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ORIGINAL ARTICLE

Conceptualising the energy efficiency first principle: insights from theory and practice

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Abstract The Energy Efficiency First (EE1st) principle has recently been placed onto the political agenda in the European Union (EU). While the general rationale for EE1st is described in EU legislation and supporting literature, a common understanding of the principle's implications for energy-related planning, investment, and policymaking is still missing. Based on an exploratory review of the literature, the objective of this article is to improve the theoretical understanding of EE1st. First, it develops a conceptual framework, describing EE1st as a decision-making principle that prioritises demand-side resources over supply-side alternatives whenever these provide greater value to society in meeting decision objectives. Second, it highlights the unique aspects of EE1st by systematically comparing the principle with associated concepts, such as Integrated Resource Planning. Third, it provides theoretical justification for EE1st by describing the economic rationale behind the principle. Fourth, it outlines policy considerations for its practical implementation. In sum, the EE1st principle is shown to have a compelling theoretical background that can help inform the design of effective policy interventions in order to move from principle to practice.

Keywords Energy Efficiency First · Energy markets · Energy supply · Market failure · Energy policy

Introduction

Energy efficiency is widely recognised as a key resource for achieving various societal objectives related to environment and climate protection, competitiveness, and energy security. Its principal merit lies in the potential it holds to lower both the economic cost and negative environmental side effects of transitions to low-carbon energy systems. To illustrate, Langenheld et al. (2018) find that focusing on thermal building renovations could reduce the cost for reaching long-term greenhouse gas (GHG) reduction targets in the German building sector by 2.5 to 8.2 billion euros per year. Moreover, energy efficiency has been associated with a variety of multiple impacts for consumers and for society at large, including improved air quality and associated health

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effects, energy security, and others (IEA, 2015a; Reuter et al., 2020). Empirical estimates indicate that their monetary impact in the buildings and industry sectors may be 0.5 to 3.5 times higher than the value of energy savings made (Ürge-Vorsatz et al., 2014).

In response, the European Union (EU) has introduced energy and climate policy strategies and measures intended to increase energy efficiency in various sectors. The European Green Deal strategy (European Commission 2019) recognises that energy efficiency is needed to achieve the EU's long-term objective of net-zero GHG emissions by 2050, as defined in the European Climate Law (European Union 2021). Established policy measures in the EU to improve energy efficiency in households, firms, and transportation include minimum energy performance standards, labelling, financial incentives, and others (IEA, 2020). Additional measures focus on efficiency improvements in energy supply, e.g. by reducing losses in electricity networks (Bompard et al., 2020).

Despite this, observers note that the EU is not investing enough in energy efficiency and demand reduction measures relative to the expansion and use of energy supply infrastructures (Bayer, 2015a; Rosenow et al., 2017a). In empirical terms, the IEA (2021) reports that capital expenditures for power generation, network assets, and other fossil fuel supply in Europe amounted to USD 178.8 billion for the year 2020, which is almost double the investment in end-use energy efficiency measures of USD 101.4 billion. In theoretical terms, there has been a long-standing academic debate around the existence and magnitude of the so-called energy efficiency gap (Brown & Wang, 2017), i.e. the deviation between the levels of energy efficiency that appear to make economic sense and the levels actually observed in practice (Gillingham et al., 2018).

To address this apparent imbalance between energy efficiency and supply-side investments, the principle of Energy Efficiency First (EE1st) has recently entered the political debate in the EU. EE1st is generally understood as a guiding principle for energy-related policymaking, planning, and investment. In essence, it is meant to consider and prioritise investments in both demand-side resources (end-use energy efficiency, demand response, etc.) and supply-side energy efficiency whenever these cost less or deliver more value than default energy infrastructure (generation, networks, storage, etc.) (Pató et al., 2019b; Rosenow & Cowart, 2019). Its advocates argue that EE1st can help to avoid lock-in situations with more expensive infrastructures, ensure that energy needs are met using the least-cost alternatives available, and thus ensure a cost-effective decarbonisation of the economy (Bayer, 2015a; Rosenow & Cowart, 2017). The EE1st principle was formally introduced into EU legislation in the Governance Regulation (European Union 2018c), which includes a formal definition and requires Member States to report on the implementation of EE1st in their National Energy and Climate Plans (NECPs).

However, while EE1st has gained traction in the political debate, it is not yet consciously grounded and supported by academic research. Existing material essentially stems from a body of grey literature which tends to be oriented to practitioners (e.g. Bayer et al., 2016a). There is hardly any peer-reviewed, academic literature on the principle (Pató et al., 2019b; Rosenow et al., 2017a). As such, the notion of EE1st lacks conceptual clarity. For instance, it is unclear how the decision between saving and supplying energy should be evaluated in terms of costs and benefits. Moreover, while a variety of policy measures have been proposed to support EE1st (Rosenow & Cowart, 2019; Zondag et al., 2020), these seem to lack a consistent framework that is substantiated by the interdisciplinary literature on energy efficiency and policy (Dunlop, 2019; Gillingham et al., 2009; Saunders et al., 2021).

This lack of conceptual clarity carries the risk that the EE1st principle could become a short-lived slogan that does not make a tangible difference to the status quo of energy-related investment and policymaking in the EU (Coalition for Energy Savings, 2015; Teffer, 2018). In fact, EU Member States do appear to struggle with moving from principle to practice.[1] While the European Commission recently issued dedicated guidelines on the implementation of EE1st (2021), there remains a need for critical scrutiny of the principle to broaden its support base and ensure that it will yield robust policy outcomes.

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[1] A recent assessment of NECPs (European Commission 2020) found that these include few references to the EE1st principle and lack dedicated instruments. Likewise, in a survey of practitioners in the energy field (Schmatzberger and Boll 2020), respondents stressed a lack of expertise, awareness, and understanding of the principle.

Against this background, the objective of this article is to improve the theoretical understanding of EE1st and thus to contribute to changes in policymaking practices in line with this principle. This article's contribution is fourfold: First, it discusses existing notions of EE1st and provides a conceptual framework. Second, it highlights the unique aspects of EE1st by systematically comparing the principle with associated concepts, such as Integrated Resource Planning. Third, it provides theoretical justification for EE1st by describing the economic rationale behind the principle. Fourth, it outlines policy considerations for its practical implementation. The paper concludes with a general summary of the principle and an outlook to further research.

Given the novelty of this subject in academic research, this article is based on an exploratory investigation of the literature, corresponding to a 'narrative review' according to the review types suggested by Sovacool et al. (2018). In addition, the examples in this article refer primarily to energy efficiency in buildings and industry and do not address transportation in detail, even though the EE1st principle could be applied to all energy-using sectors (European Commission 2021).

Definition of Energy Efficiency First

Prior to its formal appearance in EU legislation, grey literature featured multiple definitions of EE1st, with early mentions in Cowart (2014) and Coalition for Energy Savings (2015). Pató et al. (2020a) compare these definitions. In short, EE1st is understood as a decision principle that takes into account the available options for technology adoption and behaviour change, evaluates them against a set of objectives, and implements those that best meet these objectives.[2]

Perhaps the most politically legitimised definition of EE1st is the one in the EU Governance Regulation (European Union 2018c, Art. 2.18): "*energy efficiency first' means taking utmost account in energy planning, and in policy and investment decisions, of alternative cost-efficient energy efficiency measures to make energy demand and energy supply more efficient, in particular by means of cost-effective end-use energy savings, demand response initiatives and more efficient conversion, transmission and distribution of energy, whilst still achieving the objectives of those decisions*'. To enhance the conceptual clarity of EE1st, three particular aspects in this definition are discussed in the following: decision objectives, the scope of so-called resource options, and the actual decision rule. A substantiated definition of EE1st is then presented as a result.

Decision objectives

EE1st is not merely about comparing technology options but about doing so with respect to decision objectives. Conceptually, these can be broken down into energy service and policy objectives (Mandel et al., 2020). Providing energy services can be viewed as the fundamental purpose of energy systems (Droste-Franke et al., 2015), as they are the means for consumers to obtain utility or other beneficial end states (Fell, 2017; Kalt et al., 2019; Swisher et al., 1997).[3] For example, the energy service of space heating is to obtain the end state of thermal comfort (Fell, 2017). Accordingly, energy is frequently referred to as a derived demand, as consumers do not demand electricity and other energy carriers per se, but the services and eventual utility they provide (Sorrell, 2015; Yatchew, 2014). This demand for energy services drives profit-oriented firms to invest in technologies and to supply energy to consumers. It also leads consumers to opt between conversion devices (e.g. heat pumps) and passive systems (e.g. building envelopes) to obtain their desired end states (Kalt et al., 2019).

The energy system is likewise driven by various policy objectives. For example, energy security, energy efficiency, market integration, decarbonisation, and innovation are key elements of EU policy,

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[2] Note that there is no universal definition of energy efficiency per se, and the appropriate definition depends on the problem considered and the academic discipline (Saunders et al., 2021). Generally, a typical definition of energy efficiency is some form of useful output divided by energy input (Schlomann et al., 2015).

[3] Similar to energy efficiency, the term 'energy services' is subject to ambiguities (Fell 2017; Kalt et al., 2019). Fell (2017, p. 137) reviews 27 definitions and proposes the following definition: 'energy services are those functions performed using energy which are means to obtain or facilitate desired end services or states'.

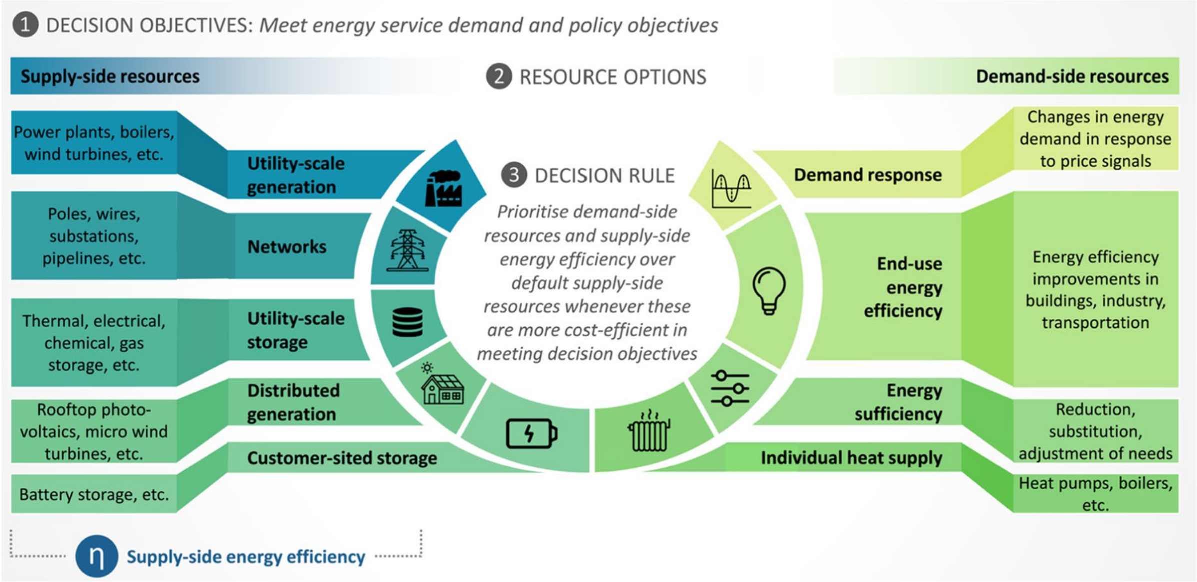

Fig. 1 Conceptual framework of the Energy Efficiency First principle. Source: Mandel et al. (2020), own adjustments

as per the Energy Union framework (European Commission 2015). A more generic set of policy objectives is the 'magical triangle' of security of supply, economic competitiveness, and environmental protection (Yatchew, 2014; Zweifel et al., 2017). From an economic perspective, the principal objective of any public policy is to bring about economic efficiency — typically operationalised as maximising the total surplus received by all members of society (Harris & Roach, 2018; Mankiw, 2017) or a weighting of particular policy objectives (e.g. distributive justice) by means of social welfare function (Mulder, 2021; Weimer & Vining, 2017).[4] Overall, energy service and policy objectives can be conceptualised as the functional units (Hauschild et al., 2018) for any decision related to the EE1st principle, i.e. the qualitative or quantitative aspects for which the trade-off between supplying and saving energy is to be solved.

Resource options

It is fundamental to EE1st that energy decision objectives can be addressed by either supplying or saving energy. For example, the expansion of wind power capacity may cover new or existing demand for energy service and enable GHG savings. However, the same could apply to measures that save energy, such as energy-efficient building envelopes that reduce the electricity demand for heat pumps and thus the need for additional generation. In Europe, these options are increasingly referred to as 'resources' in the context of EE1st (Pató et al., 2020a; Rosenow & Cowart, 2017). The principle thus acknowledges that there are a multitude of resources to achieve decision objectives, epitomised in the statement that 'a kilowatt-hour generated is equivalent to a kilowatt-hour saved' (Eckman, 2011). Figure 1 presents a conceptual framework for EE1st and distinguishes between demand-side and supply-side resources.

Supply-side resources here refer to physical assets of renewable and non-renewable energy conversion, networks, and storage facilities. For a comprehensive review of supply-side resources in electricity, heat, and gas supply, see Guelpa et al. (2019). Note that the framework indicates that supply-side energy efficiency is an overarching supply-side resource. For example, electricity and gas networks hold significant

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[4] Economic efficiency should not be equated with energy efficiency, as pointed out by various economists (Sutherland 1994; Zweifel et al., 2017). The key proposition made is that energy efficiency does not imply that fewer total inputs (capital, labour, research, etc.) are used to meet energy service demand. Instead, inputs are substituted for one another. Thus, policies intended to improve energy efficiency per se are not considered a legitimate objective for public policy per se, unless they contribute to economic efficiency (Golove and Eto 1996; Jaffe and Stavins 1994).

potentials for reductions in losses and leakages (Bompard et al., 2020; European Commission, 2016). Another example of supply-side energy efficiency is the utilisation of waste heat from industrial processes in district heating networks (Papapetrou et al., 2018). Also note the centred position of customer-sited energy storage and individual heat supply in the framework. The former work at the interface of demand and supply. The latter, in energy accounting terms, belong to the demand side as they convert final into useful energy. As discussed in the following chapter, the EE1st principle is relevant to different system boundaries, which leads to different trade-offs between resource options.

Demand-side resources are referred to here as technologies and consumer actions that reduce the quantity and/or temporal pattern of energy use for the same level of utility. These include the following resource options (Pató et al., 2020a; Rosenow & Cowart, 2017):

- End-use energy efficiency means technologies that increase the ratio of energy service output to final energy input while holding the output constant (European Union 2012). For example, light-emitting diodes (LEDs) require significantly less energy per unit of output (light emitted in lumen) than incandescent lamps. In essence, energy-efficient technologies trade off higher initial capital expenditures and lower operating expenses compared to an otherwise equivalent technology that provides the same energy services but uses more energy (Gillingham et al., 2009).
- Demand response means automated or reactive changes of load by consumers from their default consumption patterns in response to market signals (European Union 2019).[5] It primarily addresses load shifting, not necessarily energy demand reduction (Paterakis et al., 2017), and is also referred to as system efficiency in the context of EE1st (Bayer et al., 2016a).
- Energy sufficiency can be conceptualised as quantitative or qualitative changes of utility demanded or energy service delivered that lead to a reduction in final energy demand (Brischke et al., 2015; Sorrell et al., 2020). According to Brischke et al. (2015), this may come in the form of reduction (e.g. smaller appliances), substitution (e.g. using a clothesline instead of a tumble dryer), or adjustment of needs (e.g. raising the cooling temperature of refrigerators). Energy sufficiency is distinct from end-use energy efficiency in that it changes the output level in terms of energy service needs, rather than improving the ratio of output to energy input (Brischke et al., 2015).

The decision rule at the centre of Fig. 1 anticipates the following element of the EE1st definition — how to address the trade-off between supply-side and demand-side resources.

Decision rule

A final key property of the EE1st definition is the decision rule about taking the ‘utmost account’ of ‘cost-efficient’ demand-side measures (see above). These formulations are ambiguous. With regard to the former, we argue that a clear decision rule would require dedicated legal conditions defining when efforts to consider demand-side resources in investment and policymaking are considered adequate to comply with the principle. Alternative definitions of EE1st are more explicit in this regard by referring to a ‘prioritisation’ of demand-side resources whenever these provide greater value than supply-side resources (European Bayer et al., 2016a; Parliament, 2018; Pató et al., 2020a).

With regard to the latter, it is unclear from which perspective cost-efficiency — i.e. a given output metric over net costs — should be evaluated.[6] In general,

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[5] More precisely, demand response programs based on time-of-use tariffs are referred to as implicit demand response. In turn, trading committed and dispatchable flexibility in power markets by single large-scale consumers or through aggregators is referred to as explicit demand response (IRENA 2019; SEDC 2016).

[6] Some definitions of EE1st suggest the term ‘cost-effectiveness’ instead of ‘cost-efficiency’ (e.g. Coalition for Energy Savings 2015). In line with the Governance Regulation (European Union 2018c, Art. 2), we argue in favour of the latter, understanding it as a given output metric over the difference between costs and benefits, i.e. a unit of energy service or utility delivered per euro. This understanding of cost-efficiency is best illustrated by conservation supply curves (e.g. EECA 2019) that enable a ranking of demand- and supply-side resources in terms of specific cost.

there is a common distinction between a private and a societal perspective of investment appraisal (Konstantin & Konstantin, 2018; Ürge-Vorsatz et al., 2016). The private perspective, also referred to as the financial appraisal, is concerned with the profitability of an investment for its owners and investors. In terms of costs, it takes into account the actual cash flows incurred, e.g. the capital costs for a building retrofit. In terms of benefits, it values only private utility gains, e.g. reduced energy bills. Aside from actual financial transactions, this can also include a variety of multiple impacts (IEA, 2015a; Thema et al., 2019)[7] that accrue to the decision-maker alone, e.g. improved indoor comfort. Time preferences and risk are taken into account through a financial discount rate. Transfer payments — that is, direct and indirect taxes as well as subsidies (Konstantin & Konstantin, 2018) — are included as actual cash flows.

In contrast, the societal perspective, also referred to as the economic appraisal, ideally considers all the costs and benefits to society. In addition to multiple impacts that affect private utility alone, this also includes uncompensated costs and benefits that individuals impose on one another, e.g. negative externalities from fossil fuel combustion (Krugman & Wells, 2015). Policy implementation costs are also critical to take into account, e.g. expenses to design, administer, and evaluate policy measures (Ürge-Vorsatz et al., 2016). Costs and benefits are evaluated through a social discount rate, reflecting time preferences and risk from the point of view of society.[8] Transfer payments are usually omitted as they do not affect the real value of a domestic product (Khatib, 2014).

It is widely acknowledged that the trade-off between resource options in terms of cost-efficiency should be primarily addressed from a societal, rather than a private, perspective. This is evident in both official documents on EE1st (European Commission 2021) and in the academic literature (Pató et al., 2020a). The reason for this primacy of the societal perspective is that EE1st is clearly a public policy issue in accordance with EU legislation and overarching policy objectives. There is also scope for EE1st from a dedicated private perspective.[9] Yet from an economic perspective, as will be explained further below, cost-minimising or utility-maximising behaviour by households and firms is only a necessary but not a sufficient condition for social optimality, hence again the primacy of a societal perspective.

In order to accommodate both the societal and the private perspective in the definition of EE1st, we suggest an emphasis on the more flexible concept of system boundaries (Mai et al., 2013). With narrow system boundaries, the principle could, for instance, address the trade-off between end-use energy efficiency and individual heat supply from the private perspective of a building owner. In turn, with extensive system boundaries (e.g. entire EU economy), the trade-off involves a greater range of resource options and decision-makers involved. What perspective is taken depends on the context. For example, policymakers are inclined to adopt a societal perspective for impact assessments while network companies pursuing demand-side actions are driven by a private business rationale. As further discussed in 'Economic rationale for Energy Efficiency First', bridging the gap between private and societal optimality provides an essential rationale for public policy in the scope of EE1st (Boll et al., 2021).

To conclude, the definition of EE1st in the EU Governance Regulation leaves ample scope for interpretation. Based on the critical appraisal in this section, we suggest a slightly modified definition: '*Energy Efficiency First is a decision principle for energy-related planning, investment and policymaking within given system boundaries. It prioritises demand-side resources and supply-side efficiency whenever these are more cost-efficient in meeting decision objectives than default supply-side resources*'. To further characterise the notion of

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[7] The term 'multiple impacts' is used almost interchangeably with the terms 'co-benefits', 'multiple benefits', 'ancillary benefits', 'indirect costs', and 'adverse side-effects' (Thema et al., 2019; Ürge-Vorsatz et al., 2014). Following Ürge-Vorsatz et al. (2016), they are understood here as all benefits and costs related to the implementation of low-carbon energy measures which are not direct private benefits or costs involving a financial transaction.

[8] Mandel et al. (2020) discuss the role of financial and social discount rates in quantitative assessments associated with the EE1st principle, highlighting their respective areas of applications and methods to determine them.

[9] For example, a recurring theme in the EE1st literature is the trade-off between installing a large-capacity heat pump versus improving the building's energy efficiency through thermal renovation (Boll et al., 2021).

EE1st, the following chapter compares the principle with related concepts.

Relation of Energy Efficiency First to similar concepts

The idea of considering demand-side alternatives to supply-side resources is not unique to EE1st. In fact, similar concepts have been practised across the USA in the form of Least-Cost Planning, Integrated Resource Planning, and non-wires solutions. To point out the unique features of EE1st, this chapter compares these concepts in terms of the market structure required,[10] the scope of energy vectors, and the scope of costs and benefits considered when assessing resource options.

Least-Cost Planning

Least-Cost Planning (LCP) emerged in the USA during the oil supply shortages and environmental concerns of the 1970s and 1980s (IEA-DSM, 1996; York & Narum, 1996). The concept was designed for a market structure of vertically integrated monopolies in the power sector, i.e. a single company responsible for all the market activities of generation, networks, and retail. Only few early cases have been reported for LCP at gas utilities (Goldman & Hopkins, 1992). The fundamental idea of LCP was that utility companies can, to some extent, bring about reductions or shifts in consumer energy use by means of energy audits, information provision, and subsidies for energy efficient equipment — generally referred to as demand-side management (DSM) (Gellings, 2017). LCP thus marked a shift from the presumption of steady demand growth and corresponding capacity expansion to a balanced appraisal of both supply-side and demand-side options, with the objective for the utility company to determine a so-called resource plan that provides energy services at least cost (York & Narum, 1996). Costs in this context were essentially the monetary expenses incurred by the customers and the utility company for capital, operation, and DSM programmes — measured by what is known as the total resource cost test.[11]

Integrated Resource Planning

In the 1980s and 1990s, the practice of LCP gradually incorporated environmental and social concerns in its selection of resource plans, henceforth referred to as Integrated Resource Planning (IRP) (Swisher et al., 1997). With this expanded scope, the principal criterion to rank alternative resource plans shifted to the so-called societal cost test. In theory, this test is more comprehensive than the total resource cost test in LCP, as it also takes into account the external costs of air pollution and other selected impacts that have an effect beyond the service area of the utility company (Bhattacharyya, 2019; Woolf et al., 2012). Today, IRP is applied by utility companies in about 30 US states (Wilson & Biewald, 2013). US state requirements for IRP vary in terms of planning horizons, the frequency with which plans must be updated, the resources to be considered, stakeholder involvement, and the extent to which regulators are involved in selecting resource plans (Wilson & Biewald, 2013). States also differ with respect to the principal cost test used for ranking resource plans, thus blurring the lines between LCP and IRP.[12]

The concept of IRP also reached Europe in the 1990s, but did not gain the same relevance as in the USA (Pató et al., 2020a). This was related to the concurrent process of unbundling and liberalisation of power and gas markets in Europe in the 1990s, which formally began with the First Energy Package in 1995

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[10] Market structure here means the extent to which market activities in energy supply (generation, transmission, distribution, retail) are unbundled from others and which activities are conducted on a competitive basis or constitute monopoly businesses (Batlle and Ocaña 2016).

[11] Regulators in the USA have been active since the late 1980s in defining five cost-effectiveness tests to weigh up the costs and benefits of demand-side measures against alternative supply-side options from different perspectives (CPUC 2001; U.S. EPA 2008; Woolf et al., 2012). The total resource cost test is a comparison of DSM implementation and installation costs against the utility's avoided energy- and capacity-related costs. Ideally, this includes direct multiple impacts to customers (e.g. improved comfort levels). In practice, however, these non-monetary aspects are not systematically accounted for by utilities and regulators (Yushchenko and Patel 2017).

[12] Although, in theory, the societal cost test is the preferred decision criterion for IRP, about 71% of US states rely on the less comprehensive total resource cost test, thus neglecting external costs and benefits accruing to society as a whole (Woolf et al., 2012).

Table 1 Comparison of Energy Efficiency First with related concepts

Concept	Time period	Geographical scope	Market structure	Energy vectors	Costs and benefits
Least-Cost Planning (LCP)	1980s–1990s	USA	Vertically integrated monopolies	Electricity, gas	Monetary costs and benefits
Integrated Resource Planning (IRP)	1990s–ongoing	USA	Vertically integrated monopolies	Electricity	Monetary costs and benefits + external costs
Non-wires solutions (NWS)	2000s–ongoing	USA	Regulated network companies	Electricity	Monetary costs and benefits
Energy Efficiency First (EE1st)	2010s–ongoing	European Union	Unbundled monopolies/competitive markets	All energy vectors	All costs and benefits to society

(Thomas et al., 1999). Under this market structure, only the market activities of network planning and operation remained monopoly businesses that are subject to regulatory oversight. Generation and retail were gradually liberalised, i.e. became market- and competition-based activities (Faure-Schuyer et al., 2017). IRP is largely incompatible with this market structure as the concept becomes protracted and complex, the more utilities are unbundled, and the more market activities are subject to competition rather than regulatory oversight (Pató et al., 2020a; York & Narum, 1996). However, IRP can be directly relevant for the regulated monopoly activities of transmission and distribution, a practice referred to as non-wires solutions (NWS) in the USA (Chew et al., 2018; Dyson et al., 2018).[13]

Non-wires solutions

NWS are electric utility investments and operating practices that can defer or replace the need for specific transmission or distribution network projects by consistently reducing the network load in specific grid areas (Stanton, 2015). Similar to LCP and IRP, the practice of NWS is meant to consider all the resources available for providing energy services, including demand response, end-use energy efficiency, storage, and distributed generation. In the USA, driven by state-level regulation and public–private partnerships, there are an increasing number of NWS projects that cost-effectively defer or displace the need for higher-cost network infrastructure investments (Chew et al., 2018). In terms of the costs and benefits considered, NWS practices resemble the total resource cost test originating from LCP. Concerning market structure, NWS works for both vertically integrated utilities and unbundled monopolies with competitive markets as networks remain regulated monopolies in both settings. However, the greater the degree of vertical integration, the greater NWS can leverage demand-side resources to replace or defer supply-side infrastructures, leading back to the original concept of LCP.

Energy Efficiency First

Historically, EE1st emerged in the early 2010s in EU debates related to energy efficiency (Pató et al., 2020a) and is a key element of EU energy policy since 2018.[14] Table 1 indicates the characteristics of EE1st compared to the other concepts. In terms of market structure, EE1st is embedded in the EU's unbundled and liberalised energy markets. LCP, IRP, and NWS can be viewed as one-sided concepts, since regulated utilities initiate the deployment of demand-side resources for specific planning projects. EE1st, on the other hand, can be seen as a multi-sided concept, as it seeks to address all the investment decisions made in the energy system (European Commission 2021), whether initiated by regulated network

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[13] The term NWS is used interchangeably with non-wires alternatives (NWA) (Chew et al., 2018) and non-transmission alternatives (NTA) (Stanton 2015).

[14] EE1st has also been a matter of debate in New Zealand (EECA 2019) and in the province of Ontario in Canada under the label 'Conservation First' (Ministry of Energy 2013).

companies, liberalised generation companies, or individual households and businesses. Hence, in terms of energy vectors, EE1st is inherently holistic. Possible applications have been discussed not only for electricity but also for heat, gas, hydrogen, and others (Zondag et al., 2020). With regard to costs and benefits, as described above, EE1st includes not only all costs and benefits to society, i.e. the monetary costs incurred by corporate and private actors, but also multiple impacts.

To conclude, what makes EE1st unique is its wider scope in terms of market activities, energy vectors, and costs and benefits concerned. The other concepts can be considered as predecessors to EE1st. For example, the idea of NWS — which, in turn, is largely based upon LCP and IRP — is taken up again in the scope of EE1st in the form of planning guidelines and incentives for regulated network companies. However, it is clear that EE1st goes substantially beyond these existing concepts by attempting to integrate energy saving options in all energy-related planning, investment, and policy decisions.

Economic rationale for Energy Efficiency First

While EE1st is broadly acknowledged as a guiding principle for policymaking and energy-related investment in the EU, its exact rationale is not well established in the existing literature.[15] This chapter takes a techno-economic perspective to explain why end-use energy efficiency and other demand-side resources require dedicated policy by referring to aspects of neoclassical, behavioural, and regulatory economics.[16] This perspective is warranted for two reasons. First, market failures are widely acknowledged to the conditions that necessitate state interventions with a view to improving social welfare (Gillingham & Palmer, 2014). Second, the analysis of specific market failures provides an understanding of adequate policies to resolve them (Linares & Labandeira, 2010). We begin with describing the theoretical concept of well-functioning markets. Then, we discuss a range of market failures that provide the principal rationale for state intervention in the scope of EE1st.

Theoretical benchmark of well-functioning markets

The theoretical notion of well-functioning markets provides a benchmark for analysing the performance of real markets (Mulder, 2021). It thus helps determine the extent to which the EE1st principle is applied in the EU energy system. In economic theory, there are a variety of institutional arrangements that can potentially yield socially optimal levels of demand-side and supply-side resources. These range from dictatorship to central planning and markets. Under ideal circumstances, any of these arrangements may achieve the highest possible social welfare (Perman et al., 2011; Ventosa et al., 2016).

In practice, the EU energy system is a market economy, i.e. production and consumption are the result of decentralised decisions by corporate and private actors (Krugman & Wells, 2015). According to economic notions of well-functioning markets, these decisions of actors who act in their own self-interest can lead to outcomes that are collectively beneficial. This state is referred to as economic efficiency, indicating an allocation of capital, labour, energy, and other inputs that maximises social welfare or total surplus (Harris & Roach, 2018; Mankiw, 2017; Zweifel et al., 2017).

In this ideal state, decentralised decisions would yield a mix of resource options that corresponded to society's best interest in line with the EE1st principle. More specifically, individuals and firms would maximise their utility by selecting the least-cost means of obtaining energy services. As such, they would adopt end-use energy efficiency measures and other demand-side resources whenever the incremental capital expenditures and hidden costs are lower than the discounted savings in operating expenses (Allcott & Greenstone, 2012). In turn, energy companies would maximise their profit by reducing their costs of production, using all resource options at their disposal (Mulder, 2021).

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[15] Bayer et al. (2016a) broadly refer to a 'persistent bias towards increasing supply over managing demand'. Rosenow et al. (2017a) argue that demand-side investments are impeded by 'numerous barriers to individual action', while supply-side investments are favoured by 'industry traditions, business models and regulatory practices'.

[16] In general, an interdisciplinary theoretical approach to EE1st should prove valuable (Saunders et al., 2021). In this vein, Edomah et al. (2017) and Wilson and Dowlatabadi (2007) present a range of theoretical frameworks that explain the adoption of demand-side resources by broader institutional and cultural factors.

However, perfect markets and thus a state of economic efficiency require a strict set of conditions to be satisfied (Brown & Wang, 2017; Gunn, 1997; Mulder, 2021):

- Market actors are fully informed about the characteristics of goods and services (perfect information);
- Market exchanges are instantaneous and cost-free (no transaction costs);
- Consumers maximise their utility and producers maximise their profit (rationality);
- No individual producer or consumer can individually influence any market price (competition);
- Any negative or positive externalities are internalised into the marginal social costs (internalisation).

Undoubtedly, the EU and other market economies deviate in many ways from these ideal circumstances (Brown & Wang, 2017; Mulder, 2021) and, as such, do not produce economically efficient resource allocations in line with the EE1st principle.[17] Deviations from this ideal state are broadly referred to as market failures (Convery, 2011; Mankiw, 2017; Perman et al., 2011).

Before reviewing a set of persistent market failures in the EU, it is critical to emphasise the difference between the concepts of market failures and barriers to energy efficiency (Brown & Wang, 2017; Jaffe & Stavins, 1994). Market failures are a general economic concept (e.g. Krugman & Wells, 2015) that indicate deviations from the benchmark of well-functioning markets. Their presence leads to a misallocation of resource options overall, not just of end-use energy efficiency. In turn, barriers to energy efficiency are a concept from the energy literature (Brown, 2001; Sorrell et al., 2000) that impede the adoption of energy-efficient technologies per se. Barriers may or may not be market failures in the traditional economic sense.[18] As we will argue in 'Policy considerations for Energy Efficiency First', this distinction has important implications with a view to applying EE1st in practice.

Market failures

A comprehensive review of all relevant energy-related market failures in the EU economy is beyond the scope of this paper. In the following, we provide examples relevant to understanding how individual market failures distort a level playing field between demand- and supply-side resources. As further discussed in 'Policy considerations for Energy Efficiency First', these market failures provide an essential rationale for government intervention in the scope of the EE1st principle. Our review focuses on the categories of energy market failures, regulatory failures, and behavioural failures. Other categories — including information, innovation, and capital market failures — are thoroughly discussed elsewhere (Brown & Wang, 2017; Gillingham et al., 2018; Saunders et al., 2021).

Energy market failures

Energy market failures are fundamental imperfections in how markets allocate levels of resource options (Brown & Wang, 2017; Gillingham et al., 2009). Note that this is not merely about the internal energy markets for electricity and gas but, more globally, about the 'market for energy services' (Golove & Eto, 1996) as a collection of overlapping markets between the production and ultimate use of energy.[19] Although

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[17] If and to what extent energy efficiency is below optimal deployment levels has been disputed for several decades under the term 'energy efficiency gap' (Hirst and Brown 1990; Jaffe and Stavins 1994). In the context of EE1st, the energy efficiency gap can be defined as the difference between welfare-optimal deployment levels of demand-side resources and the actual deployment levels. A dedicated discussion of the energy efficiency gap is beyond the scope of this paper. Useful discussions on the existence and magnitude of the gap and ways to address it are provided in Brown and Wang (2017); Gerarden et al. (2017); and Gillingham and Palmer (2014).

[18] For example, low energy prices, high technology costs, and uncertainty can be seen as barriers that act against the adoption of energy-efficient technologies. However, in itself, they are characteristics of the normal functioning of markets which does not qualify them as genuine market failures (Linares and Labandeira 2010; Ordonez et al., 2017).

[19] More specifically, on the supply side, profit-oriented firms deliver energy in the form of electricity and other vectors. Some of these firms are rate-regulated while others set prices in response to competitive pressures of the market. On the demand side, consumers purchase energy carriers, adopt technologies for their conversion into useful energy, and make decisions between using and saving energy. In between these

well known, energy market failures are not necessarily well addressed in the EU. Below, we give three particular examples.

Externalities are uncompensated costs or benefits that an individual or firm imposes on others (Krugman & Wells, 2015). By definition, externalities are not reflected in the market price of goods and services and lead to an economically inefficient outcome (Laloux & Rivier, 2016; Mankiw, 2017). Most energy conversion processes generate significant negative externalities, i.e. have an external cost for society. In particular, fossil fuel combustion leads to emissions of carbon dioxide and air pollutants, which have adverse impacts on the climate, human health, and ecosystems (González Ortiz et al., 2020). Negative externalities can also be created by renewable supply-side resources in the form of direct land use, water use, reduced aesthetics, noise, etc. (Sovacool et al., 2021). As the cost-effectiveness of demand-side resources depends on the price of energy, externalities create a systematic bias to their adoption. To correct this market failure and thus contribute to the implementation of EE1st, externalities must be internalised, i.e. added to the market price. This creates an incentive for consumers to save energy and penalises producers for adverse impacts (Allcott & Greenstone, 2012). Pollution permits and Pigouvian taxes are established mechanisms to internalise the externality of emissions and other negative externalities (Mankiw, 2017). However, Smith et al. (2020) estimate that only around 40% of the external costs associated with power and heat production in the EU are internalised through the emissions trading system, carbon taxes, and other corrective measures.

Although EU electricity markets are seen as liberalised in the sense of competitive generators, there remains the market failure of imperfect competition between supply- and demand-side resources. Applying EE1st in this context means acknowledging that demand response and other demand-side resources in various markets (wholesale, balancing, capacity, etc.) can reduce the amount of energy and capacity procured and, in the long term, help to avoid supply-side investments. This may also benefit consumers by lowering clearing prices (Rosenow et al., 2017a). For demand-side resources to contribute to perfect competition in various power markets, market rules are needed in terms of free entry and exit (Krugman & Wells, 2015).[20] In other words, there should be no obstacles in the form of governmental regulations or additional costs associated with leaving the market that prevent individuals and aggregators from entering the market and providing their services. However, market access is still restricted for demand-side resources and its aggregators in various EU power markets and value streams (Pató et al., 2019b; smartEn, 2020). Aside from electricity markets, imperfect competition is also present in district heating systems. Market access for third-party waste heat providers in district heating systems could improve supply-side efficiency but is likewise impeded by market access restrictions (Bacquet et al., 2021; Holzleitner et al., 2020).

Average-cost pricing is another pervasive energy market failure (Brown, 2001; Gillingham et al., 2009). From an economic viewpoint, price signals are efficient if they reflect the marginal cost of supply, i.e. the costs of generating and transmitting an additional unit of energy. Common consumer prices, however, average these marginal costs over a period of months, thus concealing short-term dynamics. This leads to underuse or overuse of energy relative to the economic optimum: if average prices are lower than the marginal cost at a certain point in time, consumers are encouraged to overuse energy with respect to the economic optimum, and vice versa (Gillingham et al., 2009). As a result, generation and network capacities may be used more than is socially optimal. Time-of-use (TOU) pricing can address this market failure by bringing marginal costs in line with consumers' willingness to pay. This makes them an important enabler of implicit demand response in line with the EE1st principle. By shifting their demand to off-peak or lower-price time intervals, consumers can reduce their energy expenses, and investments in generation or network infrastructures can be deferred (IRENA,

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Footnote 19 (continued)
two ends lies a spectrum of manufacturers, vendors, and retailers that influence these transactions (Golove and Eto 1996).

[20] To be precise, according to economic theory, free entry and exit is not strictly a necessary condition for perfect competition, but a common feature of most perfectly competitive industries (Krugman and Wells 2015).

2019).[21] In practice, TOU tariffs are increasingly being adopted for electricity supply in most EU countries. However, obstacles to their widespread adoption remain (ACER/CEER 2021; Eid et al., 2016).

Regulatory failures

In the unbundled EU power and gas markets, transmission and distribution (T&D) constitute monopoly businesses, which is why they are subject to regulation by regulatory authorities (Batlle & Ocaña, 2016). To comply with the EE1st principle, it is widely argued that regulated utilities should take systematic account of demand-side resources in their system planning and operation, similar to the concept of NWS described above (Bayer, 2015b; Pató et al., 2019b). There is comprehensive evidence from the USA that demand-side resources implemented through utility-managed DSM programmes can be cost-effective alternatives to traditional T&D network infrastructure investment (Chew et al., 2018; Neme & Grevatt, 2015). However, in the EU, network infrastructure investment tends to be carried out without systematic consideration of lower-cost demand-side alternatives (Rosenow & Cowart, 2019).

This lack of consideration can be classified as regulatory failure. Regulatory authorities are said to fail when they do not produce the outcomes stipulated in their mandates (Baldwin et al., 2012). Regulators of T&D companies in the EU are instructed to minimise the cost of providing energy services while ensuring a satisfactory quality of supply and system reliability (Laloux & Rivier, 2016). To steer regulated utilities towards systematically considering demand-side resources, regulatory authorities can use extrinsic and intrinsic mechanisms in the form of planning guidelines and incentive structures, respectively (Pató et al., 2019b; Thomas et al., 1999). Guidelines can range from legal provisions to force systematic consideration of demand-side resources in an integrated cost–benefit analysis to procedures that utilities can adopt voluntarily. Such requirements can prevent the overestimation of energy demand, and hence superfluous investments in energy infrastructure (Petroula et al., 2016).

Besides guidelines, regulated utilities need to be intrinsically motivated to consider demand-side resources in their planning practices. As noted by Thomas et al. (1999), the strongest incentive for regulated utilities to implement DSM actions is the possibility of increased profit. If the financial benefit of avoided network use is greater than DSM implementation costs and lost revenue due to reduced sales, such measures are likely to be carried out. The ways in which demand-side actions influence a utility's profit depend largely on the remuneration schemes or price control regimes prescribed by regulators. The remuneration schemes traditionally imposed on power and gas network utilities have been associated with adverse effects on the cost of energy supply and thus regulatory failure.

Cost-of-service remuneration, also known as rate-of-return regulation or cost-plus regulation, is widely seen to result in the regulatory failure of moral hazard (Joskow, 2014; Mulder, 2021).[22] In this remuneration scheme, T&D companies have no incentive to relieve network investments through DSM actions because all actual costs are reimbursed through the tariffs charged to consumers. In other words, demand-side actions do not pay off as they cannot increase profits for the T&D company. Rate-of-return regulation may also give the company an incentive to over-invest in supply infrastructure if the allowed rate of return exceeds the actual costs of capital in the capital market. This so-called gold plating (Gómez, 2016; Mulder, 2021) is formally referred to as the *Averch-Johnson effect* (Averch & Johnson, 1962).

These well-known problems with cost-of-service regulation have lead regulators in the EU to rely on revenue cap regulation for T&D companies (CEER, 2020). It largely solves the regulatory failure of moral hazard as the regulator sets a maximum allowed revenue ('revenue cap') that the T&D company can charge over a regulatory period. This creates an incentive for the company to reduce costs below the cap as it will retain as profit any difference between

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[21] To illustrate, the French Tempo tariff, a form of TOU pricing launched in the 1990s, has been found to have reduced the national peak load by about 4%, with households shifting about 6 GW of load daily (Rosenow et al., 2016).

[22] In economic theory, moral hazard means the distortion of incentives for effort to lower costs when someone else bears the costs of the lack of care or effort (Krugman and Wells 2015).

the cap and its actual costs. Cost savings are gradually passed on to consumers with the periodical review of the cap (Mulder, 2021; Rious & Rosetto, 2018b). While a T&D company under cost-of-service remuneration is incentivised to use capital-intensive solutions to solve network congestions, a company under revenue cap regulation may work towards reducing line losses in terms of supply-side energy efficiency (Mulder, 2021).

However, it is increasingly recognised that classic revenue cap regulation alone does not sufficiently incentivise T&D companies to make use of demand-side resources in system operation and planning. This regulatory failure can be broadly described as X-inefficiency, i.e. the notion that regulated companies do not achieve the minimum costs that are technically feasible (Weimer & Vining, 2017). Pató et al. (2019a) suggest that, in the definition of the revenue cap for the regulatory period, T&D companies should receive a rate of return on their avoided capital expenditures in order to make the financial incentives for demand-side resources comparable to investment in traditional network assets. Referred to as TOTEX allowances (‘total expenditures’) (Rious & Rosetto, 2018b), companies still have the incentive from the revenue cap to reduce their overall costs, but have a stronger incentive to also consider demand-side resources (Pató et al., 2021).

Rious and Rosetto (2018a) further point out that T&D companies may view demand-side resources as immature and risky, raising the need for innovation funding to trigger such activities. Finally, the deployment of demand-side resources could be included as an output in so-called performance-based regulation (Pató et al., 2019a; Rious & Rosetto, 2018b), making T&D companies subject to a reward-penalty scheme associated with the outputs delivered. In sum, more research is needed to determine effective remuneration schemes for T&D companies that deliver demand-side resources in line with the EE1st principle, and to discuss the limitations of these regulatory approaches in terms of the technical expertise and financial means required as well as unintended side effects.

Behavioural failures

Besides energy market and regulatory failures, recent literature from the discipline of behavioural economics indicates behavioural failures as another significant market failure that leads to an economic imbalance between demand- and supply-side resources (Gillingham & Palmer, 2014; Häckel et al., 2017; Saunders et al., 2021). As noted above, one condition for markets to reach economic efficiency is that decision-makers act rationally. Producers maximise profit while consumers maximise utility, i.e. the value they attach to goods and services (Mankiw, 2017).

On the supply side, the assumption of rational producers may hold, for example, in the case of electricity wholesale markets where the only option for producers to maximise their profits is to choose an optimal mix of capital, labour, and other inputs (Mulder, 2021). On the other hand, there is growing evidence that consumers do not make consistent and systematic choices in the sense of rationality.[23] Even if provided with perfect information, they exhibit biases, heuristics, and other irrational tendencies in their energy-related decisions (Frederiks et al., 2015; Madrian, 2014). Behavioural failures have been generally defined as deviations in an actor’s behaviour from rational choice theory (Shogren & Taylor, 2008). More systematically, Gillingham et al. (2018) define them as ‘*any feature of decision-making that leads the consumer to exhibit a deviation between the utility at the time of the decision – known as decision utility – and the utility at the time when the consequences of the decision occur* [known as expected utility]’.

In practice, well over twenty-five behavioural failures have been identified as relevant to economic decision-making (Shogren & Taylor, 2008).[24] To

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[23] Implicit discount rates (IDRs) are an established metric to make these irrationalities and other market imperfections visible (Schleich et al., 2016). However, as various authors contend (Allcott and Greenstone 2012; Stadelmann 2017), IDRs typically do not correctly factor in rational decision variables that are part of the individual’s utility function and thus reflect a *privately optimal* decision. Such decision variables include specific preferences (e.g. high rates of time preference, subjective risk, and uncertainty considerations) and confounding variables that influence purchase decisions (e.g. hidden costs for finding and installing a more energy-efficient product).

[24] The reason why behavioural failures occur at all is being investigated in neuroeconomics, attempting to understand the neural pathways that control how consumers make decisions (Fehr and Rangel 2011; Gillingham and Palmer 2014). Other authors associate them with lifestyles, social practices, and other structures that individuals act in (Thomas et al., 2019).

illustrate, it is widely acknowledged that consumers exhibit bounded rationality, meaning limited cognitive abilities to process and evaluate all information available to make rational choices (Madrian, 2014; Shogren & Taylor, 2008). As a result, they rely on a sub-set of choice alternatives and follow simple rules-of-thumb heuristics to accelerate the decision-making process (Bhattacharyya, 2019). Simplification strategies may help reduce cognitive overload and facilitate more effective energy-related decision-making (Frederiks et al., 2015). For example, positive experiences have been made with so-called logbooks provided to building owners as a comprehensible digital repository of possibly cost-effective thermal renovation measures (Pató et al., 2020b).

Another example of behavioural failure is loss aversion, i.e. the notion that consumers value the impact of losses more than that of gains (Gillingham & Palmer, 2014; Häckel et al., 2017). Investing in end-use energy efficiency measures is a risky decision for consumers due to the uncertainty surrounding market prices, policies, and the long-term financial payoffs (Frederiks et al., 2015; Hirst & Brown, 1990). When loss aversion is present, consumers may refrain from engaging in otherwise cost-effective investments because they attach too much weight to the losses associated with them — whether from possible negative payoffs or the loss of the initial capital expenditure itself (Schleich et al., 2016). To address loss aversion, energy savings insurances or guarantees could be promoted to reduce the likelihood of negative payoffs, while presenting novel business cases for insurance companies (Häckel et al., 2017).

Overall, behavioural failures create a systematic bias in the adoption of supply- and demand-side resources. While producers consistently invest in power plants, storage facilities, and other assets whenever there is a robust chance of profit, consumers are impeded from investing in otherwise cost-effective energy efficiency measures because of their bounded rationality and other behavioural failures. Fostering the EE1st principle would mean systematically addressing these imperfections in order to move closer to the theoretical benchmark of well-functioning markets. Government intervention is generally considered legitimate to address behavioural failures, given that they are systematic and pervasive biases to decision-making (Gillingham et al., 2018; Häckel et al., 2017). Allcott and Mullainathan (2010) hold that some behaviourally informed policies can be just as effective as price-based policies. However, which behavioural anomalies qualify as genuine behavioural failures and therefore warrant government intervention has not gone unchallenged (Gillingham et al., 2018). Moreover, most work focuses on the residential sector, with much less attention given to possible behavioural failures in the commercial and industrial sectors (Gerarden et al., 2017).

Policy considerations for Energy Efficiency First

In recent years, a growing body of literature has outlined how EE1st as a general principle could be put into practice. Rosenow and Cowart (2019) present four steps for applying EE1st. These include *planning* (e.g. recognising the value of multiple impacts in EU impact assessments); *targeted energy efficiency policies* (e.g. building codes); *infrastructure decision rules* (e.g. performance-based regulation); and *compliance and review* (e.g. periodic reviews of targets). Bayer et al. (2016a) refer to similar steps, stressing also the aspect of *finance* (e.g. EE1st as a guiding principle for allocation of EU funds). Perhaps most prominently, the European Commission's guidelines on EE1st (European Commission 2021), based on the principle's definition in the Governance Regulation (European Union 2018c), refer to *planning*, *policy*, and *investment* decisions to be addressed in the scope of EE1st, without clearly delineating these terms.

It is evident that there are various aspects to EE1st and that its implementation currently lacks a theoretically substantiated and widely acknowledged framework for Member States to act upon. In this chapter, we first focus on the aspect of 'targeted energy efficiency policies' (Rosenow & Cowart, 2019), also referred to as 'delivering' (Bayer et al., 2016a) or 'incentivising EE1st' (European Commission 2021). In other words, what policy instruments could be selected for consumers and producers to invest in and operate their assets in line with the EE1st principle. Based on the theoretical background presented above, we first propose a conceptual distinction between wider policies based on the Energy Efficiency First principle (EE1st policies) and energy efficiency policies (EE policies). Our key proposition is that EE1st policies differ from traditional EE policies (e.g. standards) in that the former address the interplay between resource options and corresponding market failures, rather than promoting end-use energy efficiency per se. Second, we focus on the relevance of the EE1st principle in overarching policy formulation, i.e. the process by which policies are designed within government, through both strategic planning and technical analysis (Birkland, 2020).

Policy instruments

The EU and its Member States have a well-established package of policy instruments dedicated to improving energy efficiency in various sectors (IEA, 2020). Numerous review articles (Bertoldi, 2020; Del Solà et al., 2021; Markandya et al., 2015; Shen et al., 2016; Trotta et al., 2018) and databases (ODYSSEE-MURE, 2022; IEA, 2015b) provide different classifications of these instruments. For example, Markandya et al. (2015) distinguish between (i) command and control approaches (e.g. building codes), (ii) price instruments (e.g. grants), and (iii) information instruments (e.g. labels). More comprehensively, Bertoldi (2020) classifies energy efficiency policies as (i) regulatory (e.g. standards), (ii) financial and fiscal (e.g. soft loans), (iii) information and awareness (e.g. information campaigns), (iv) qualification and training (e.g. capacity building), (v) market-based (e.g. energy efficiency obligation schemes), (vi) voluntary action (e.g. voluntary certification), and (vii) infrastructure investment (e.g. smart meter roll-out).

What is notable about these policy instruments is that they are justified predominantly on the grounds of barriers to energy efficiency (Bertoldi, 2020; Cattaneo, 2019; Markandya et al., 2015), not all of which are market failures. As proposed in the 'Economic rationale for Energy Efficiency First', there is a critical difference between the two concepts. The former impede the adoption of end-use energy efficiency as one particular resource option, while the latter affect the competition or *level playing field* between demand- and supply-side resources overall. To illustrate, a common justification for grants and tax incentives as financial instruments are high upfront costs, scarcity of private capital, and perceived risk (Bertoldi et al., 2021). None of these barriers constitutes genuine market failures (Linares & Labandeira, 2010). Likewise, minimum energy performance standards and building codes are not directed towards a specific market failure, but a market outcome (Sutherland, 1996). We suggest that instruments targeting barriers should be referred to as energy efficiency policies (EE policies) because they are aimed at reducing energy demand, rather than explicitly addressing the interplay between resource options.

In turn, based on the definition developed in 'Definition of Energy Efficiency First', we believe there is a justification for framing policies for EE1st policies on the grounds of market failure. If each market failure was addressed by one or several policy instruments, energy system investments and operation would correspond to the theoretical benchmark of well-functioning markets and thus, according to economic theory, maximise welfare in line with the EE1st principle. For instance, the market failure of imperfect competition calls for market rules that treat demand-side resources on an equal competitive footing with supply. Negative externalities can be addressed by Pigouvian taxes or cap-and-trade instruments, thus incentivising end-use energy efficiency while dis-incentivising adverse energy supply. The regulatory failure of X-inefficiency requires intricate design changes to regulatory price control regimes, including TOTEX allowances and performance-based incentives. Table 2 compares EE1st and EE policies. Note that this distinction is more conceptual than practical, given the frequent overlap between the concepts of market failures and barriers.[25]

Hence, as expressed by Pató et al. (2019b), EE1st policies are *more* and *less* than traditional EE policies at the same time. They are 'more' than EE policies in that the logic of addressing market failures involves areas of energy policy that are not themselves primarily aimed at reducing energy use (e.g. market access rules).[26] They are 'less' than EE policies in that they aim to establish a level playing field between demand- and supply-side resources, rather than commanding the adoption of energy-efficient technologies

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[25] For example, information instruments like labels and audits could be interpreted as both EE1st and EE policies because the underlying issue of imperfect information constitutes both a common barrier to energy efficiency (Cattaneo 2019) and a general market failure as per economic theory (Brown and Wang 2017).

[26] With few exceptions (e.g. Warren 2019), such policy instruments do not yet seem to be consciously addressed in the research literature on energy efficiency policy, but typically associated with supply-side or renewable energy policy (e.g. Edenhofer et al., 2013).

Table 2 Difference between Energy Efficiency First and energy efficiency policies

	Energy Efficiency First (EE1st) policies	Energy efficiency (EE) policies
Rationale	*Market failures* | Establish a level playing field between demand- and supply-side resources by addressing fundamental market imperfections	*Barriers to energy efficiency* | Contribute to welfare-optimal and equitable levels of energy efficiency by addressing barriers that are not necessarily market failures
Scope	*Multilateral* | Policies to address the economic imbalance between demand and supply where energy efficiency is one possible market outcome	*Unilateral* | Policies to enhance energy efficiency and to reduce energy demand per se
Example	Market access rules for demand response in power markets to address the energy market failure of imperfect competition	Grants for energy-efficient building renovations to address the barrier of high upfront costs
Limitations	Political and jurisdictional constraints, distributional concerns	Transaction and policy enforcement cost, rebound effects, free-rider effects, consumer heterogeneity

or behaviour as a market outcome (European Commission 2021).

In designing a sound package of policy instruments (Kern et al., 2017; Rosenow et al., 2017b), EE1st policies and traditional EE policies should not be seen as mutually exclusive, but as complementary in nature. Standards, subsidies, and other established EE policies are generally found to be effective in bringing about energy savings (ODYSSEE-MURE, 2022), while contributing to an equitable distribution of wealth and income (Ordonez et al., 2017). In return, they are frequently associated with rebound and free-rider effects, relatively high policy implementation costs, and the issue of heterogeneous consumer properties (Gillingham et al., 2018). This has led to some scepticism among economists about their cost-effectiveness from a societal viewpoint (Allcott & Greenstone, 2012; Sutherland, 1996).[27]

A broad consideration of EE1st policies in the policy mix could fill important gaps in the scope of energy efficiency policy and contribute to welfare-optimal levels of resource options. At the same time, it has to be taken into account that, in practice, addressing each market failure through one or several EE1st policies is limited by political economy constraints. These include jurisdictional limitations, political inertia, incomplete scientific evidence, and other issues (Fischer et al., 2020; Jenkins, 2014). For instance, a rigorous implementation of carbon pricing across the EU's building and transportation sectors would have a disproportionate effect on low-income households and thus raise distributional concerns that are likely to result in significant political opposition (Thomas et al., 2021).

In sum, based on the theoretical background presented in 'Definition of Energy Efficiency First' and 'Economic rationale for Energy Efficiency First', we consider the defining feature of policies for Energy Efficiency First to be the removal of market failures that are not just barriers to energy efficiency. Considering such EE1st policies would be an important complement to the existing scope of energy efficiency policies. In addition to dedicated policy instruments, the debate around EE1st has been accompanied by a renewed interest in the process of policy formulation.

Policy formulation

The process of policy formulation establishes the wider context in which policy instruments are designed and implemented (Birkland, 2020; Turnpenny et al., 2015). In this section, we touch upon three aspects particularly relevant to implementing the EE1st principle. First, there is the need to integrate long-term policy strategies. Strategies such as the NECPs are critical to an effective economic transformation in line with GHG reductions, security of supply, and other policy objectives. Acknowledging the EE1st principle in this context means providing, wherever possible, integrated strategies concerning all technically feasible resource options. In practice,

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[27] In a recent meta-analysis, Gillingham et al. (2018) found that the cost-effectiveness of EE policies ranges from 1.1 cent for information programmes to 47.9 US cents and higher per kilowatt-hour for energy savings subsidies. Some of these policies are thus not cost-effective or welfare-enhancing relative to the marginal cost of energy.

however, the landscape of strategies set out in EU legislation tends to be fragmented into 'silos of policy-making' (Boll et al., 2021). This carries the risk that strategies are not internally coherent and thus fail to deliver the most cost-efficient resources to meeting energy service needs.

To illustrate, the Energy Efficiency Directive (European Union 2012, 2018a, Art. 14) requires Member States to carry out 'comprehensive assessments' of the potential for efficient district heating and cooling. With respect to EE1st, these assessments fall short in terms of integrating end-use energy efficiency and other demand-side resources among the options to be considered (Pató et al., 2021). In parallel, the 'long-term renovation strategies' required under the Energy Performance of Buildings Directive (European Union 2018b, Art. 2a) are intended to promote the renovation of residential and non-residential buildings, but do not explicitly factor in the range of possible supply-side resources. Boll et al. (2021) suggest the joint preparation of these two strategies to ensure coherent quantitative projections and an integrated appraisal of resource options, and thus to achieve robust policy outcomes.

Second, EE1st needs to be consciously considered in computerised models, cost–benefit analysis, and other tools of policy formulation (Turnpenny et al., 2015). At the EU level, before introducing a new legislative proposal, the European Commission estimates the potential economic, social, and environmental impacts of alternative policy options in a model-based impact assessment. Acknowledging EE1st in this process means evaluating costs and benefits primarily from a societal rather than a private perspective in order to enable a fair comparison of resources (Bayer et al., 2016b).

As set out in the 'Definition of Energy Efficiency First', besides revisiting the discount rates used for demand- vs. supply-side resources (Hermelink & Jager, 2015), adopting a societal perspective also requires determining the wide range of multiple impacts that go beyond private utility gains (Fawcett & Killip, 2019). In practice, for example, Shnapp et al. (2020) argue that cost-optimal levels of building energy performance requirements under the Energy Performance of Buildings Directive (European Union 2018b) should properly factor in multiple impacts to both individuals (e.g. comfort gains) *and* society at large (e.g. air pollution reductions) in order to capture the true value of end-use energy efficiency, and thus to legitimise more ambitious building codes.[28]

Finally, another aspect relevant to policy formulation in line with EE1st is to review the causal model underlying policy instruments, i.e. the cause-impact relationship to both desired and undesired outcomes (Birkland, 2020). A frequently cited case (Boll et al., 2021; Pató et al., 2021) is the provision of public funding for new or upgraded renewable heating installations that does not take into account the energy performance of the building envelope as an eligibility criterion. This may result in an unintended outcome in the sense that the systems installed are over-dimensioned in terms of their rated capacity, resulting in higher heating costs than if the building had also undergone an upgrade of the thermal envelope. Proponents of EE1st have been arguing that public funding for heating, air conditioning, and other technical building systems should be contingent on the building having high levels of energy performance. This so-called fabric first idea has been practised, for instance, in Ireland, where the government provides grants for heat pump systems only if the building complies with a minimum level of energy performance (Pató et al., 2020b).

Note that it is simplistic to assume that policy formulation can proceed in a fully logical, comprehensive, and purposive manner. In practice, governments will continue to be faced with incomplete information, uncertainty, pressure from interest groups, and other constraints (Hill & Varone, 2021; Weimer & Vining, 2017). These phenomena influencing policy formulation can be conceptualised as government failure (Weimer & Vining, 2017), similar to the idea of regulatory failure associated with regulatory authorities described above. In summary, policy design for EE1st should be informed not only by an

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[28] Policymakers and other practitioners at the EU level seem to lack expertise, inter alia, on how to incorporate multiple impacts in policy formulation and related impact assessments (Schmatzberger and Boll 2020). This is also reflected at the national level where the European Commission (2020) criticised a lack of systematic consideration of 'co-benefits' in Member States' NECPs. At the local level, a similar indifference to multiple impacts has been observed in regional development plans (Oikonomou and Eichhammer 2021). In response, there have been efforts to formulate guidance on the proper comparison of resource options in the scope of EE1st (Mandel et al., 2020).

understanding of market failure but of government failure as well.

Conclusion

The EE1st principle has recently been gaining momentum in EU energy and climate policy. However, some of its key aspects and implications for policymaking remain unclear, with the associated risk that EE1st remains merely a slogan without tangible impact on energy-related investment, planning, and policymaking. This article set out to address four aspects within the current debate around EE1st.

First, we proposed a conceptual framework for the EE1st principle, emphasising the role of decision objectives, resource options, and the overall decision rule therein. EE1st is thus theorised as a decision principle that prioritises demand-side resources and supply-side energy efficiency over default supply-side resources whenever they provide greater value to society in meeting decision objectives. An important line of inquiry is how the notion of multiple impacts can be integrated into established economic concepts of private utility and societal welfare and, subsequently, how these can be operationalised for quantitative and model-based assessments.

Second, we addressed the question of how EE1st differs from related planning concepts that consider end-use energy efficiency and other demand-side resources alongside supply infrastructure expansion and operation. EE1st is found to be a unique concept in this regard. As it is embedded in the EU's unbundled and liberalised energy markets, it relies on a multitude of decision-makers and addresses not only electricity but also all energy vectors. An associated feature is its focus on the societal perspective, making it a principle of public policy rather than only regulated utility business.

Third, we demonstrated that EE1st can be justified as a guiding principle on the grounds of economic efficiency and the theoretical benchmark of well-functioning markets. Relevant market failures were presented that help explain why the EU market economy does not yield welfare-optimal levels of demand-side resources in line with the EE1st principle. While energy market failures are a well-established feature of the energy literature, regulatory failures have so far received little attention with a view to exploring how to incorporate demand-side resources in the system planning and operation of regulated network companies. Likewise, as is the case for behavioural failures, more research is warranted to match specific policy approaches to the individual failures. In addition to the existing literature on barriers to energy efficiency, the concept of EE1st would benefit from an exhaustive account of genuine market failures as per economic theory. Such investigations are logically prior to questions of how particular policies should be designed (Sanstad & Howarth, 1994).

Fourth, we outlined possibilities for how EE1st as a theoretical decision principle could be practically implemented in the EU. Our key proposition is that EE1st policies (e.g. market access rules) differ from traditional energy efficiency policies (e.g. minimum energy performance standards) in that the former aim to level the playing field between resource options, rather than promoting energy-saving measures per se. As such, applying the EE1st principle calls for a broader policy response that goes beyond the portfolio of established energy efficiency policies — including performance-based regulation for network companies, dynamic pricing, behaviourally informed policies, and other instruments. At the same time, given the range of practical constraints, traditional energy efficiency policies like standards and subsidies must remain a critical element of the policy framework at EU and Member State levels.

Apart from dedicated instruments, we also highlighted the need for thorough consideration of the EE1st principle in the policy formulation process. Strategic planning within government is a key issue. Combining sector-specific strategies into integrated holistic ones that address all the technically feasible resource options could help achieve robust policy outcomes. Another important aspect of policy formulation is the adoption of a genuinely societal perspective in ex ante impact assessments and related energy system models. This involves the rigorous assessment of multiple impacts as well as the proper use of discount rates. EE1st also needs to be a guiding principle in the causal logic underlying policy instruments, e.g. when designing grants, loans, and other forms of public funding.

To conclude, the EE1st principle is found to have a compelling theoretical background. This knowledge can help guide policymakers and regulators in supporting and enabling the application of the principle in practice. Long-term strategies and policymaking in the EU and its Member States will show how thoroughly the principle is taken into account.

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Declarations

Conflict of interest The authors declare no competing interests.

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