainly three types of forecasts, from the perspective of forecasting horizon: (1) short-term forecast, which is a one-day ahead hourly forecast; (2) mid-term forecast, which is several days ahead for daily data; (3) long-term forecast, which is a one or more years ahead forecast. Several methods can be used for the forecast, including statistical models (e.g. regression, times series), artificial intelligence techniques (e.g. neuro networks, support vector machines), and others.

For the implementation of DSM service, the hourly short-term forecast is most crucial, with a particular importance of the peak demand. Then based on the adoption of information and communication technologies (ICTs), design and application of demand-response programs, and introduction of DSM service providers (e.g. aggregators), the peak demand will be cut or shifted. There is one article in the library concerning this question.

Title	Author	Year	Description
Short-term forecast of daily curves of electricity demand and price	Germán Aneiros, Juan Vilar, Paula Raña	2016	This paper provides two methods to predict next-day electricity demand and price daily curves given information from past curves.

Action 3: Define market access rules

The regulatory authority should provide the market access rules for the DSM service provider.

Q6: What are the barriers for DSM service providers to access the market*?*

Apart from the theoretical potential for the flexibility of electricity consumers, there exist barriers for the introduction of DSM service in practice, mainly categorized into three aspects. First are the technical difficulties, related to the ramping times and security aspects of technologies. Second are the economic barriers, the financial viability of the DR measures. Third are the practical barriers, referring to the willingness of the consumers. Besides, no standard processes and contracts for the settlements is also an important barrier. There is no literature available in the library concerning this question.

Q7: Are there existing market access rules design for DSM service providers?

The design of the market access rules for the DSM service providers should at least contain two aspects. First, it should contain the standard processes and contracts regulating their interaction with the electricity consumers, i.e. the companies or households who sell their flexibility of demand-response to them. The second aspect is about how the DSM service providers are allowed to participate in the electricity market and the ancillary services market. There is no literature available in our database concerning the design of market access rules. For the balancing markets in the EU, the information can be found in the online marketplaces, such as regelleistung.net.

Action 4: Define the CBA method

Based on the regulatory framework provided by the policymaker, the regulatory authority should define the CBA method for the DSM provider to systematically assess their investment options.

Q8: What are the investment options for a DSM service provider? How can the benefits and costs of these investments or the business model of DSM service providers be evaluated?

A DSM service provider acts as an intermediator between electricity end-users, distributed energy resource providers, and power system participants that wish to exploit these services [65]. The provider invests in the information and communication technologies, as well as necessary energy storage systems, to manage three kinds of resources. First are the demand-side resources, i.e. loads that are aggregated and remotely controlled to provide ancillary services. Second are the generation resources, i.e. generator units within a specific capacity range, including wind and PV units, as well as small hydro and CHP. Third are bi-directional resources, i.e. static or movable energy storage devices, e.g. sodium-sulphur batteries installed in substations and electric vehicles with vehicle-to-grid function. Based on these resources, the DSM service provider can sell in the electricity market, or participate in the balanced markets and sell ancillary services.

The business model of a DSM service provider includes four parts: enrolment and qualification, information prediction, trading, and the settlement process [66]. Enrolment and qualification refer to the stage where the DSM service providers design multiple reasonable techno-economic contracts for diversified customers and qualify them to be eligible for the involvement in DR programs and market trading. Information prediction is the prerequisite and foundation for all business of the DSM service providers, including predicting loads, electricity price, and flexibility. Trading includes two layers: (1) providing attractive financial rewards to the customers who provide the three resources introduced above; and (2) trading in the electricity and ancillary service market. At last, the settlement process refers to obtaining corresponding remuneration or punishment and then compensating customers correspondingly.

The library contains two articles concerning this question.

Title	Author	Year	Description
Measuring and reporting energy savings for the ESD – how it can be done.	Wuppertal Institute on behalf of the EMEEES Consortium.	2009	This report contains a chapter 2.10 explaining the basics of different relevant CBA perspectives.
Understanding Cost-Effectiveness of Energy Efficiency Programs: Best Practices, Technical Methods, and Emerging Issues for Policy-Makers.	US Environmental Protection Agency (US EPA). National Action Plan for Energy Efficiency (ed.). Energy and Environmental Economics, Inc. and Regulatory Assistance Project	2008	This guidebook presents considerable detail for CBA of energy efficiency programs, based on the several decades of experience with Integrated resource Planning and EEOS in the USA.

Action 5: Implementation plan check

The regulatory authority should check the plan proposed by the DSM service provider. This is an iterative process and should lead to real implementation only when the plan is fully justified. For the questions and literature relevant, please refer to the action *Define the CBA method*.

4.3. Power transmission and distribution network planning

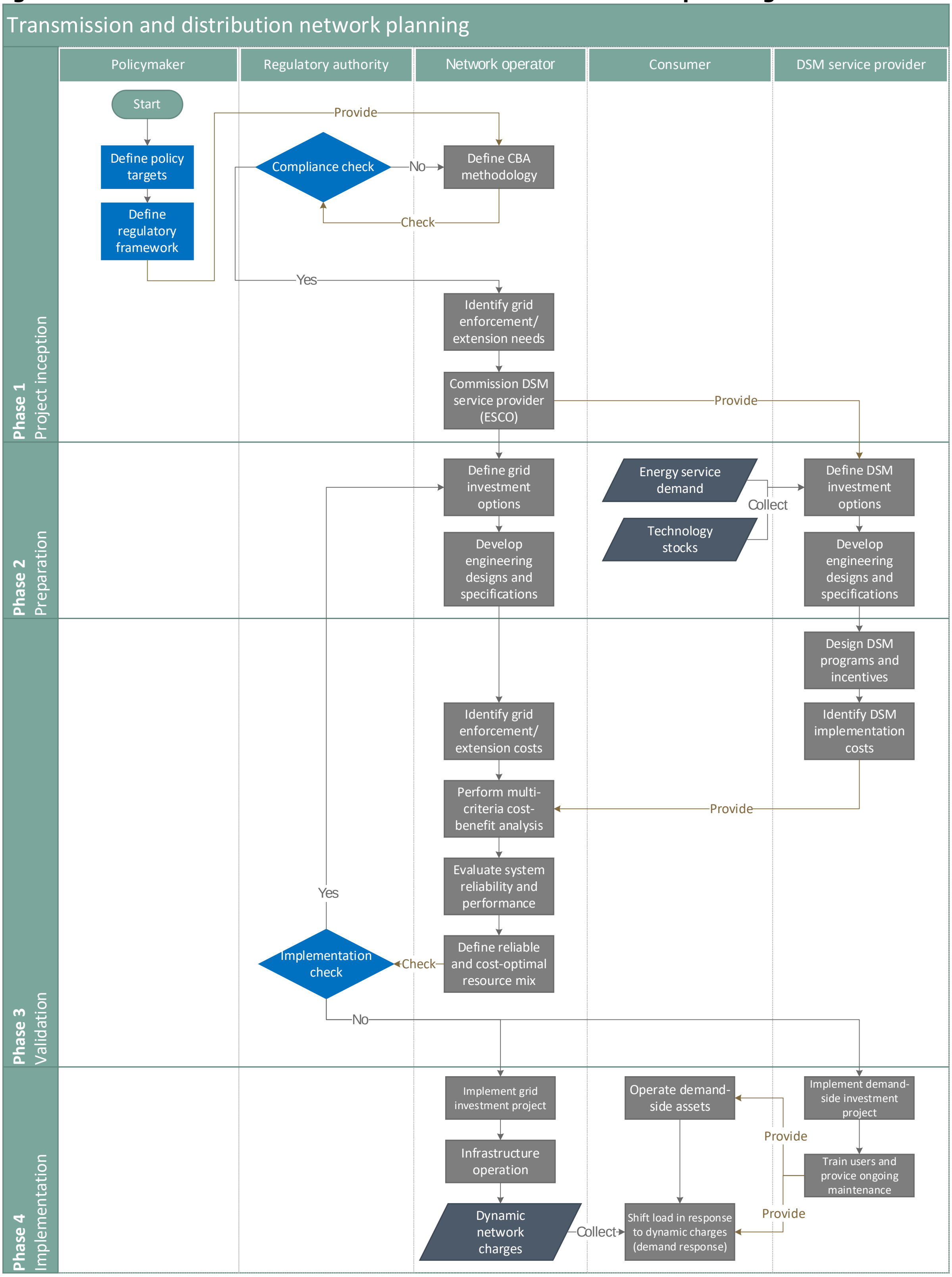
Transmission and distribution (T&D) networks are the backbone of the power system, connecting large and geographically scattered production centres to demand hubs and providing branches in multiple directions to carry electric power to its end-users. Consisting of steel-cored aluminium conductors, towers, substations, up to underground distribution lines, T&D infrastructures generally are a capital-intensive business. According to the IEA, total investment in such electricity networks in Europe sum up to $243 billion between 2015 and 2020 [67]. As the installed capacity of renewable power generators (wind, PV) continues to increase, along with the electrification of formerly fuel-based end-uses (e.g. space heating through heat pumps), these investments are likely to rise in future years. This raises the question, whether in line with the EEF principle the construction of a part of these infrastructures can be substituted, or at least delayed, by more cost-effective energy efficiency measures and demand response programs that reduce peak loads and overall electricity use and thus provide network services in the most cost-effective way.

The following application of the decision-making tool explores the actors and decision steps involved in the regulation-driven integrated planning of T&D networks. It is inspired by practical international experiences, particularly from the U.S. context [15,68], which illustrate how geographically targeted demand-side resources (energy efficiency, demand response) are used to successfully defer T&D investments. The application is based on the following assumptions: First, international experiences highlight that operators of T&D networks (hereinafter 'network operators') must have some sort of regulatory incentive – beyond traditional cost-of-service regulation – to procure these resources. Based on this premise, the following application assumes that network operators are subject to a form of incentive-based regulation (e.g.

Performance-Based Regulation, PBR) that encourages them to deliver on energy efficiency.[4] While the exact design of these incentives is beyond the scope of this application, more information is available in the policy element *'Transmission and distribution network planning'* as well as in [16,69,70]. Second, in line with the practical experiences from the U.S., the actual implementation of demand-side measures is assumed to be performed by DSM service providers (or Energy Service Companies, ESCOs) that are commissioned by the network operators. Third, in line with the policy element *'Network tariff design'*, consumers are assumed to be offered incentives to shift loads in response to dynamic network tariffs.

[4] Note that, as of 2018, indeed only a few Member States (e.g. Estonia) still have traditional cost-of-service regulation in place for DSOs and TSOs [69].

Figure 7 Decision-tree of transmission and distribution network planning



For the critical actions of the policymaker and regulatory authority, relevant questions and supporting literature are provided below.

4.3.1. Policymaker

Action 1: Define policy targets

The policymaker should define the targets for the planning of the transmission and distribution networks. Then, provide the targets to regulatory authority for further steps.

Q1: What policy targets are usually applied to transmission and distribution networks, and how to measure them?

T&D network planning is nested in the overall objectives of European energy policy. As reaffirmed in the Clean Energy for All Europeans package, these include the construction of appropriate cross-border interconnections, diversification of supply sources and routes, promotion of energy efficiency, and the acceleration of the transformation to low-carbon energy. In this context, the planning and operation of T&D networks is subject to a continuous trade-off between economic efficiency on the one hand, and system reliability on the other.

Economic efficiency means the effort of TSOs and DSOs to minimise the entire chain of costs incurred in providing the service of transmitting and distributing power to its final consumers. In traditional T&D power network planning, these costs essentially include investment costs for network assets as well as operating costs. Under consideration of the EEF principle, this cost perspective ideally expands to the incremental costs incurred for the procurement of demand-side resources as well as to the (monetized) environmental and socio-economic impacts of different network investment and operation plans – summing up to the notion of maximising social welfare instead of economic efficiency in a narrower sense. Note that maximised social welfare presupposes that the TSO and DSO businesses remain financially viable in a sense that revenues are sufficient to enable these utilities to cover their operating costs and make necessary investments while earning adequate return on the capital invested [71].

System reliability in T&D network planning and operation can be considered just as important as economic efficiency. Social welfare would be low for both industrial and residential consumers if service were cheap but impaired by power outages. Outage-free network service cannot be guaranteed because of a number of uncertainties, including rainfall, real demand growth, generating, transmission and distribution equipment failures or lack of wind or solar input. It is clear, however, that such likelihood of failure can be reduced by investing in more facilities and operating more conservatively in a way of sufficiently sizing T&D systems to meet peak loads in each local area [72]. In more technical terms, system reliability is related to (1) reliability of supply, i.e., the number and severity of power supply outages; (2) voltage quality, defined as the existence or otherwise of disturbances that may affect the proper operation of apparatus and equipment connected to the mains and (3) consumer satisfaction with the service standards, for instance time for providing new connections, maintained by the network company [71].

Overall, the first criterion, cost minimisation, must be qualified to accommodate the second criterion, which reflects system reliability [72]. An explicit consideration of demand-side resources in T&D network planning in accordance with the EEF principle affects both of these trade-off dimensions. International experiences suggest that energy efficiency and demand response as the prime demand-side resources can successfully defer or substitute capital-intensive network assets, thus enhancing economic efficiency. Yet, implementing these demand-side resources in the daily operations of T&D systems require particular scrutiny of the extent to which they can safeguard system reliability.

The library contains two articles:

Title	Author	Year	Description
Efficiency first in Europe's new electricity market design – how are we doing?	Pato Zsuzsanna, Richard Cowart, Jan Rosenow	2019	This paper addresses (inter alia) the following question: Are transmission and distribution investment plans open to alternative (and more cost-effective) "non-wires" solutions?

Michigan Distribution Planning Network	MPSC	2018	The purpose of this report is to outline the Michigan Public Service Commission Staff's recommended path forward to achieving an open, transparent, and integrated electric distribution system planning process in Michigan.

Action 2: Define regulatory framework

Based on the targets defined in the first step, the policymaker should define the regulatory framework in which the planning process is performed.

Q2: To achieve the targets listed in the first step, what policy and regulatory approaches can be applied?

Power transmission and distribution companies in the unbundled EU power market structure are regulated monopoly businesses[5], implying that investments in network upgrades, as well as daily network operations, are subject to the guidelines and authorisation of the regulatory authorities. Applying the EEF principle to T&D network planning would mean to have rules in place requiring DSOs and TSOs to plan for and invest in the most cost-effective portfolio of demand- and supply-side resources, and providing national regulators with an active role for monitoring and enforcement. There are different approaches and instruments that regulatory authorities can use for this purpose.

The central instrument of regulatory authorities is the type of remuneration for the T&D network companies which eventually determines their business models and, with regard to the EEF principle, the extent to which they consider demand-side resources in their investment considerations. Depending on the Member State and the individual TSO or DSO at hand, regulatory entities use a wide range of instruments [72]. The oldest approach is for the regulator to remunerate T&D companies based on the incurred cost of service, which includes a reasonably attractive rate of return on the invested capital, referred to as cost-of-service regulation. However, since this remuneration scheme strongly incentivises network companies to overinvest in capital expenditures and disincentivises activities that reduce throughput and thus revenues (in particular, energy efficiency measures) [71], its use has been ceased in most Member States. Alternative utility remuneration schemes include price or revenue caps, which set a ceiling on the price that the network company is allowed to pass on to consumers or on the revenue that a company is allowed to earn. In essence, the effect of these remuneration schemes is that network companies are not penalized by reduced revenues when energy efficiency decreases network throughput [16]. Performance-based regulation (PBR) is yet another form of utility remuneration. Its objective is to shift the utility's focus from inputs, such as capital expenditures for network upgrades and maintenance, to outputs, such as improved reliability, deployment of distributed energy resources (DERs), increased energy efficiency, and environmental protection. By rewarding network companies with increased revenues for specified performance or, conversely, by punishing them with reduced revenues for failure to perform, PBR aims to encourage utilities to deliver on important goals of public policy in order to maximise their profits [70].

Another important regulatory instrument is to steer the behaviour of network users towards demand response and energy efficiency via tariff design (see also policy element *Network tariff design* in Chapter 2.3). The tariffs paid by consumers for a kWh of electricity purchased are, in essence, price signals that either incentivise or disincentivise consumers to invest in electricity-saving energy efficiency measures and to shift loads under demand response schemes. Network charges, which typically make up about a quarter of the electricity price paid per kWh by consumers [73], are collected by the network companies to cover the costs for power lines and other network assets. Gradually replacing the established fixed or flat rate network charges with

[5] T&D networks are characterized as natural monopolies because they are bound to the physical space where they are located. Introducing competition in this type of activities is inefficient as it would duplicate expense involved in two competing electricity network companies building the same type of infrastructure in the same area to provide the same service. These duplicate networks would be redundant and users would end up paying roughly double the price for the same service [71].

dynamic charges would provide effective incentives to consumers to shift use to less congested periods, thereby avoiding or reducing network expansion needs and lowering system costs [3].

Another key regulatory instrument for implementing the EEF principle in T&D network planning are mandatory cost-benefit tests considering energy efficiency and other alternatives to traditional network expansion. Network companies can be required to explicitly consider demand-side resources (end-use efficiency, demand response) alongside supply-side options (e.g., substation upgrades) in a cost-benefit analysis (CBA) [70]. To some extent, this idea is applied to pan-European transmission networks as part of the ten-year network development plans (TYNDP) (see also policy element *Security of supply strategic planning* in Chapter 2.3). For inclusion in the TYNDP, each transmission project has to go through a CBA. The CBA methodology [38] is developed by ENTSO-E in consultation with stakeholders and adopted by the European Commission. Note, however, that so far this methodology does not explicitly require the consideration of end-use efficiency and demand response as explicit alternatives to supply-side network expansion.

To conclude, regulatory authorities have different instruments at hand to incentivise T&D network companies to procure and invest in demand-side resources. The case example presented here presumes that regulators can obligate T&D companies to carry out an integrated CBA with explicit consideration of demand-side resources, providing the most straightforward EEF application of the instruments presented. However, given the vast regulatory capacity and cost required for controlling such integrated CBA and its implementation, European legislation as well as its implementation through Member State regulatory authorities relies on a mix of regulatory instruments to enable cost minimisation and reliability in T&D network planning and operation.

The library contains three articles.

Title	Author	Year	Description
The Non-Wires Solutions Implementation Playbook - A Practical Guide for Regulators, Utilities, and Developers	RMI	2018	Using the Playbook, grid planners can improve on this approach to infrastructure investment by more systematically evaluating opportunities to deploy modular—and often lower-cost—NWS portfolios.
Modelling an aggressive energy-efficiency scenario in long-range load forecasting for electric power transmission planning	Alan H. Sanstad, Stuart McMenamin, Andrew Sukenik, Galen L. Barbose, Charles A. Goldman	2014	This paper describes a "hybrid" load forecasting approach combining econometric and technological elements that are designed to improve the representation of end-use energy efficiency, and of the effects of policies and programs to promote it.
Levelling the playing field through least-cost energy planning: in limbo, too late or, just right?	Pedro Guertler	2011	This paper concludes the appropriateness and implications of an LCEP revival for the EU's energy markets and policy agenda.

Q3: What are the existing experiences of these policy instruments?

There are various examples for the successful use of performance-based regulation as a utility remuneration scheme to incentivise investments in demand-side resources. For example, at least 26 U.S. states have used PBR incentives to encourage energy efficiency deployments. These incentives range from allowing a utility to earn (a) a percentage of program costs for achieving a savings target (eight states), (b) a share of achieved savings (13 states), (c) a share of the net-present-value (NPV) of avoided costs (four states), and (d) an altered rate of return for achieving savings targets (one state). Over time, energy efficiency program performance improved significantly in states offering these incentives [74]. While there is evidence for successful performance-based regulation (PBR), there have also been notable international programs with early forms of PBR that featured ill-conceived incentives which were different from what was intended. One such example is an energy efficiency PBR mechanism in the State of Washington in the U.S. In 1980, state regulatory authorities directed a 2% increased return on equity to utilities for energy efficiency investments. Utilities quickly figured out that the incentive structure encouraged them to spend as much as possible on energy efficiency measures that save as little as necessary – maximizing the incentive while minimizing the lost revenue. The state of Nevada learned the same lesson 25 years later [74]. Such negative examples illustrate the practical challenges associated with using PBR for incentivising the use of demand-side resources in European T&D network planning.

There also exists abundant international experience with designing consumer tariffs to incentivise the deployment of demand-side resources – most notably demand response. With regard to consumer responsiveness to dynamic time-of-use tariffs, a pilot programme was conducted in Gotland, Sweden. During its initial stage, 23% of total electricity use occurred during the five most expensive hours of the day. In response to the newly integrated price signals, this dropped to 19% and 20% in the first and second year of the programme [75]. Another example is French Tempo tariff – a critical peak pricing tariff launched in the 1990s – which has reduced national peak load by about 4%, with households shifting about 6 GW of load daily [76].

Finally, regulatory authorities can consult international applications of prescribing mandatory cost-benefit analyses (CBA) to network utilities. For example, the New York Public Service Commission prepared a CBA framework that the utilities have to consider when preparing their own CBA methodology. The framework developed is considered to be a complex but robust CBA methodology encompassing most of the best practices in integrated assessment of supply- and demand-side resources [77].

The library contains one article.

Title	Author	Year	Description
Incorporating energy efficiency into electric power transmission planning: A western United States case study	Galen L. Barbose, Alan H. Sanstad, Charles A. Goldman	2014	This paper describes an innovative project to explicitly incorporate end-use efficiency into transmission planning and transmission planning studies. It illustrates the kinds of technical and institutional issues that must be addressed to incorporate energy efficiency into regional transmission planning activities.

4.3.2. Regulatory authority

Action 1: Compliance check

The regulatory authority should check whether the cost-benefit analysis methodology proposed by the network operator complies with the policy and regulatory framework.

Q4: What are the technology alternatives for grid reinforcement and expansion?

There is a diverse set of demand-side resources with the potential to substitute for conventional network infrastructure solutions. Taking the residential sector as an example, substantial energy efficiency potentials lie in the thermal refurbishment of existing buildings. With the increasing deployment of electric heat pumps, more electricity needs to be transported to households to provide heating – particularly at the distribution network level. Improving the thermal performance of buildings reduces useful energy demand and thus the amount of final energy in the form of electricity needed to heat the building. Other significant electricity-related energy efficiency potentials in buildings are the end-uses of electrical appliances and lighting. Replacing such equipment with more efficient units again reduces final energy demand and thus affects the dimensioning of supply-side investments in power lines, substations, and other capital-intensive assets. Potentials for saving electricity through energy-efficient systems and equipment are even larger and more cost-effective in industry and non-residential buildings. Another important technology alternative for grid reinforcement and expansion is demand response, which can enable T&D network operators to save on investments in network capacities by shifting demand to off-peak or lower-price time intervals.

An important consideration in this technology trade-off is the suitability of demand-side resources for deferring network infrastructure assets. These need to be established by leading jurisdictions. For example Rhode Island's System Reliability Procurement (SRP) criteria [78] define type, size, and minimum cost of projects that qualify for consideration. EU regulatory authorities could follow this approach by defining the criteria for types of projects that qualify for demand-side alternatives – requiring T&D network utilities to identify candidate projects that meet defined criteria, and conducting pilots in each service territory to validate effectiveness of the demand-side solutions. The result would ideally establish a workable process for substituting demand-side resources for more expensive network investments, saving customers money and expanding the market for demand-side alternatives [78]. No literature available for this question in the library.

Q5: How to evaluate the costs of network reinforcement/expansion and alternative demand-side measures (DSM)?

The following steps are relevant for T&D network companies that attempt to take explicit account of demand-side resources (DSR) to minimize system costs, while maintaining system reliability [78].

1. Forecasting of loads and demand-side resource deployment: Future circuit and substation loads and peak demands are forecasted over a 5-20 year time horizon. Forecasts should be adjusted for weather impacts, expected growth rates, and known changes in load such as addition or loss of major consumers. More importantly, probabilistic network modelling approaches should be used to consider varying levels of DSR (energy efficiency, demand response) deployment. This implies modelling the economics of DSR adoption for each customer site to determine the amount of DSR capacity that is cost-effective according to specified financial metric. The end result of this DSR adoption forecasting process is the adoption probability for each DSR technology at each individual customer site, based on achievable potential calculated [78,79].

2. System assessment: This step involves quantitative power flow modelling to determine if the existing network can accommodate the forecasted demand, maintain adequate voltage, and safely operate during normal and abnormal system conditions.

3. Identification of network needs: Networks investment needs and solutions to address the needs are identified. This typically includes multiple alternatives to address these needs – ranging from low cost (e.g. reconfiguring a circuit) to high-cost (e.g. adding new circuit or substation). Overall financial metrics may include levelized cost of energy; payback period; net present value, etc.

4. Solution identification (including demand-side resources): This step involves the development of capital and operations and maintenance plans and associated budgets as well as the identification of the locational value for system nodes where DSR deployment could induce peak load reduction or other capacity relief [78]. In sensitivity analyses, these results should be tested for changes in the following variables (where relevant for the project): regulatory (e.g. changes in utility remuneration); demand (e.g. inadequate analysis of climatic conditions affecting the energy demand for heating and/or cooling); design (e.g. inadequate design cost estimates); operation (e.g. accumulation of technical breakdowns); procurement (e.g. procedural delays) [79].

5. Project design and implementation: Once T&D network utilities have identified grid needs and opportunities for DSR, they must acquire or source the alternative solutions. The process starts with clearly defined and transparent disclosure of network needs and performance requirements. Utilities define a set of discrete services and performance levels to meet operational requirements that (if provided by DSR) could effectively substitute for conventional infrastructure projects. These services are typically defined in neutral manner rather than specifying a pre-determined DSR technology. DSR providers (e.g. ESCOs) then have opportunity to propose solutions to utilities that meet the requirements. As party responsible for the planning process, the utility may assess the alternatives gathered, determine the preferred solution for each need and then report and explain its recommendations for regulatory approval. What follows then is the acquisition of the DSR resources.

The library contains three articles.

Title	Author	Year	Description
The Cost of Saving Electricity: A Multi-Program Cost Curve for Programs Funded by U.S. Utility Customers	Charles A Goldman, Ian Hofffman, Sean Murphy, Natalie Mims Frick, Greg Leventis, Lisa Schwartz	2020	This study analysed the cost performance of electricity efficiency programs implemented by 116 investor-owned utilities between 2009 and 2015 in 41 states. We applied our typology to characterize efficiency programs along several dimensions (market sector, technology, delivery approach, and intervention strategy) and report the costs incurred by utilities and other program administrators to achieve electricity savings as a result of the programs. Such cost performance data can be used to compare the relative costs of different types of efficiency programs.
Transmission System Integrated Resource Planning: Leveling the Playing Field	Philip H Mosenthal, Stuart A Slote	2004	VELCO's analysis raises substantial issues regarding electric system policy, especially related to cost-effectiveness, funding, and equity. This paper will describe the IDUP process, analysis, and results. It will address policy considerations currently under discussion in regulatory hearings. The pending resolution and issues surrounding the use and usefulness of the planning study will also be addressed.
A welfare analysis of electricity transmission planning in Germany	Claudia Kemfert, Friedrich Kunz, Juan Rosellón	2016	This paper employs an economic modelling approach to analyse two different network planning settings: both with and without a trade-off between transmission network development and generation dispatch.

The library also contains two articles about benefit-cost-analysis from different actor perspectives in general.

Title	Author	Year	Description
Measuring and reporting energy savings for the ESD – how it can be done.	Wuppertal Institute on behalf of the EMEEES Consortium.	2009	This report contains a chapter 2.10 explaining the basics of different relevant CBA perspectives.
Understanding Cost-Effectiveness of Energy Efficiency Programs: Best Practices, Technical Methods, and Emerging Issues for Policy-Makers.	US Environmental Protection Agency (US EPA). National Action Plan for Energy Efficiency (ed.). Energy and Environmental Economics, Inc. and Regulatory Assistance Project	2008	This guidebook presents considerable detail for CBA of energy efficiency programs, based on the several decades of experience with Integrated resource Planning and EEOS in the USA.

Q6: How can demand-side measures be applied as alternatives to grid expansion and reinforcement? Are there any existing case studies or assessment studies?

The T&D utilities' acquisition of demand-side resource (DSR) from customers and third parties is typically based on the mechanisms of pricing, programs, or procurement [78].

- *Pricing* refers to DSR provided in response to time-varying rates, tariffs and market-based prices. This may involve modifying and targeting existing or designing new dynamic pricing options to deliver locational benefits. For example, the Salt River Project (SRP) in Arizona uses time-of-use price plans to incentivise electric vehicle drivers to charge later than they normally would [80].

- *Programs* refer to DSR deployed through programs operated by the T&D utility or third parties with funding by the utility customers through tariffs or by the government. For example, Central Hudson Gas & Electric's Peak Perks program targets the deployment of Wi-Fi-enabled smart thermostats and pool pump controls on specific circuits to reduce peak loads and postpone or avoid system upgrades [81]. The manifold experiences of EU energy companies in Member States with Energy Efficiency Obligation Schemes can also serve as references.

- *Procurement* refers to DSR sourced through competitive solicitations. For example, the Brooklyn/Queens Demand Management program in which the local utility conducted auctions to procure energy efficiency, demand response, storage and other resources, contributed to the deferral of a new $1.2 billion substation [82]. Demand response resources that are bid in balancing power markets in the EU, or the German energy efficiency auction scheme, are further examples.

The library contains one article.

Title	Author	Year	Description
Incorporating energy efficiency into electric power transmission planning: A western United States case study	Galen L. Barbose, Alan H. Sanstad, Charles A. Goldman	2014	This paper describes an innovative project to explicitly incorporate end-use efficiency into transmission planning and transmission planning studies. It illustrates the kinds of technical and institutional issues that must be addressed to incorporate energy efficiency into regional transmission planning activities.

Action 2: Implementation check

The regulatory authority should assess the investment plan suggested by the network operator, i.e. whether there is a more cost-effective and reliable resource mix than the one proposed. This assessment should be in line with the policy targets and regulatory framework defined by the policymaker. This is an iterative process and will lead to real investment until the plan is justified. For the questions and literature relevant, please refer to the action *Compliance check*.

4.4. Investment decisions in local transport planning and management

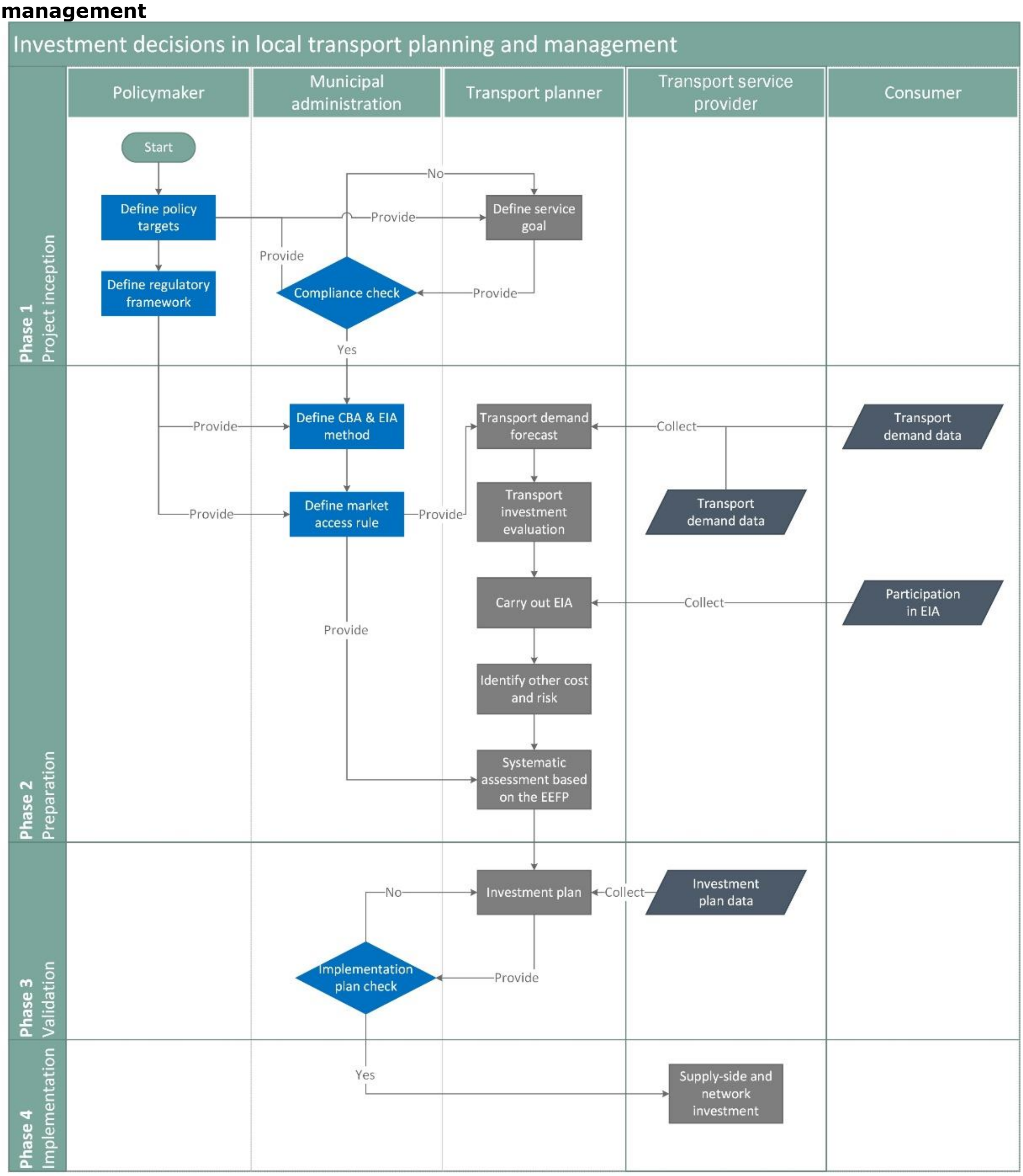
The transport sector is responsible for around a quarter of the EU's GHG emissions, making it the second biggest GHG emitting sector and key policy area, which requires improving efficiency to achieve EU climate and energy goals. Transport energy efficiency is not the goal itself but one of the means to achieve sustainability and reduce externalities (e.g. GHG emissions and use of fossil fuels). Therefore, the analysis of actions promoting the Energy Efficiency First principle in the transport sector must be understood from this prism.

Transport planning and management not only includes the planning of public transport networks, transport services and infrastructure. Strategic and proactive planning by the authorities should address all modes of transportation and can thus enhance a cities' energy efficiency through various avenues. Energy efficiency considerations in local transport planning are usually concerned with the basic policy target of realising a reduction in energy consumption or CO2 emissions [83].

In this regard, the digital technologies, joint undertakings, and sustainable urban mobility plans (SUMPs), but also national road and rail network planning and operation authorities can integrate energy efficiency considerations to optimise resources for travel that are made. In other words, it is necessary to both integrate digital technologies into the planning and management of urban day-to-day mobility/transport/travel activities (to optimise these) as well as to take the relative energy efficiency of transport modes and vehicles into account in the planning. In particular, public transport, cycling, and walking should be appraised as alternatives to expanding or maintaining the infrastructure for car and lorry traffic.

In sum, the Energy Efficiency First principle can be utilised by transport planners and management at all levels to identify how to optimise the investments in order to ensure that energy efficiency is enhanced throughout all journeys. In this real-life example, we examine how investment decisions can be taken in investments in transport planning and management at a local level to apply Energy Efficiency First principle.

Figure 8 Decision-tree of investment decisions in local transport planning and management



Note to Figure 8: Transport demand can also be influenced and partially avoided by activities of local planning. This is, however, beyond this *transport* planning and management case.

For the critical actions of the policymaker and regulatory authority, relevant questions and supporting literature are provided below.

4.4.1. Policymaker

Action 1: Define policy targets

The policymaker should define the targets for investments in local transport planning and management. Then, provide the targets to local administration & transport planners for further steps.

Q1: What policy targets area usually applied for investments in local transport planning and management decisions?

Transport planning and management not only includes the planning of public transport networks, transport services and infrastructure. Strategic and proactive planning by the authorities should address all modes of transportation and can thus enhance a cities' energy efficiency through various avenues. Energy efficiency considerations in local transport planning are usually concerned with the basic policy target of realising a reduction in energy consumption or CO2 emissions [83]. Since transport also affects a significant number of co-benefits which may be harder to measure, expert scores form another important decision tool relating to (for example) city network and urban sprawl. The library includes two sources on this question [84].

Title	Author	Year	Description
Urban Transport and Energy Efficiency	GiZ	2012	This publication provides a comprehensive overview of measures, approaches and policies designed to promote greater energy efficiency in transport. Its focus is at the local level, where it helps decision makers.
Quantifying the effects of sustainable urban mobility plans	Joint Research Centre	2013	This technical note uses the expert scoring information available in current scientific literature in order to explore the impacts and effects that different urban measures may have in planning for sustainability on a European wide level.

Action 2: Define regulatory framework

Based on the targets defined in the first step, the policymaker should define the regulatory framework, in which multiple policy instruments can be integrated.

Q2: To achieve the targets listed in the first step, what policy instruments can be applied?

Traditionally, transport measures on EU level are often linked to vehicle efficiency [84]. However, three major exceptions to this on the application of the EEF principle in transport planning and management at the EU level. Firstly, Sustainable Urban Mobility Plans have been designed to tackle transport-related problems in urban areas more efficiently and the provisions of clean and efficient transport modes for citizens in cities to complete their work and leisure trips in the city. Secondly, the EU's Intelligent Transport Systems has supported digital technical, enabling automated mobility and smart traffic management systems.

Local policy instruments related to local transport planning and management are often understood to include two main categories [83]. First is to enhance system efficiency, i.e. to avoid increased transport activity and reduce the current demand for transport. Second is to improve travel efficiency, by shifting demand to more efficient modes of transport. Thirdly, there is an element of ensuring better planning (e.g. to achieve better journy optimisation). These measures, in combination with vehicle efficiency, will determine the overall performance of energy efficiency. Several examples of relevant and specific policy options are summarized in Table 7. It should be noted that not all measures are also associated with significant economic costs. For instance, network facilitation in itself has been shown to effectively enhance efficiency in the context of (i.e.) land-use planning [85].

Table 7 Summary of policy instruments for local transport planning and management

Type of efficiency	Type of local transport	Policy instrument
System efficiency		Urban mobility planning Land-use planning Management of demand for transport
Travel efficiency	Public transport	Proposing a modal shift to walking and cycling Promoting the use of public transport by incentives and investments.
	Private transport	Penalising or discouraging the use of private vehicles. Car-pooling and bike sharing.

The library contains three articles which discuss various possibilities and case examples in more detail.

Title	Author	Year	Abstract
Urban Transport and Energy Efficiency	GiZ	2012	This publication provides a comprehensive overview of measures, approaches and policies designed to promote greater energy efficiency in transport. Its focus is at the local level, where it helps decision makers.
Technology assessment of the two most relevant aspects for improving urban energy efficiency identified in six mid-sized European cities from case studies in Sweden	Iana Vassileva, Javier Campillo, Sebastian Schwede	2017	This paper presents results from a technology assessment tool developed together with six mid-sized European cities. The main areas of focus have been evaluated based on the cities' priorities: transportation (both public and private) and consumers' perspectives on the use of smart electricity meters.
Mobility management in early planning processes and its impact on energy efficiency in the transport sector	Adam Mickiewicz	2015	This paper examines how mobility management can be used as a regulatory tool employed by the SEA in regard to striving towards the Swedish national energy-efficiency goals in the transport sector.

Q3: What are the existing experiences of these policy instruments?

Concerning existing EU regulation on transport planning and management, three European initiatives serve as examples to illustrate how the EEF principle has been practically applied in transport management and planning decisions can be carried out to promote energy efficiency. Firstly, Sustainable Urban Mobility Plans have been designed to tackle transport-related problems in urban areas more efficiently and the provisions of clean and efficient transport modes for citizens in cities to complete their work and leisure trips in the. Secondly, the EU's Intelligent Transport Systems has supported digital technical, enabling automated mobility and smart traffic management systems. Through stronger communications, congestion is detected and avoided, reducing the energy use of a journey. Thirdly, the EU's SESAR joint-undertaking which concerns air-traffic management and uses trajectory-based operations' (meaning that aircraft can fly their preferred trajectories without being constrained by airspace configurations). This has enabled air traffic management to take operational and technical choices which reduce the length of a journey of a flight, thereby making those routes more fuel-efficient, something which the European Green Deal seeks to further improve. Finally, the TEN-T Regulation ((EU) 1315/2013) addresses the implementation and development of a Europe-wide network.

On a local level, measures often revolve around municipal fleet efficiency and improvement of public transport [86]. However, research emphasizes that there is still significant room for enhanced energy efficiency in the transport sector, with measures ranging from 'interoperable ticketing and payment systems' to 'improvement of the efficiency of city logistics by the use of ICT' [83] – in all EU countries, regardless of their developmental state. Charging in congestion zones is seen as a particular promising measure in terms of potential CO2-reduction [84], having yielded positive results in several cities [86]. Integration across sectors and regions is considered an important prerequisite to kickstart the effectiveness of such measures [86,87]. Regarding the importance of digitalisation in local transport planning, a recent study concludes that despite the focus on innovations in the smart city agenda, EE measures are rarely driven by such advanced technology [86]. The library contains five articles.

Title	Author	Year	Abstract
Urban Transport and Energy Efficiency	GiZ	2012	This publication provides a comprehensive overview of measures, approaches and policies designed to promote greater energy efficiency in transport. Its focus is at the local level, where it helps decision makers.
Are smart city projects catalysing urban energy sustainability?	Håvard Haarstad, Marikken W.Wathne	2019	This paper uses case studies of three cities (Nottingham, Stavanger, and Stockholm) funded by the Horizon 2020 Smart Cities and Communities program and examines how urban energy sustainability was advanced and realized through the smart city initiatives.
Quantifying the effects of sustainable urban mobility plans	Joint Research Centre	2013	This technical note uses the expert scoring information available in current scientific literature in order to explore the impacts and effects that different urban measures may have in planning for sustainability on a European wide level.
Do we have effective energy efficiency policies for the transport sector? Results and recommendations from an analysis of the national and sustainable energy action plans	Maria Ntovantzi, Paolo Bertoldi, Silvia Rivas Calvete, Marina Economidou, Albana Kona, Tiago Serrenho, Craig Lee Morton	2015	This paper presents, discusses and evaluates the current energy efficiency policies for the transport sector, mainly focusing on road transport. It discusses both EU as well as national and regional policies.
Navigating towards efficient urban transport: A compilation of actor-oriented policies and measures for developing and emerging countries	Susanne Böhler, Hanna Hüging, Robert Gruber	2015	The main element of the paper is an overview of different energy efficiency policies and measures for the key actors in energy-efficient transport on local and national levels. A set of measures is assigned to each actor identified. The compilation was adapted to the circumstances in developing and emerging countries and includes examples for the successful implementation of several measures.

4.4.2. Local administration/local transport planners

Action 1: Compliance check

Based on the policy targets provided by the policymaker, the local administration & transport planners should check the investment goal proposed by the transport service provider. This is an iterative process and will lead to further processes until the plan complies with the targets.

Q4: How to evaluate the contribution of the investment in the local transport planning and management to the policy targets listed in Q1 for step 1.1? What are the potential trade-offs among the policy targets?

To measure the success of energy efficiency strategies and to quantify the energy savings achieved, several indicators are used often in a local and disaggregated approach. This includes measures related to energy use, such as 'passenger transport energy use per capita (MJ/person)', but also indicators on the 'modal split of all trips' within a specific geographic region [87]. With regard to transportation and mobility, the quantification of energy efficiency potentials of modal shifts and reduced transport volumes by changed and reduced movement of goods and persons requires a quantitative database of current geographical properties of settlements and their spatial relationship [88]. Sustainable investments options may require trade-offs relating to transport efficiency. For example, there could be trade-offs relating to investments in promoting access to public transport for areas in which the current transport system does not extend to. Similarly, there could be trade-offs in the sense that investments could be made in making transport more affordable for those who are socially vulnerable.

The library contains three articles.

Title	Author	Year	Abstract
Urban Transport and Energy Efficiency	GiZ	2012	This publication provides a comprehensive overview of measures, approaches and policies designed to promote greater energy efficiency in transport. Its focus is at the local level, where it helps decision makers.
Technology assessment of the two most relevant aspects for improving urban energy efficiency identified in six mid-sized European cities from case studies in Sweden	Iana Vassileva, Javier Campillo, Sebastian Schwede	2017	This paper presents results from a technology assessment tool developed together with six mid-sized European cities. The main areas of focus have been evaluated based on the cities' priorities: transportation (both public and private) and consumers' perspectives on the use of smart electricity meters.
Documentation and dataset from the analysis and mapping of cities with similar topography and demography and the relation to energy efficient transport and mobility	sEEnergies	2020	The dataset will allow transport studies within the sEEnergies project at an extraordinary geographical scale and with a very detailed data base of Urban Areas, and their connections within a European transport system.
Trade offs and entanglements among sustainability dimensions: the case of accessibility as a missing pillar of sustainable mobility policies in Italy	Roberta Cucca & Enrico Tacchi	2017	This article analyses the trade-offs between the environmental and social dimensions in sustainable mobility policies (focusing on an Italian Context).

Action 2: Define CBA & EIA method:

Based on the regulatory framework provided by the policymaker, the local authority/transport should define/clarify/draw attention to the cost-benefit-analysis (CBA) method for its operations and for the transport service provider(s) to systematically assess its investment options. On top of this, the Environmental Impact Assessment (EIA) method must necessarily also be considered.

Q5: What are the investment options for the municipal transport planner and the transport service provider (bicycle lanes, electric vehicles, investment in roads, public transportation)? How to evaluate the benefit and cost of these investments?

Local authorities are often confronted with a number of urban mobility issues, for which a multitude of alternative solutions are available [89]. This is complicated further by the various decision makers at the local level, including mayors and city governments, transport planning divisions, land use planning divisions, economic development divisions and financial divisions [83].

Authorities may be supported in their choice among specific investment with decision support tools such as the cost-benefit analysis. Such analyses can express the viability of a project by defining (as many as possible) of a measure's relevant direct and indirect impacts in monetary terms [89]. CBAs assist policymakers in understanding the wider impacts of a project, including its external costs – as well as help make results across various investment options comparable.

Difficulties may arise in the monetisation of non-monetary effects (e.g. sense of well-being, sense of community and participation, and physical health) with current approaches still making different choices on how to assign monetary values to specific effects. A sound understanding of the structures of an urban transport system is also necessary for the calculation of potential benefits, since (due to its complexity) a small change can cause big changes to energy consumption and emissions [90]. As such, details on matters such as land use and traffic flow should form a key input in any cost-benefit analysis [91].

The library contains nine articles.

Title	Author	Year	Abstract
Urban Transport and Energy Efficiency	GiZ	2012	This publication provides a comprehensive overview of measures, approaches and policies designed to promote greater energy efficiency in transport. Its focus is at the local level, where it helps decision makers.
Technology assessment of the two most relevant aspects for improving urban energy efficiency identified in six mid-sized European cities from case studies in Sweden	Iana Vassileva, Javier Campillo, Sebastian Schwede	2017	This paper presents results from a technology assessment tool developed together with six mid-sized European cities. The main areas of focus have been evaluated based on the cities' priorities: transportation (both public and private) and consumers' perspectives on the use of smart electricity meters.
Documentation and dataset from the analysis and mapping of cities with similar topography and demography and the relation to energy efficient transport and mobility	sEEnergies	2020	The dataset will allow transport studies within the sEEnergies project at an extraordinary geographical scale and with a very detailed data base of Urban Areas, and their connections within a European transport system.
A system dynamics approach to scenario analysis for urban passenger transport energy consumption and CO2 emissions: A case study of Beijing	Xue Liu, Shoufeng Ma, Junfang Tian, Ning Jia, Geng Li	2015	This paper constructed a variety of policy scenarios based on management experience in Beijing. The analysis showed that priority to the development of public transport (PDPT) could significantly increase the proportion of public transport locally and would be helpful in pursuing energy savings and emission reductions as well.
Future energy use and CO2 emissions of urban passenger transport in China: A travel behavior and urban form-based approach	Peilin Li, Pengjun Zhao, Christian Brand	2018	The present study extends the existing activity, modal share, energy intensity, fuel/carbon intensity (ASIF) modelling framework by disaggregating travel activity into key structural components and city-specific factors for 288 prefectural level cities in China. Policy recommendations are given.
Technology assessment of the two most relevant aspects for improving urban energy efficiency identified in six mid-sized European cities from case studies in Sweden	Iana Vassileva, Javier Campillo, Sebastian Schwede	2017	This paper presents results from a technology assessment tool developed together with six mid-sized European cities. The main areas of focus have been evaluated based on the cities' priorities: transportation (both public and private) and consumers' perspectives on the use of smart electricity meters.

Title	Author	Year	Abstract
Evaluating mobility and sustainability in the transportation sector at the city level	Shruti Vaidyanathan, David Ribeiro	2017	This paper will discuss the approach taken in ACEEE's City Energy Efficiency Scorecard for evaluating local governments on their actions to improve transportation energy efficiency. It will also identify potential improvements and refinements to these methods.
D.5.1 Methodologies for cost-benefit and impact analyses in urban transport innovations	TIDE	2012	TIDE focuses on 15 innovative measures in five thematic clusters: financing models and pricing measures, non-motorised transport, network and traffic management to support traveller information, electric vehicles, and public transport organisation. The aim of the present analysis of existing tools for impact analysis is to identify methodologies that meet the needs of practitioners in different contexts.
The Cost Benefit Analysis for the Concept of a Smart City: How to Measure the Efficiency of Smart Solutions?	Kamila Turecková & Jan Nevima	2020	This paper discusses a methodical approach towards the efficiency evaluation of proposed smart city solutions. The detailed literature review provides the basis for a formulation of general principles of using a CBA for innovative smart city solution efficiency evaluations based on chosen cases.

Q6: How to evaluate the impact of policy instruments on motivating the demand-side management of the local transport system?
A6: No specific literature identified.

Q7: What is the EIA impact of the investment options the different modes of transport?
A7: No specific literature identified.

Action 3: Define market access rules:

Based on the regulatory framework provided by the policymaker, the local authority/transport should provide the market access rules for the transport planners and the transport service operator.

Q8: What are the barriers for transport service provider to access the market?
A8: No specific literature identified.

Q9: Are there existing market access rules design of transport service providers?
A9: No specific literature identified.

Action 3: Implementation check:

The local administration/transport planners should check plan proposed by the transport service provider. This is an iterative process and will lead to real investment until the plans is justified. For the questions and literature relevant, please refer to the action

Q9: How to define the CBA and EIA
A9: No specific literature identified.

5. LIBRARY SUPPORTING THE DECISION TOOL

5.1. A guide to the library

The library with the available literature is provided in a separate Excel file. For each of the 229 articles listed, a number of characteristics are included. Table 5.1 lists the characteristics with a short explanatory note. An explanatory list of the terms used is included in a separate sheet of the Excel file.

Table 5.1 Characteristics used in the literature analysis

Characteristic	Explanatory note
Title	
Author(s) / Institute	
Year of publication	
General category	Methodology, data or assessment
Subcategory	Details on the kind of methodology, data, or assessment
Policy area	Energy supply, transport, etc. (see task 1.1).
Policy element	See task 1.1.
Country / region	The geographical region the study focuses on (if applicable)
Governance level	EU, national, local
Type of decision	Policy, planning, investment
Public source?	Yes, no, semi-public
Source location	Internet page, scientific journal, etc.
Decision step	Relevance to the particular questions and steps in the decision-making process
Description	Free field with a few notes on the contents of the document

The Excel file contains all the necessary information for linking the literature to the decision tool. The actual linkage between the Excel file and the tool in Visio is achieved by importing the Excel file into Visio. The resulting link between the library and the tool is shown in the task 1 deliverables.

5.2. Gap analysis report

5.2.1. Literature collection methodology

The literature search was conducted in a systematic manner, divided over three types of sources: academic literature, non-academic literature and EU projects.

For the academic literature, high-quality journals were selected, including Energy Policy, Energy Efficiency, Energy Economics, and Applied Energy, etc. To obtain the most suitable articles, we used one or two search criteria for each policy element, which were composed of the keywords of the respective policy element as well as the term ‘energy efficiency’. In journals which did not focus on policy articles specifically, we also added the term ‘policy measures’ or ‘policy’ to the criterion. For example, to find articles for the policy element ‘market access to district-heating’, we used the criterion ‘energy efficiency district heating market access’ for articles in Energy Policy, and the criterion ‘energy efficiency district heating market access policy measures’ in the other journals. It should be noted that for most articles, the exact search criterion used can also be found in the literature list.

For Energy Policy, Applied Energy and Energy Economics, the searches were performed on the website of the journal’s publisher: ScienceDirect. Due to issues with the search engine of the publisher of Energy Efficiency, we used Google Scholar instead, filtering for this particular journal.

For all searches, the first 25 hits were analysed by reading the abstract. If the article was deemed potentially relevant, the introduction and conclusion were also scanned and (if applicable) put on the literature list. At a later stage, all papers were investigated in more detail to make sure they were relevant for the purpose of the study. It should be noted that, for a limited number of policy areas (mainly relating to digitalisation), very few sources were found using the approach described above. This is why we also decided to include the relevant articles among the first fifteen hits on Google Scholar. Finally, we also included the most relevant papers from the ECEEE website on transport.

In some rare instances, we also included papers which were not found using one of the search criteria mentioned above. These papers were found, for example, through the reference list of another article. This was also recorded in the literature list.

With regard to the non-academic literature, we used a very similar methodology. Our search criteria again included the keywords as well as 'energy efficiency' and 'policy measures' or 'policy'. Google was used as our search engine. The first 25 hits were analysed by scanning through the introduction or (if available) the abstract.

We considered three EU projects as relevant sources for the library: Enefirst, sEEnergies and Odyssee-Mure. For the Enefirst project, we drew upon the literature list which was compiled for the project. We studied all (roughly 100) sources and selected slightly less than half for inclusion in the library. The websites of the other two EU projects (Odyssee-Mure and sEEnergies) were examined and all relevant sources were included in the library as well.

5.3. Literature overview

General sources

In addition to sources on energy efficiency in the specific policy elements, we also collected literature which gives a more general view of energy efficiency. First, there are several sources which provide practical examples of several cases in which energy efficiency policy or the EEF principle was applied (Energy Union et al., 2016; Enefirst, 2020) – or areas which introduce interesting policy options with regard to energy efficiency (PWC et al., 2014). Second, a relatively large number of sources look into the measurement of cost-effectiveness of EE-programs (Yuschenko and Kumar Patel, 2017; EPA, 2008), including literature on an indicator set (Reuter et al., 2020), the socioeconomic benefits (Bartoszewicz-Burzcy et al., 2014) and non-energy impacts (Thema et al., 2019). Another source investigates the implementation side of energy efficiency in energy legislation (Rosenow et al., 2017). The list also includes the links to some recently developed tools on energy efficiency in the Odyssee-Mure and Enefirst projects. Summing up, this general literature could be beneficial for introducing policymakers to the theme of energy efficiency and the EEF principle.

Network tariff design

With regard to the policy element 'Network tariff design', there are many suitable sources for policy makers. Most directly compare alternative tariff designs in terms of cost reflectivity, cost effectiveness and energy use (Bergaentzle et al., 2019; Abdelmotteleb et al., 2018; Eurelectric, 2013; Energy Community Secretariat, 2018). Other papers also clarify to what extent these solutions are actually possible considering (EU) regulations (ClientEarth, 2019). Furthermore, other sources address how to best implement these tariffs using various policy measures (Faruqui, Harris and Hledik, 2010), including the use of consumer data on their preferences (Belton and Lunn, 2020). There are a few papers which also specifically address who needs to do what in the implementation of a new network tariff design (Ref-E et al., 2015; Energy Community Secretariat, 2018), even offering a very detailed step-by-step plan for the introduction of a time-of-use system (IRENA, 2019). The main issue for this element is that there are only a limited number of sources which take energy efficiency as the central starting point for the analysis (CEER, 2017). Instead, "energy use" and/or "clean energy" are used to compare various measures.

Transmission and distribution network planning

There are several suitable sources for the policy element "Transmission and distribution network planning". One paper specifically addresses the actors involved in (US) transmission planning, and how to incorporate (cost-effective) energy saving (Mosenthal and Slote, 2004). Another US paper which is closely related, outlines a methodology for incorporating the principle of energy efficiency into transmission planning (Galen et al., 2014). Other papers take a broader approach and analyse various national policies for energy planning on an urban level, which are compared with regard to energy use as well as cost efficiency (Yazdanie et al., 2017). Goldman et al. (2020), on the other hand, do not focus on transmission planning as such, but rather on comparing various energy efficiency programs, which can be used as input for transmission planning. Two ECEEE papers are a bit more general and address some qualitative issues (including the regulatory framework) regarding the implementation of the EEF principle into transmission planning (Zsuzanna et al., 2019; Guertler, 2011). While relatively more papers focus on energy efficiency, it is again not the central concept in each paper. Furthermore, relatively many papers focus on transmission planning. Distribution planning receives less attention. More papers about distribution network planning would contribute to a well-rounded literature overview of this policy element. Also, more specific case studies about transmission planning could help to further clarify this policy element.

Market access of demand-side resources

There is a large number of sources available for the policy element 'Market access of demand-side resources'. Most papers compare various policies and also seem to be fairly well distributed among the different decision steps. Several papers juxtapose demand response and energy efficiency as two different options for increasing the share of renewable energy (Wohlfarth, Worrell and Eichhammer, 2020) or the forward capacity markets (Liu, 2017). The paper by Wohlfarth et al. (2020) also clearly describes the regulatory barriers for demand response. Another paper which considers demand-side resources as an alternative option for energy efficiency is a report by California ISO, which describes various pathways for maximising preferred resources (California ISO, 2013). Most other papers, however, consider demand policies as a means to achieve the energy efficiency goal. The main challenge with this policy element is the diversity in articles about demand. Some focus on various measures to increase demand side management (Bergeantzle, Clastres and Khalfallah, 2014), or demand response (Yilmaz, Rinaldi and Patel; Girod, Stucki and Woerter, 2017; Zancanella, 2017). Demand side flexibility is considered by the European Commission (2013), Swedish Energy Markets Inspectorate (2017), Nordic Energy Regulators (2017). A relatively small subset of the literature specifically considers demand-side resources. For example, Crossley (2013) addresses effective mechanisms to increase the use of demand-side resources. A methodological contribution is offered by Keane et al. (2011), who illustrate the usefulness of the unit commitment model to show how demand side resources can contribute to more efficient systems. In sum, there is a need to clearly define which of the above categories fall under the umbrella term of demand-side resources.

Governance

The main issue for the policy element 'Governance' is that sources are not very uniform across the different governance categories. The main categories which can be identified are (i) national long-term strategies (ii) National Energy and Climate Plans (NECPs) and (iii) security of supply. With regard to security of supply, it was quite hard to find suitable articles which also focus on energy efficiency. Various sources do mention security of supply, but as a co-benefit of one of the policy options discussed, such as those for the development of renewables and transmission grid (Held et al., 2018) or of the TEN-E policy which is also associated with energy efficiency (Trinomics, 2018). Energy security and energy efficiency are also explicitly linked as co-benefits in Ecofys (2018) and Rosenow and Cowart (2017). In a paper focusing on Iran, security of supply is an integral factor in a generalizable model to identify barriers that prevent the use of renewables in Iran (Alizadeh et al., 2020) – but in that case energy efficiency was not at the centre of the paper. A second set of papers specifically focusses on NECPs – which specifically address energy efficiency. For example, one paper introduces a methodology to perform CBA for such plans in Italy (Sofia et al., 2020). Another methodology is given by Gkonis et al. (2020), who describe how to design a cost-optimal energy efficiency policy. Other papers focus on national long-term strategies more generally. Streimikiee (2012), for example, discusses how the national plans for energy efficiency should be implemented on a local level. Similarly, Ringel (2017) describes how a multi-level administration structure affects energy efficiency policy governance. Finally, Mikova et al. (2019) discuss a methodology on how to compare and assess policy settings in European scenarios. In sum, there is a fair amount of information available for the different aspects and decision steps, but more attention is required to the energy efficiency aspects of this policy element.

Public procurement rules

The literature available for public procurement rules is useful and relatively complete. Due to the characteristics of this policy element and the scope of the selected energy journals, almost all of the literature sources are non-academic. The documents are clear and provide good indications on how energy efficiency can be incorporated into public procurement procedures. For example, the paper by Effect (not dated) provides many tips about this topic, including lifecycle costing, and even provides a template with a summary of all main features of the necessary specifications. While this paper is focused on national procurement rules (Effect (n.d.); Smart SPP, 2011), others focus on local rules (Pro-EE; EPA, 2011). It should be noted that national issues can also be applicable to the local level. Some papers provide detailed descriptions of case studies, which should be useful to policymakers (Payne et al., 2013; EPA, 2011). Papers also address how to best implement these rules, including the usefulness of training sessions (Pro-EE; Annunziata et al., 2014). A subset of studies is even more specific, and addresses procurement of products specifically (EPA, 2011) or even a certain category of products – IT hardware (Shakti, 2016). The library also includes two links to websites which directly compare various products in energy efficiency (superefficient.org; energystar.gov). Lastly, we also included a source about the public procurement of energy efficiency services (World Bank, 2010). In general, most papers address how public procurement can address cost-effectiveness (i.e. lifecycle costs) and who is responsible for implementation.

Industry

Several papers deal with current industry trends on energy efficiency (Odyssee (not dated); Martinez and Silveira, 2013), which could be a useful starting point for many policymakers. The main difficulty with literature on this topic is that it contains on the one hand highly site-specific analyses of individual production facilities and on the other hand general, nationally aggregated analyses. Several academic articles take this broader approach and establish a cost-benefit analysis for either one particular policy option (Xylia et al., 2017, on the EEO in Sweden; Vreuls, 2017, on the Dutch Industrial Voluntary Agreements; Stenqvist and Nilsson, 2012, on the PFE in Sweden) or for various policy options (Brown, 2013). The library includes a link to an online tool, which helps develop future industry energy scenarios based on a range of potential energy efficiency measures (sEEnergies, 2020). A tool is also available for smaller businesses (Viesi et al., 2017). The paper by Safarzadeh (2020) is a literature review, which addresses various policy options on energy efficiency (i.e. a subsidy scheme or white certificates) and contains some interesting references to more detailed papers. Other papers focus more on implementation – how does the individual firm implement an energy efficient technology? Arens et al. (2016) investigate this for Germany. Using a qualitative approach, Viklund (2015) discusses this for excess heat recovery in Swedish industries. A model on how to evaluate energy efficiency in industry is also included in our list (Li and Tao, 2017). Summing up, the literature describes various policy options for industry. However, the policy element ranges very broadly. Different policy options might therefore not be comparable. It might be beneficial to further specify this element so only the most relevant literature can be included. This would also help in finding more relevant literature for the implementation of energy efficiency measures).

Data centres

After re-evaluation of the literature on data centres, several were considered too specific for policy purposes and therefore have been deleted from the initial list. A useful paper by Avigenerou et al. (2017) describes the current trends in energy efficiency for data centres and would be useful as a starting point for drafting policy. Many other papers focus on qualitative policy recommendations for efficiency improvements (Koronen et al., 2020; EPA, 2007; E3, 2014; Anthesis and NRDC, 2014). Other papers do not focus specifically on policy, but instead consider how to measure energy efficiency in data centres (Rasmussen). Finally, some papers do not focus on policy per se, but consider how data managers should implement energy efficiency in their operations (Newcombe, 2008), which provides valuable insights for policymakers as well. Unfortunately, this policy element still largely lacks quantitative comparisons of various policy options. Furthermore, implementation remains understudied.

5G Network

Literature about the 5G network is very sparse, with only four relevant sources. Rapone et al. (2015) address the techniques or actions that the network operator should consider for the network's evolution. Hui et al. (2020) consider the role of 5G in demand response. Buzzi et al. (2016) and Usama and Erol-Kantarci (2019) discuss the various energy-efficient techniques for 5G networks. However, these articles focus mostly on technical issues, and (almost) no attention is given to policy impact. We conclude that more research is required to assist policy makers with this policy element.

Water treatment

The literature on water treatment mostly comes from non-academic sources. These reports provide various recommendations and tips for policymakers when deciding upon a certain process for wastewater treatment, or in improving existing facilities (Spartan Controls, 2016).

Some papers focus on various case studies (KWR, 2010), while others provide a step-by-step plan for policymakers (EPA, 2013). Only a few reports also consider the cost-effectiveness of policy options (KWR, 2010; NL Agency, 2010) – but do so only to a limited extent. The academic literature provides a method for assessing energy efficiency in wastewater treatment, which could provide valuable information to policymakers (Longo et al., 2019). To provide more context, the literature list also includes an example on the evaluation of a large wastewater treatment plant in Italy (Panepinto et al., 2016). Unfortunately, there is little information about costs and benefits. There is also little guidance on the implementation of energy efficiency measures.

Hydrogen infrastructure

The list includes some valuable sources about hydrogen policy. However, most papers focus on hydrogen in general, and treat hydrogen infrastructure as a subtheme. Furthermore, energy efficiency is often not a central component in the discussion (IRENA, 2018; CCC, 2018; TKI Nieuw Gas; Wietschel et al., 2006). Some papers focus specifically on the cost-effectiveness of hydrogen (Hydrogen Council, 2020). Other reports address more specifically the hydrogen *fueling* infrastructure, like ICCT (2018). In their case study for North Rhine-Westphalia, Pastowski and Grube (2010) also focus on this theme and address the cost aspect (i.e. which strategies may help to keep initial hydrogen and infrastructure costs low). The academic articles are more about hydrogen *infrastructure* and can serve as input for policy (Wietschel et al., 2006). However, energy efficiency is again not a central theme. Various strategies are discussed, including that of a cluster (Ogden and Nicholas, 2011). Several articles address a specific part of infrastructure, namely hydrogen storage. For example, Haghi et al. (2018) directly address cost-efficiency and compare various alternative policy options. A case study for a specific wind park is discussed in Kroniger and Madlener (2014). In sum, this policy element does not yet have enough relevant sources, the main reason being that although there is a small body of literature about hydrogen available, not much could be found for hydrogen infrastructure in particular. Furthermore, most papers do not focus on energy efficiency per se.

Energy storage

The literature on energy storage gives a clear overview of the current developments in energy storage and their associated costs. While some papers focus specifically on battery storage (Applied Economics Clinic, 2018; Ecofys et al., 2017), others take a more general approach (IRENA, 2017; European Commission, 2017; IEA, 2014). While energy efficiency is often mentioned in the papers, it is almost never a central concept. Most papers use the term when explaining that energy storage can contribute to energy efficiency by increasing flexibility (European Commission, 2017; IEA, 2014). The articles do not, as the explanation of the policy element hints at, evaluate the trade-off between storage facilities and energy-efficient appliances. Instead, various storage options are compared with each other. Many reports touch upon the cost-effectiveness of various options. One paper also clearly describes who needs to do what as energy storage is implemented increasingly (IEA, 2014). Most of the papers are quite uniform in their scope – i.e. describing benefits, challenges and recommendations for various options.

Power generation planning

The literature on power generation planning can be considered quite sparse. Only one non-academic relevant source was found. IRENA (2018) describes the role of power generation planning in the global energy transformation. Some policy recommendations are given, but while energy efficiency is emphasized throughout the document, the two are not compared (as in the description of this policy element). Searching Google with alternative search criteria (e.g. 'energy efficiency generation capacity') did not yield any additional suitable results. The academic literature is more extensive but focuses on rather specific topics. While one paper focuses on the long-term future of fossil-fuelled power generation (Tzimas and Georgakaki, 2010), most papers are centred around the integration of renewable sources in power generation. For example, Lee and Shih (2010) introduce a methodology for choosing between various options of renewable power generation technologies. Similarly, Poulikkas et al. (2011) address how to integrate renewable energy sources for power generation. While the aforementioned papers only mention energy efficiency in passing, Jaraite and Di Maria (2012) take a broader view and address the efficiency of the EU public power generating sector as a whole. Finally, Zhou et al. (2011) consider how to stimulate more investment in renewable energy in generation capacity planning. With the exception of Jaraita and Di Maria (2012) and Zhou et al. (2011), most of the other articles are not centred around energy efficiency. In conclusion, more sources are needed to provide effective guidance for policymakers, specifically on implementation.

District heating

The literature about district heating is extensive. Various non-academic resources provide information on how to increase energy efficiency in the district heating/cooling sector (i.e. Aalborg University Denmark, 2019; Energy Charter Secretariat, 2006). Several case studies illuminate potential issues and recommendations in the implementation (Klapman et al., 2016; Steinbach et al., 2013). Very useful for policy purposes is the dataset by sEENergies, which identifies available heat potentials. A number of distinct topics are discussed in the remainder of the literature. For example, some papers discuss the interconnection between industry and district heating (Viklund, 2015; Weinberger et al., 2017; Karlsson et al., 2009). A second subset of papers investigates the potential of demand side management in district heating networks (Guelpa et al., 2019; Sweetnam et al., 2018). Other papers focus on how to regulate district-heating (Asim et al., 2019; Wissner, 2014) or specifically address how to integrate renewable resources into district heating (IRENA, 2018). Most sources directly address either the energy savings and/or cost savings associated with a certain policy or investment. Energy efficiency is often a central concept in the papers. All in all, this policy element seems well-rounded with enough suitable sources, covering all steps.

Transport

The literature on transport is extensive and addresses the various aspects of the policy element description. For example, there are papers about urban mobility, as well as on the energy efficiency of vehicles. The library also includes information about the taxation and pricing of fuel and vehicles. In general, the sources are relatively well distributed over all the different decision steps, although the literature on implementation could still be expanded.

Gap analysis methodology

The gap analysis starts from the perspective of a policy maker. It determines whether sufficient guidance is available for each of the steps in the decision-making process facilitated by the decision-making tool. Where such guidance is lacking, a gap is identified.

In general, policy makers should ideally have available for their decision: 1) a methodology for applying the EEF-principle to their policy area, 2) sufficient data for quantitative analysis and calculations, and 3) one or more real life examples of the application of the EEF-principle to their policy area.

Furthermore, a policy maker follows a step-by-step process to reach a decision. The application of the EEF-principle requires following at least the following four steps: 1) the definition of a policy goal and the possible measures (both energy efficiency and non-energy efficiency related) to achieve it, 2) estimating the effectiveness of those measures, 3) analysing the costs and benefits of the different policy options, 4) implementation of the chosen measures. The availability of data, applications and methodologies is useful for each step.

The procedure outlined above can be summarised in the following matrix.

Availability of literature for policy area X

	Methodologies	Data	Applications
Goals & measures	High	…	…
Effectiveness	Low	…	…
Costs & benefits	Etc.	…	…
Implementation	…	…	…

The evaluation of the ‘sufficient’ availability of literature is not an exact science. First of all, there is both a qualitative and a quantitative aspect to consider. Although in general, “the more the better” applies, the quality of articles (in the sense of applicability) can vary widely. As the specific needs of policy makers vary as well, there is no single yardstick against which the availability can be measured, nor is there a clear criterion for judging when availability is sufficient. Having said this, it is possible to assess for each policy element whether the body of literature as a whole provides a good basis or not and whether there are specific gaps in the type of guidance offered (methodology/data/example) and in the guidance for each step in the decision process.

5.3.1. Gap analysis results

The Excel file containing all literature shows for each of the articles included 1) for which policy element it is most relevant, 2) what type of guidance it provides (methodology/data/example) 3) to which step in the decision process the guidance pertains. It is therefore possible for any user of the library to determine quickly and easily what type of guidance is offered and where guidance is lacking. What follows below is a summary of the results for each policy element and a few pointers on which gaps are most clearly visible.

Network tariff design

For the policy element ‘Network tariff design’, 15 sources are available. They are a balanced mix of methodologies and assessments. Some data are available, but these are rather limited. There are relevant sources available for each step in the decision process, but there is relatively little available for the implementation step. In general, literature focusing on energy efficiency (let alone the EEF-principle) is lacking.

Transmission and distribution network planning

There are 10 sources available for the policy element “Transmission and distribution network planning”. Most are assessments, but a few methodologies are provided as well. Data is almost completely lacking, which constitutes the biggest gap. Most sources are relevant for defining goals & measures and for assessing their effectiveness. Cost effectiveness and especially implementation are not covered as well. Finally, most sources focus on transmission rather than distribution, meaning policy makers interested in distribution network planning are lacking guidance.

Market access of demand-side resources

18 sources are available for the policy element ‘Market access of demand-side resources’. This provides for a good mix of methodologies and assessments. However, data availability is limited. Little is known about the cost-effectiveness of measures. The other decision steps are covered reasonably well. The broadness of the term “demand-side resources” means that the articles differ widely in topic and scope. When looking at a specific instance of demand-side resources, a policy maker may therefore find that the relevance of the articles collected is limited.

Governance

The ‘Governance’ policy element contains 10 sources, divided evenly over the national long-term strategies, the National Energy and Climate Plans (NECPs) and security of supply. For the limited number of sources, the coverage of different types of guidance and different decision steps is quite good, with the exception of the implementation step. The main gap for this element is the lack of focus on energy efficiency, which is often not more than a side note.

Public procurement rules

There are 10 available sources for public procurement rules. The element is one of the best covered from the list. It has multiple methodologies and applications, and an unusually good amount of data. It also covers the different decision steps reasonably well, although the cost effectiveness of measures gets relatively little attention. No obvious gaps remain for this element, although improvement is still possible on most aspects.

Industry

15 sources are available for the policy element ‘Industry’. They provide good coverage of different decision steps and guidance types. The main issue with this element is the specificity of the literature collected. If policy makers are looking for a different kind of measure than is covered here, they may find the applicability of the literature to be limited.

Data centres

The policy element ‘Data centres’ is discussed in 9 sources. Energy efficiency is often a topic of interest for data centres, which means the literature provides a good basis for policy makers on this subject. There are two main gaps for this element. First of all, most of the analysis is qualitative. Second, guidance on implementation is missing.

5G Network

There are only 4 sources available for the 5G-network. This policy element as a whole can be therefore be considered a gap. The available papers are mostly written from a technical perspective, which means the relevance for policy makers is limited.

Water treatment

The policy element ‘Water treatment’ has 8 available sources, which is also relatively limited. However, the sources provide some useful insights for policy makers. In particular, the coverage of the data is relatively good. The main gap for this element is a lack of cost-benefit analyses.

Hydrogen infrastructure

There are 11 sources in the library pertaining to hydrogen infrastructure, a number which is relatively high considering the short history of the topic. However, most papers focus on hydrogen in general, and treat hydrogen infrastructure as a subtheme. Furthermore, energy efficiency is often not a central component in the discussion. Due to the limited relevance of most papers, this element as a whole can also be considered a gap.

Energy storage

The literature on the policy element ‘Energy storage’ is limited, with only 5 sources available. While there is a good quantitative coverage of the different options for energy storage, both with regard to technical aspects and costs, they are seldom linked to energy efficiency. They are mostly compared to other storage options instead. The trade-off between energy storage and energy efficiency is therefore both a gap and a promising area of future research.

Power generation planning

The literature on power generation planning can be considered sparse, with only 7 sources. The applicability of the sources is also limited, as energy efficiency does not receive much consideration. The comparison of different renewable sources of power provides some guidance with regard to the possible goals & measures and their effectiveness, but little on energy efficiency for a comparison. Furthermore, guidance on implementation is completely missing.

District heating

The literature about district heating is extensive, with 22 available sources. There is information on possible ways to increase energy efficiency and case studies on how they were implemented. There is also a large dataset available on heat potentials. All in all, this is one of the best covered elements, with no obvious gaps remaining.

Transport

The literature on transport is vast, with 33 sources. The number focusing on management & planning is however rather limited, with only 3 sources. Due to the broadness of the initial search, the applicability could be limited for specific policy questions. In addition to the gap for this element in general, there is a lack of literature on the implementation of policy measures in this area.

6. CONCLUSIONS & DRAFT POLICY RECOMMENDATIONS

This report provides a detailed overview of policy areas that hold the potential to embrace the Energy Efficiency First principle and to establish a level playing field between demand- and supply-side resources. A total of 18 policy elements are selected from 7 policy areas, which cover the most relevant energy system planning and investment decision-making cases for the application of EEF principle. The selection also highlights well that the least-cost planning idea behind EEF principle is already – explicitly or implicitly and to varying extents – featured in various policy areas at the EU level.

Embedding the EEF principle must not be limited to idle overarching strategies and principles of action. More importantly, it requires explicit consideration and strengthening in distinct policy elements, planning processes, and investment decisions to achieve least-cost portfolios of energy and other resources to meet wide-ranging consumers' needs as well as the EU's objectives for market integration, the security of supply, competitiveness, and sustainability.

Based on a consistent analytical framework, this report emphasises the present status and highlights entry points for EEF principle within these 18 policy elements, and provides a tool for the policymakers and regulatory authorities to support their application of the EEF principle. Within the predefined structure and based on the identified elements, this report provides the users with a hands-on framework to establish decision-trees for different cases, and organise relevant decision-makers and their actions. Questions noting the most relevant aspects to consider are listed, together with a library consisting of supporting literature. Finally, by applying the tool to four real-life examples, the tool is further illustrated, tested, and refined.

In line with the proposed methodology, the objective of this Task is to provide an assessment and critical evaluation of the outputs of this project. The provisions of these recommendations are based on that fact that, given that this assignment is limited in its duration and size, there has not been room for extensive testing, learning and revisions to the outcomes. Thus, recommendations are provided on how to further the outcomes of the project, as well as how to link this project to other policies, initiatives and projects.

6.1. Recommendations for furthering outputs of this project

We will commence this chapter by addressing a number of issues which analyse how the decision tool has been developed, considering its strengths, weaknesses and potential for further action to enhance this decision-making tool. We will then underline some key issues faced through the development of the library of the information, and recommendations will be proposed for taking forwards the library in the future, including an executive overview of the gap analysis. Thirdly, we will provide some initial considerations on how the EEF principle could be better operationalised in policy, planning and investment decisions. Throughout this process, the explanations and reasoning are followed by a set of recommendations of how to take further the work in this regard in the future:

6.2. Recommendations on furthering the decision tool

6.2.1. Strengths of the decision tool

In brief, the tool provides its users with a constructible decision-tree model that can be adapted to different planning or investment cases. Combined with the library, the tool serves as a hands-on framework to organise the decision-makers and their actions into a systematic decision-making process, with a literature-based solution for the policymakers and regulatory authorities. In other words, the decision tool is used to visualise, in a user-friendly way, complex decision-making processes, to make explicit the structure of decision-makers and their actions, and to gain a shared understanding of these processes. The prioritisation of this clear visibility and user-friendliness has been a central consideration throughout the development of the tool. This has been done on both a broad level (i.e. through the use a generic decision-making tree), as well as more specific policy sector levels (i.e. through the real-life examples).

> ***Recommendation 1:*** *Future developments of the tool should prioritise clear visibility and user-friendliness, thereby clearly defining and distinguishing between decision makers and different decision steps, to ensure clarity in the complex decision-making process.*

We consider that a key added value of the decision-making tool is the fact that it has been able to broadly identify decision makers who are relevant for the application of the EEF principle principle in different policy areas. To be more precise, the EEF as a principle cannot be implemented simply by virtue of political proclamations. Rather, it requires adjustments and decisions in distinct policy areas (e.g. reforming tariff design to incentivise load shifting). In this context, the major added value of the tool is its ability to point out the major decision-makers involved in different policy areas, their investment rationales, as well as the (visual) description of how the regulatory framework should be designed to effectively achieve the application of EEF in the policy area.

Nevertheless, it should be noted that since the individual decisions and regulatory frameworks are quite complex per policy area, the tool developed so far has not been able to address every aspect in detail (e.g. what regulatory instruments are most effective to incentivise district heating operators to account for energy efficiency resources in their decision-making). Although, the literature database does provide a good starting point for policymakers/researchers to focus on these detail aspects individually.

> ***Recommendation 2.1:*** *When taking forward and promoting the outcomes of this project, particular attention should be paid to the added value created through the distinctions (and explanations) of different decision makers involved in various policy areas (when considering the implementation of the EEF principle principle).*
>
> ***Recommendation 2.2****: Despite the value-added identified above, future work on this topic must add further detail to the considerations and choices for the actors which have already been identified.*

Weaknesses of the decision tool

One of the key problems for the decision tool could be considered that, in some sectors, it does not accommodate for/respond to the sector-specific actor constellations and processes, and/or the differences in national decision-making/competence structures. In other words, policymaking, planning processes, investment rules (and thereby the actors involved) differ between sectors and may differ within EU Member States. An example could be district heating: in this sector, there are a lot of different arrangements in terms of actors and policies, ranging from publicly-owned systems (who can quite easily include provisions on the consideration of demand-side resources and environmental impacts in their investment decision-making) to privately-owned systems (whose primary objective is profit, so they may not prioritise EEF principle unless there are strict regulatory incentives/regulation to do so). On the other hand, however, there exist other policy frameworks, such as for electricity/gas markets, where these differences do not represent an important problem, because regulation is very harmonized at EU level.

> ***Recommendation 3:*** *The EEF principle decision making tool in its current state does not fully accommodate for different sectoral and/or national decision-making and competence structures. Further activities need to be carried out to identify clearly which energy and non-energy sectors have reached common European harmonised rules (and thereby can promote the use of the tool in a generic form) as well as to identify which sectors have more national peculiarities (and thereby require more tailoring of the decision-tree depending on which Member State is applying the principle). A way forward in this respect could be to elaborate real-life application examples of the tool for each of the 18 Policy elements analysed in chapter 2, and possibly analyse country-specific variants.*

Overall, in the tool, we could not account for national/regional particularities in single member states, but instead we describe the most common actors/policies by virtue of EU regulation. Indeed, in order to provide a tool which is both flexible and detailed enough, it was decided to provide a framework (with actors, actions, questions, and literature), and illustrate how to design such a tree for a specific case. An effective/fully operational decision-tree needs to be designed based on specific context. However, this specific need leads to another problem, namely that it was not possible to describe 15 policy elements and provide 4 detailed "real-life examples" in sufficient detail within the time and resource limitations of this project. As an illustration, the scope and size of the present project could also be devoted entirely to analysing the regulation of the district heating sector and to how to properly account for EEF in this realm (see Recommendation 6 below).

Another fundamental problem has been that the generic decision-making tool is less adaptable to non-energy policy sectors and for policy-decisions. This was predicted from the outset, given that often the specific type of decision makers may vary, the priorities in the sectors may differ, the types of rules and regulations governing the activities may diverge, etc. In this regard, the "traditional" energy sectors (supply of gas/electricity/heat; demand in households/commercial/industry sectors) all exhibit somewhat similar characteristics, and it is quite straightforward to find a common ground there. Crucially, the literature is also not specific enough to answer the questions relating to the EEF principle applied to different decisions and actors in non-energy policy sectors. The tool ultimately looks and functions rather differently for these different sectors. For example, for water, the priority in this policy sector would rather be to modify the energy efficiency first principle to the water efficiency first principle (i.e. saving water before increasing its supply). This will indirectly also save energy, although the more important impact is the water savings. For transport, the priority chain of avoid-shift-improve is the sector-specific formulation of the EEF principle: thus, it is considered that this chain is the most suitable for planning or investment decisions, especially for the energy-related policy elements.

> ***Recommendation 4:*** *The current decision-making tool can most convincingly and credibly be applied and promoted in energy policy sectors concerning planning and investment decisions. Further development and consideration are required in its future development to make it more accommodating for policy decisions and non-energy sector decisions. A way forward in this respect could be to elaborate real-life application examples of the tool for the non-energy Policy elements analysed in chapter 2.*

The decision-tree is developed based on the Microsoft Visio software and saved as a PDF file, embedded with links to the library display page and Excel library database. We consider this choice of PDF format based on Visio as a limitation on the user-friendliness of the project (although we have strived to make the decision tool as user-friendly as possible). This can be explained in a number of ways:

- Visio is not interactive in a way that you can click on a decision (yes/no) and then follow a different decision route/ rather due to the fact that everything is already there as one single flowchart;
- Using the Visio format has not been very helpful to add prompts to further guide the user/reader;
- The design of the decision-making tool is not visually attractive;
- Java/HTML-based may allow for materials to be updated more easily and for users to communicate by posting their questions and answers (i.e. creating an online community).

> ***Recommendation 5:*** *We would recommend the future development of the decision-making tool to use either a Java or HTML format in order to enhance its. interactivity and user friendliness.*

Recommendations on furthering the library of information

In order to reiterate what has already been noted in this regard, an extensive library of information has been collected and 229 articles have been listed. This extensive search including numerous different sources has been carried out, however, the literature collected often provides little to no guidance on applying the EEF principle explicitly. Furthermore, the availability of sources varies considerably from element to element. Methodologies and assessments are, on the whole, provided reasonably well in the literature. The definition of goals and measures, as well as the effectiveness of measures are also covered reasonably well by the literature. However, the availability of data is often low, cost benefit analysis is lacking in some areas, and guidance on implementation is lacking in many areas. As a consequence of the above, the following recommendations are suggested:

Recommendation 6: *Commission further research explicitly on the application of the EEF principle to specific policy areas and policy elements which have the least amount of relevant literature. Key examples which stem from the gap analysis include the implementation phase of EEF principle in network tariff design; any literature on application of EEF principle to hydrogen infrastructure; supporting policy makers initiating action in the design of 5G networks; guidance on the implementation phase of EEF principle in power generation planning in the EU (although a lot of mostly older literature exists from the USA); cost-benefit analysis of EEF principle application to water treatment; implementation of policy measures on EEF principle in transport planning and management.*

Recommendation 7: *Future work on the topic ought to continue to/ further identify the gaps in the literature needed to really use/apply the decision tree to a specific policy element. In order to do so, this requires choices on what the most important policy areas are, as well as which are the most relevant policy makers (i.e. national government, local government, network operator, regulatory authority, etc). This will provide insight into where the guidance is lacking most (i.e. is it in defining policy options, or in assessing costs and benefits, or in implementation plans, etc). Thus, by creating an iterative process of going through the tree and adding sources to the library based on the information gaps in the tree, it may be possible to really build a useful policy tool.*

Recommendation 8: *A number of processes and methodologies which are not identical but similar to the EEF principle have been identified. To name one: integrated resource planning (IRP) is a method with a long track record and plenty of literature. It would be useful if the European Commission would take a position and provide guidelines on whether these methodologies can be adopted by policy makers, if so in which policy areas and where they need to be adjusted to fit with the EEF principle.*

Recommendations on furthering operationalising the principle in policy, planning and investment decisions

On a more general level, for the better operationalisation of the EEF principle, we believe that the most fundamental requirement here is to take a case-specific approach that considers:

a) A requirement for the central players to apply the EEF principle

This largely will come from the regulators or the policy makers

b) Specific tools for assessing the cost-effectiveness, and guidance on the benefit-cost perspectives/tests that should be used[6]:

Quantitative energy system models for individual purposes (e.g. for evaluating the costs of building refurbishment options for a given urban area; and then another model to calculate grid expansion costs if building refurbishment was not pursued). Costs and benefits will always be case-specific.

c) A requirement and/or incentive for the central actors who need to do policy, planning, or investment decisions

[6] Consider.

Recommendation 9: *A general three-step approach for better operationalising the EEF principle is recommended:*

1) *Require relevant players to apply the EEF principle;*
2) *Provide them with specific tools and guidance for cost-benefit assessments;*
3) *Additional specific requirements/incentives based on the decision being taken.*

Nevertheless, it is possible to take some measures and considerations in order to better operationalise the principle in policy making, planning and investment decisions. These are further detailed in the sections below.

Better operationalisation of EEF principle in policy decisions

In this regard, a variety of different recommendations have been identified:

On a general basis, we would recommend requiring an energy efficiency impact analysis for each policy decision in the energy field (water, transport, any other energy-using sector). In other words, as an example, if there is the idea to reduce taxes or levies on electricity in order to promote electric vehicles and power storage, there needs to be a consideration of the negative incentive for electricity end-use efficiency and whether it may lead to worse effects on climate (than) compared with the positive incentive for electric vehicles and power storage. Crucially, there also needs to be a requirement for taking the results into consideration.

Recommendation 10: *Require an energy efficiency impact analysis for each policy associated to the implementation or decision about it in the energy field (including water, transport or any other energy-using sector)*

More specifically, in order to better operationalise the EEF principle in policy making decisions, its inclusion in National Energy and Climate Plans is considered essential. As outlined further below, the Energy Efficiency First principle is not yet fully integrated. Consequently, what is recommended is that the NECPs should include a specific requirement to elaborate an impact assessment (like e.g. the European Commission performed for the 2050 decarbonisation target) with a variety of pathways/scenarios featuring different contributions from EE vs. RES and other emission reduction options, in order to determine the optimal contribution of energy efficiency (considering total cost and other important impacts). This optimal contribution will need to become the basis for the planning of the GHG emissions reductions and the other dimensions of the Energy Union.

Recommendation 11: *In order to better embed the EEF principle in the NECPs, a specific requirement for an impact assessment of different pathways/scenarios should be done. This would reflect on how the EEF principle would contribute towards overall emissions reductions and the other dimensions of the Energy Union.*

Another way to ensure that policy decisions are encouraged to operationalise the EEF principle is through requiring (though inclusion in the terms of reference) that an external evaluation of policies/regulations/initiatives which concern energy has to be undertaken. As an example, Ecorys is currently finalising the evaluation of the TEN-E Regulation and one of its key recommendations concerns how the EEF principle is considered both in the text of the TEN-E Regulation and its implementation. In this regard, in the stakeholder consultations, opinions on this matter were also gathered. By doing so, significant attention is drawn to the EEF principle in specific energy-related policies and valuable insights are given to its written consideration as well as implementation. In particular, specific recommendations also follow in these evaluations on how to better implement and operationalise the EEF principle in that given policy field.

***Recommendation 12:** The request for an external evaluation of any energy-related (including water, transport, etc. energy-using sector) policy, regulation, initiative, project, should ensure that the criteria for the evaluation consider the contribution of/implementation of the EEF principle. This should also require recommendations on how to better operationalise the EEF principle in the policy being evaluated.*

Better operationalisation of EEF principle in planning decisions

In terms of long-term public/supply infrastructure or business planning processes, there exist non-governmental/regulatory supply-side decision-makers (e.g. electricity network operator). However, typically, these types of decision makers are not fully aware of the benefit of energy efficiency for their business models, or do not have the appropriate incentives to include energy efficiency. It should be made clear to these actors that energy efficiency/demand response can avoid/defer substantial investments in infrastructure assets (e.g. new power stations) if properly implemented. Thus, in order to convey this message to such actors, it would be useful to create a simplified modelling tool that introduces supply-side decisions to the potential (monetary) benefits from demand-side resources for different contexts.

***Recommendation 13:** In order to help non-governmental/regulatory supply-side decision makers become better aware of the benefits of energy efficiency for their business's models, the creation of a simplified modelling tool should be encouraged/promoted (created) that introduces supply-side decision to the benefits from demand-side resources for different contexts.*

On the other hand, there are also planning processes driven by governments and regulators, such as power system planning for security of supply. In this setting, the EEF principle can play an important role by substituting or deferring long-lived supply-side investments whilst savings energy and costs. Here, in order to better operationalise the EEF principle in such planning decisions, energy efficiency impact assessments and the analysis of relevant economic perspectives should be required. Thus, for example, the implementation of the EEF principle under the TEN-E guidelines could come as a provision that, in evaluating PCIs, cost-effective demand-side resources must be evaluated alongside supply-side resources in meeting cross-border needs.

***Recommendation 14:** In order to help ensure governments, regulators and decision makers operationalise the EEF principle in planning decisions, energy efficiency impact assessments and the analysis of relevant economic perspectives should be required in any such decisions.*

Better operationalising EEF principle in investment decisions

In terms of better operationalising the EEF principle in EU-level investments, we would encourage the European Commission to have specific calls/objectives dedicated to the research on and support with the application of the principle in two major funding streams. The first being the European Regional and Development Funds (ERDF). Here, Managing Authorities should be encouraged to ensure that their Operational Programmes to make specific reference to the promotion of the EEF principle in their portfolios and objectives. In light of the Green Deal, it is inevitable that almost all Operational Programmes will make some reference to environmental and sustainable energy purposes. By making specific reference already in the Operational Programmes, regional actors and applicants will become ever more acutely aware of the availability's finances (and importance attached) to analysis and implementation of the EEF principle. More specifically, Ecorys will be carrying out an evaluation of the energy efficiency and renewable actions in European Regional Development Fund and Cohesion Fund Programmes 2021-2027, analysing all the draft Operational Programmes of the Managing Authorities and their considerations to energy efficiency and renewable. Specific attention must be paid here to the inclusion of the EEF principle and recommendations/suggestions will be provided to all Managing Authorities on how to maximise attention and encourage activities relating to the principle. Secondly, as part of the new Horizon Europe research and innovation funding stream, specific calls for funding should also be released on the research and pilot testing on the EEF principle.

Recommendation 15a): *In order to promote investments in the EEF principle at the EU-level, in the new MFF 2021-2027, ERDF funding must ensure that objectives and priorities are made concerning the analysis and implementation of this principle. In particular, Managing Authorities ought to draft their Operational Programmes in a manner which requires application of the EEF principle. Ecorys will, in its evaluation of all draft Operational Programmes, take stock of the potential for investments in the EEF principle and provide recommendations on how to promote such investments.*

Recommendation 15b): *As part of the new Horizon Europe research and innovation funding stream, specific calls for funding should also be released on the research and pilot testing on the EEF principle.*

6.3. Recommendations on how to further embed the EEF principle principle in EU-level decision making

In line with what has been conveyed in the proposal for this project, here we will consider three different sub-elements in order to provide recommendations on how to further embed the EEF principle principle in decision-making at the EU level. Firstly, we will consider how the EEF principle can be integrated into the EU Better Regulation Guidance and Principles. Secondly, we will explore how the EEF principle has been considered in the National Energy and Climate Plans.

6.3.1. Integrating the EEF principle into the EU Better Regulation Guidance and Principles

The Better Regulation guidelines set out the principles that the European Commission follows when preparing new initiatives and proposals, as well as impact assessments when managing and evaluating existing legislation. The guidelines apply to each phase of the law-making cycle.

It has been recognised in a 2019 JRC report on the EU Better Regulation Agenda that there may be insufficient coverage of certain impacts in the toolbox and guidance[7]. More specifically, the Guidelines have been criticised for their lack of priority given to environmental concerns [92]. Furthermore, it has been said that the rhetoric of the EC is focused much more on burdens and regulatory costs than benefits [93–96]. The real issue is whether the legislation in question ultimately brings benefits that outweigh the costs it generates, not only in economic but also in broader (importantly environmental) terms [94,95]. Indeed, at this point, the EEF principle is not yet included in the Better Regulation Guidance and Principles, and the topic of energy is omitted completely.

In this context, we believe that only a minor text change (yet high in significance) can be achieved in the better regulation guidance and principles. This comes in the form of Chapter 3: Better regulation guidelines on Impact Assessments. Indeed, this will not come as a surprise as in the sections above, we have already reflected on the need to increase the impact assessments and cost-benefit analysis of the EEF principle in various forms of decision making.

Currently, as part of its key requirements, Impact Assessments "must compare the policy options on the basis of their economic, social and environmental impacts (quantified costs and benefits whenever possible) and present these in the IA report". Although we do not believe it would be realistic or feasible to make a specific reference to the EEF principle as part of the key requirements of the Impact Assessments, we believe that there is scope to insert and detail the EEF principle to being considered as a part of the "environmental impacts".

Specifically, a requirement to consider the EEF principle could be included as part of "Question 5: What are the impacts of the different policy options and who will be affected?". Indeed, this could be detailed in p.25 under Chapter 2.5.1 (Identifying all potential impacts of the options). This subchapter details how and what potential impacts must be mapped out, according to their expected magnitude and likelihood and to the specific parties that would be impacted.

[7] https://publications.jrc.ec.europa.eu/repository/bitstream/JRC116035/kjna29691enn.pdf.

Currently, when detailing the classifications for the impacts, under environmental impacts only the following considerations are listed “quality of the environment and combating climate change”. We would therefore propose that that an additional consideration is included, which pays specific regard to whether the EEF principle has been implemented in the decision in the form of “compliance with the EEF principle”.

> ***Recommendation 16:*** *Chapter 3 of the EU Better Regulations Guidance and Principles on Impact Assessments can consider the EEF principle as part of the 5th Question (assessment of impacts of different policy options) by requiring an assessment of whether there has been compliance with the EEF principle.*

6.3.2. Taking stock of the EEF principle in NECPs and recommendation for improvement

As requested in the ToR, this document serves to take stock of the application of the principle by MSs in the final NECPs. In total, all 27 Member State NECPs were analysed. The table below both takes stock of all provisions within the NECPs which are relevant to the EEF principle. All relevant provisions in the NECPs have been extracted and cited. On top of this, the provisions have also been characterised in order to describe the sort of reference/application of the EEF principle.

More specifically, the analysis carried out found that seven Member States have made no reference or commitment to applying the EEF principle in their NECPs. Those countries include Croatia, Czech Republic, France, Greece, Malta, Slovenia and Sweden. This group represents a highly broad geographical, political and socio-economic spread across Europe, thereby it is not possible to attribute any such characteristics to Member states which have failed to give due consideration to the EEF principle.

Another four member states have only provided very minimal reference to the application of the EEF principle in their NECPs in the form of a footnote, serving to state that when considering issues of internal energy market and/or security of energy supply, the importance of the EEF principle will be considered. These Member States include Bulgaria, Estonia, Lithuania and Slovakia (thereby including namely Baltic and eastern states). The majority of Member States do however provide specific reference to the importance of the EEF principle in their NECPs, both in itself and as a means of ensuring compliance with EU energy and climate commitments.

Some Member States have much more elaborate and detailed commitments than others. Countries such as Austria, Finland, Latvia, Ireland, Portugal and Spain have dedicated chapters/sub-chapters to the EEF principle, in which the importance of the principle is explained/integrated into national energy objectives. Furthermore, to varying degrees of preciseness, methods for implementing the EEF principle are also introduced in the NECPs. It is worth noting that Spain is the only Member State which dedicates a specific figure/budget for the implementation of the EEF principle. Portugal makes the implementation of the EEF principle a clear and top priority for its 2030 energy policy objectives. Interestingly, Germany provides reference to the outcome of the consultation with the federal states, who commented on how to better implement the principle. Latvia and Ireland identify and briefly explain a number of concrete sectors in which the EEF principle ought to be applied.

Annex 1 has a comprehensive and detailed overview (in terms of an extensive table) of the integration of the EEF principle in Member State NECPs.

> ***Recommendation 17:*** *To properly account for the EEF principle in future NECPs, it would be crucial that member states break down more clearly how the principle is implemented in all decision-making steps and how this will be ensured and monitored. The European Commission should issue a guidance for this. This should include at least:*
>
> *(1) Detailed information of how policymakers include the EEF principle in their policy making process (How are options compared? What is considered (e.g. multiple benefits, (economic) efficiency potentials)? How is this ensured at all geographical scales? Results of the impact assessment of different scenarios/pathways to determine the optimal contribution of energy efficiency in the NECP (Recommendation 10));*

(2) The removing of barriers for demand-side investments (including the prevention of distorted markets, the provision of capital and information and the reduction of risks and uncertainties;

(3) A consideration of societal challenges (e.g. adequately addressing energy poverty when/by applying the EEF principle);

(4) An advanced and running approach for monitoring and verifying the mechanisms laid out above.

6.3.3. Better integrating the EEF principle into the EU legislation

In 2018, the amending Directive on Energy Efficiency (2018/2002) was agreed to update the policy framework to 2030 and beyond. The new Directive differs from the preceding Energy Efficiency Directive (2012/27/EU) in that there are explicit references to the Energy Efficiency First Principle.

These references appear on two occasions. Firstly, in the second verse of the preamble, which recognises that "The energy efficiency first principle should be taken into account when setting new rules for the supply side and other policy areas". Secondly, in the replacing Article 1 paragraph 1, it is stated that "This Directive contributes to the implementation of the energy efficiency first principle".

Nevertheless, it can be considered that these references to the Energy Efficiency First Principle are rather toothless and do not envisage any enforcement of the implementation of the Principle at national level. The current provisions can be seen as an intention to acknowledge the principle, with no requirements or practical guidance on how to transpose it into national law.

Consequently, in order to strengthen the transposition, enforceability and clarity of the principle, three revisions can be suggested in the revised Energy Efficiency directive.

Recommendation 18: *To ensure that the EEF principle is properly applied at national level, it is recommended that the European Commission provides sufficient guidance on implementing the Energy Efficiency First principle and supports its application in the Energy Efficiency Directive.*

(1) European Commission should take a closer look at the existing EED articles and develop more specific provisions endorsing application of the principle.

(2) In that direction, it would also be good to extract the list of policy areas from chapter 2 of our report, so as to cross-check which of them are already addressed by articles of the existing EED.

(3) And then also look at how specific recommendations of this report could be incorporated either in existing or new EED articles.

ANNEX I: OVERVIEW OF INTEGRATION OF EEF PRINCIPLE IN MEMBER STATE NECPS

This annex presents a comprehensive and detailed overview of the integration of the EEF principle in Member State NECPs. The overview is displayed in the table on the following page.

COUNTRY	TYPE OF REFERENCE	EXTRACT OF REFERENCE	PAGE
Austria	Citing EC recommendation to better implement EEF principle	On 10 September 2019 Austria participated in the 'Technical Workshop for Renewables and Energy Efficiency'. Technical recommendations from EC include… 'Energy efficiency first' the positive effects of energy efficiency on the other areas (internal market, security of supply, decarbonisation) must be demonstrated. It must be shown how the principle is implemented and monitored in Austria.	P58
	Recognition of EEF principle as central to achieving an energy union	Energy efficiency measures are among the best economic measures for preventing greenhouse gas emissions and are high on the agenda in Austria, as well as being a recurring theme of the energy union ('energy efficiency first' principle).	P83
	Commitment to aligning energy policy with EEF principle	In Austria's Climate and Energy Strategy, special emphasis is therefore placed on policies and new technology which may greatly help to improve energy efficiency. This includes, for example, continuously improving the energy efficiency of the building stock (thermal renovation and high standards for new buildings) and focusing on electromobility in transport. These and other initiatives will be stepped up over the coming years in order to comply with the 'energy efficiency first' principle under the Regulation on the Governance of the Energy Union and Climate Action.	P170
Belgium (Wallonia)	Recognition of importance of EEF principle	In addition, in accordance with the "principle of energy efficiency first", Belgium seeks to decrease energy intensity and thus reduce dependence on foreign supplies from sources primary energy. The measures that will be taken in this context are listed in chapter 3.1. (Energetic efficiency).	P115
Belgium (Flanders)	No reference		
Bulgaria	Minimal reference to ensure compliance with EEF principle	Footnote: Internal energy market policy measures must be in line with the principle 'energy efficiency first'.	P152
Croatia	No reference		
Cyprus	Recognition of importance of EEF principle to achieving EE targets	In addition, it should be stressed that improving energy efficiency is a key horizontal priority, as it leads to multiple benefits such as reducing greenhouse gas emissions, reducing energy costs, improving comfort conditions in buildings, increasing added value and employment and improving the competitiveness of businesses. Towards this, the energy efficiency first principle has been taken into account.	48
	Application of the EEF principle in planned policies and Measures	The "Energy Efficiency First Principle" has been considered in the preparation of the final NECP by giving priority to policies and measures that improve the efficiency of the energy system and by taking into account that other decarbonisation measures can be considered only after energy efficiency actions are deemed unfeasible or very costly…. • As a result of energy efficiency measures, the energy supply of Cyprus will be lower in comparison to that of the WEM scenario. This means that energy efficiency has indeed been given priority in comparison, for example, to stronger deployment of renewable energy; • It is particularly important to note that the PPM scenario foresees energy efficiency measures in transport (modal shift towards public and non-motorized transport and electrification of cars)	72-73

COUNTRY	TYPE OF REFERENCE	EXTRACT OF REFERENCE	PAGE
		which involve very significant investments, at substantial levels for the size of the Cypriot economy. This underlines how strongly the Energy Efficiency First principle has been taken into account; • Apart from the cost-effectiveness argument mentioned above, further prioritising demand-side measures such as energy efficiency improvements, and would put Cyprus at risk of not meeting two main Energy Union objectives which are related to energy supply: the renewable energy target and the reduction in emissions of ETS sectors – which in the case of Cyprus is predominantly power generation. Therefore, measures in the electricity supply that have been foreseen in the PPM scenario are indeed those which are absolutely necessary for Cyprus to meet the above-mentioned commitments.	
	Use of EEF principle for analysis of EE in all sectors	The improvement of energy efficiency in all sectors has been examined in the framework of the energy efficiency first principle. The policies and measures set for improving energy efficiency contribute significantly to reducing greenhouse gas emissions.	P105
Czech Republic	No reference		
Denmark	Recognition of importance of EEF principle for ensuring electricity supply security.	Another objective for the future Danish energy system is to make sure that the demand for electricity does not rise to levels that cannot be met by the supply and to make the most efficient energy investments in line with the energy efficiency first principle. Energy efficiency objectives in terms of energy savings in buildings and households and for appliances are described in section 2.2. Reducing demand contributes to the EU's overall energy efficiency target of 32.5 % in 2030.	P58
Estonia	Minimal reference to ensure compliance with EEF principle	Footnote: Energy Security Dimension policies and measures must reflect the principle 'energy efficiency first'	P107
Finland	Dedicated section on explaining the EEF principle and the sectors in which it will be implemented	Finland aims to benefit from the "smart and efficient integrated energy system" approach to implement the idea of "energy efficiency first" principle: Combined generation of heat and power, and related district heating and cooling with smart demand response mechanisms improve energy efficiency, help to increase the share of renewables and link heating with electricity to provide flexibility. Finland has for decades used the potential for aligning energy efficiency and renewable energy policies, linking heating with electricity for flexibility and integrating more renewables in both heating and electricity, and utilising waste heat and waste cold. Bearing in mind the benefits from greater sector coupling through electrification as the energy system decarbonises, the heating/cooling sector is critical, and the use of more renewable sources will be encouraged. Taking overall cost-efficiency into account at the whole energy system level from supply to end use of energy will help to facilitate the "energy efficiency first" -principle also in practice.	P110
France	No reference		

COUNTRY	TYPE OF REFERENCE	EXTRACT OF REFERENCE	PAGE
Germany	Perspectives from Federal States on how to implement EEF principle, as part of public consultation.	Summary of the responses received as part of the public consultation on the Federal Government's integrated National Energy and Climate Plan: Question 12: In your opinion, how and with what measures could the guiding principle of 'Energy Efficiency First' set out in the NECP be implemented? Response: Some stakeholders welcomed the guiding principle of Efficiency First (BL: Saxony, Baden-Württemberg, U: dena, UV: DUH). However, they and other stakeholders also said that the principle of Efficiency First must not in any way prevent energy consumption but instead should reduce inefficient energy consumption (U: dena, ZDH, N.N.; IV: BDEW NGO: DIHK UV: DUH). Other stakeholders called for the principle of Efficiency First to be given top priority (IV: ZVEI; U: N.N. PP: PPx2). Many stakeholders called for an Energy Efficiency Act combining clarity, intelligibility and visibility with minimum red tape (U: dena, ZDH UV: VfW; PP: PPx5). Many stakeholders said that they would like to see efficiency measures implemented ideally on market economy terms (U: dena, IV: BDEW, ZVEI, VIK PP: PP). Other stakeholders felt that energy efficiency should play a role for the entire supply chain (from generation to consumption) (FI: BPIE IV: VKU UV: DUH).	P245
Greece	No reference		
Hungary	Recognising importance of EEF principle and committing to implement the principle in future	In the coming years, one of the key measures of energy efficiency policies will be to apply the principle of 'energy efficiency first' in day-to-day decision-making. Applying the principle of 'energy efficiency first' – as prescribed by Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11 December 2018 on the Governance of the Energy Union and Climate Action – contributes to achieving all of our main energy and climate policy objectives and to improving the competitiveness of the Hungarian economy.	P174
Ireland	Overall recognition and commitment to EEF principle	Ireland is committed to applying the energy efficiency first principle to all proposals, decisions and investments flowing from this Plan.	P12
	Commitment to applying the EEF principle to land-use planning and public transport	In line with the energy efficiency first principle, public transport use and modal shift should be encouraged through efficient planning.	P115
Italy	Minimal reference to ensure compliance with EEF principle	Footnote: Energy Security Dimension policies and measures must reflect the principle 'energy efficiency first'.	P208
Latvia	Target for 2030 to fully implement EEF principle	The objective by 2030 is that the 'energy efficiency first' principle has been fully incorporated into development and policy planning, and into the investment planning and implementation process.	P96
	Acknowledgement of failure of implementing EEF principle	The 'energy efficiency first' principle has not been incorporated into the Latvian policy planning system, and only arbitrarily taken into account in investment planning. Sectoral development takes place when needed by sectors, so more efficient alternatives are often ruled out.	P96

COUNTRY	TYPE OF REFERENCE	EXTRACT OF REFERENCE	PAGE
	Actions and activities to implement EEF principle	‘Energy efficiency first’ means considering, before approving industry planning, policy and investment decisions, whether cost-efficient, technically, economically and environmentally sound alternative energy efficiency measures, for example, cost-effective end-use energy savings, demand response initiatives and more efficient conversion, transmission and distribution of energy, whilst achieving the objectives of those decisions, will ensure the achievement of the objectives of those decisions. It is also recommended that the ‘energy efficiency first’ principle be incorporated into the conditions for the acquisition of funding of EU and public funds (in the measures funded within the scope of EU structural funds and other sources of public funding) and taxation measures, if applicable. Therefore, ensuring improvement of energy efficiency – efficiency of use of energy sources, reduction of use of resources – should be considered when implementing these measures.	P97
Lithuania	Minimal reference to ensure compliance with EEF principle	Footnote: Energy Security Dimension policies and measures must reflect the principle ‘energy efficiency first’.	P147
Luxembourg	Recognition of the importance of the EEF principle & demonstration of (continued) implementation	Energy efficiency is considered a top priority (implementation of the ‘energy efficiency first’ principle enshrined in EU legislation) and is of particular importance for Luxembourg in achieving its energy and climate objectives, given its extremely dynamic economy. In the area of new buildings, Luxembourg is already at the forefront of the implementation of the energy efficiency requirements for residential buildings with virtually zero energy consumption and has successfully decoupled population growth from CO2 emissions. In line with the European ‘energy efficiency first’ principle, Luxembourg intends to continue to pay particular attention to improving energy efficiency in the building sector. By increasing the renovation rate of buildings and using all available smart technologies, this sector has much to offer a climate neutral and competitive economy. As 50% of electricity consumption is in industry, this will also be a focus of energy efficiency policy.	P100
Malta	No reference		
Netherlands	Brief reference to EEF principle being considering in climate policy	The "energy-efficiency first" principle is included as part of the cost-effective reduction of greenhouse gas emissions.	P37
Poland	Brief recognition of importance in executive summary	This document is to produce synergy through the delivery of activities in the five interrelated dimensions of the Energy Union, taking into account the “energy efficiency first” principle.	P18
Portugal	Recognition of importance	Portugal is committed to the principle of ‘Energy Efficiency First’ in decisions on investment projects in the energy sector, with a view to sustainability and cost effectiveness. Experience shows that the challenge of energy efficiency is the same as, or greater than that of renewable energies.	P5

COUNTRY	TYPE OF REFERENCE	EXTRACT OF REFERENCE	PAGE
	Inclusion of EEF principle as 1/8 Portuguese targets for the 2030 horizon	2. PUT ENERGY EFFICIENCY FIRST Reduce the consumption of primary energy in various sectors in a context of sustainability and cost-efficiency, focusing on energy efficiency and the efficient use of resources, prioritising the rehabilitation and renovation of buildings and promoting zero-emissions buildings.	P14
	Establishing EEF principle as central guideline for energy policy	Energy efficiency is one of the most important factors in achieving the transition to a carbon neutral economy, while also generating growth, employment and investment opportunities. This is why energy efficiency is not only an opportunity for development and modernisation but is also viewed as a priority source of energy in the sense that energy that is not produced/consumed is the safest, cleanest and cheapest energy. This vision is in keeping with Community policy as the EU has defined 'Energy efficiency first' to be one of the main guidelines for its energy policy.	P87
Romania	Recognition of EEF principle as a central component of the Energy Union	"The Energy Union" constitutes one of the ten priorities of the current Commission; this objective has been consistently supported ever since the publication of the Energy Union Framework Strategy in that the Commission prepared proposals to deliver on the energy efficiency first principle, support EU global leadership in climate action and renewable energy and provide a fair deal for energy consumers.	P30
	Minimal reference to ensure compliance with EEF principle	Footnote: Energy Security Dimension policies and measures must reflect the principle 'energy efficiency first'.	P111
Slovakia	Minimal reference to ensure compliance with EEF principle	Footnote: Energy Security Dimension policies and measures must reflect the principle 'energy efficiency first'.	P130
Slovenia	No reference		
Spain	Recognition of EEF principle and a core principle within the NECP	'Energy efficiency first' is one of the core principles that has guided the preparation of this Plan. Indeed, the measures envisaged are expected to achieve a 39.5% improvement in energy efficiency by 2030. Specifically, the reduction in primary energy consumption proposed in this INECP is equivalent to improving primary energy intensity by 3.5% each year up to 2030, which will undoubtedly have a positive impact on the Spanish economy as a whole.	P8
	Investments to implement the EEF principle	In total, this INECP will mobilise EUR 83.54 billion of additional investment in energy efficiency, satisfying the 'energy efficiency first' principle that must inform policies to combat climate change. This will require nearly EUR 30 billion of public funds (national and European), in the form of direct public aid and public support for the financing of energy efficiency projects.	P160
Sweden	No reference		

ANNEX II: REFERENCES

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