EERA
European Energy Research Alliance

Energy Demand Reduction as part of the Clean Energy Transition in Europe:

Research and Policy Strategies

About EERA

The European Energy Research Alliance (EERA) is the association of European public research centres and universities active in low-carbon energy research. EERA pursues the mission of catalysing European energy research for a climate-neutral society by 2050. Bringing together more than 250 organisations from 30 countries, EERA is Europe's largest energy research community. EERA coordinates its research activities through 18 Joint Programmes and is a key player in the European Union's Strategic Energy Technology (SET) Plan.

ISBN: 978-2-931174-04-3

Citation: EERA, 2023, Energy demand reduction as part of the clean energy transition in Europe: Research and policy strategies.

Available for download: www.eera-set.eu

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Acknowledgements: Valuable review and feedback were provided by Maria Luisa Fernández Vanoni (EERA), Rosita Zilli (EERA), Karina Veum (TNO), Guillermo Borragán Pedraz (VITO)

Language editor: Moira Bluer

Design: Marjolaine Bergonnier

Date: October 2023

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List of abbreviations and acronyms

ABM	Agent-based modelling
AI	Artificial intelligence
AR	Assessment report
ASI	Avoid-Shift-Improve
bcm	Billion cubic metres
BECCS	Bioenergy with carbon capture and storage
BEMS	Building energy management systems
CCS	Carbon capture and storage
CCU	Carbon capture and utilisation
CEC	Citizen energy community
CET	Clean energy transition
CETP	Clean Energy Transition Partnership
CRM	Critical raw material
CRMA	Critical Raw Materials Act
DLS	Decent living standard
DR	Demand-response
EC	Energy community
EED	Energy Efficiency Directive
EERA	European Energy Research Alliance
EJ	Exajoule
EMD	Electricity Market Design
EPBD	Energy Performance of Buildings Directive
EU	European Union
ETS	Emissions Trading System
FEC	Final energy consumption
GJ	Gigajoule
GDP	Gross domestic product
GHG	Greenhouse gas
HVAC	Heating, ventilation and air conditioning
IAM	Integrated assessment modelling

ICT	Information and communication technology
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
IRA	Inflation Reduction Act
IoT	Internet of Things
IWG	Implementation working group
JP	Joint Programme
JP EEIP	Joint Programme on Energy Efficiency for Industrial Processes
LED	Low Energy Demand
LTS	Long-term strategy
Mtoe	Million tonnes of oil equivalent
NECP	National energy and climate plan
NZEB	Nearly zero-energy building
NZIA	Net Zero Industry Act
ODEX	Index that measures energy efficiency progress in economic sectors
OECD	Organisation for Economic Co-operation and Development
PEC	Primary energy consumption
PJ	Petajoule
PRIMES	Price-Induced Market Equilibrium System
Q(1,2,3,4)	Quarter of the calendar year
R&D	Research and development
RE	Rebound effect
REC	Renewable energy community
RED	Renewable Energy Directive
SDG	Sustainable Development Goal
SME	Small and medium-sized enterprise
TES	Thermal energy storage
TJ	Terajoule
TPB	Theory of planned behaviour
UK	United Kingdom
UN	United Nations
UNEP	United Nations Environment Programme
VUX	Value-based User eXperience
WAM	With additional measures
WEM	With existing measures
WTP	Willingness to pay

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Foreword

It is broadly accepted that economic growth has brought widespread prosperity in the post-World War II era, reducing poverty and allowing progressive public policies in most Western countries. However, the neoliberal central emphasis on economic growth has gradually revealed its profound social and environmental consequences, compromising these other two elements of the traditional definition of sustainability [1].

From a social perspective, promoting the pursuit of economic growth and the maximisation of profit as a cornerstone of the system has arguably created greater social inequalities and an unprecedented concentration of wealth, alongside increasing poverty levels, leading to widespread social discontent, growing distrust in democracies and the rise of populist voices.

From an environmental point of view, the consequences are no less stunning. Last year, the global average temperature was 1.26°C higher than the pre-industrial level [2], and a very recent study established that 2023 has, for the first time, seen six out of nine planetary boundaries being transgressed, with pressure increasing on all of them [3]. There is a strong case that the continuous pursuit of economic growth is in conflict with the planet's boundaries and renders a sustainable climate trajectory increasingly unattainable. This highlights the urgency to devise a transformative model able to generate social welfare while remaining compatible with planetary boundaries.

This report intentionally does not address the important debate about the compatibility of economic growth with global sustainability [4], [5], but instead proposes an open, agnostic and fact-based perspective concentrating on conditions pertaining to driving an accelerated decarbonisation path aligned with the EU's intermediate and long-term climate objectives.

Science indisputably tells us that our 1.5°C carbon budget will be exhausted in just a few years' time [2]. Global emissions are still on the rise, and the world is on track to largely overshoot the upper 2°C limit. It is believed that this trajectory will trigger several tipping points that would irreversibly propel human society into an unpredictable future.

A chasm exists between the observed rates of carbon abatement, the foreseeable technology improvements and the required rate of emission reduction to be achieved year on year up to 2050. Acknowledging that decarbonisation of the supply side of the economy undeniably appears to be happening too slowly, reason urges us to now address the demand side as well.

Since the 1970s oil crises, demand-reduction policies – with the notable exception of efficiency measures – have mostly been banned from the policy discourse as essentially clashing with the very principle of economic growth. However, the full-scale Russian war on Ukraine and the consequential energy crisis have suddenly revived the debate, with demand reduction now being included as an integral part of Europe's REPowerEU policy response.

But while this measure has primarily been seen as crisis-related, i.e. "a temporary short-term fix", the time has come to structurally integrate long-term demand-reduction strategies into the core of clean energy transition policymaking.

This report analyses the various levers that can be used to bring about a reduction on the energy demand side and provides policymakers with essential insight for the purpose of engaging in ambitious and decisive demand-reduction policies.

Energy demand-reduction strategies can broadly be conceptualised as a set of distinct yet complementary approaches. In addition to the well-established concept of "**energy efficiency**", the report explores the less common, more complex, yet essential notion of "**energy sufficiency**". It also provides a detailed analysis of the drivers underpinning "**behavioural change**" that defines decision patterns and enables energy sufficiency and/or efficiency measures to be successfully implemented.

The report essentially breaks with the commonly accepted idea that technology gains, including those relating to increasing energy efficiency, could alone drive GHG emissions down to satisfactory levels without constraining demand for energy services. It highlights the imperative to have recourse to a structural and long-term reduction in required energy services, fundamentally impacting the way economic agents – citizens, communities and businesses – relate to energy. These changes, affecting deeply rooted social norms, uses and values, have longer cycle times than technology changes but are expected to significantly impact required energy consumption levels and patterns.

While deliberately not delving into the debate on economic growth, the report analyses the relationship between energy demand and human well-being in order to advise on policy strategies fostering energy reduction scenarios and narratives that remain compatible with citizens' aspirations and expectations.

In its 2021 flagship report, "EERA White Paper on the Clean Energy Transition" [6], the EERA scientific community had already called for a holistic approach. This would require a combination of best-in-class technology progress and socio-economic research on sustainable consumption and energy demand narratives, with the aim of driving the clean energy transition to successful completion. In the present report, the EERA community urges policymakers to exploit the full decarbonisation potential of energy demand-reduction measures and to integrate the wider scope of demand-reduction strategies within the core of the CET policymaking process.

Adel El Gammal
EERA Secretary General

Executive summary

Despite the global scaling up of renewable energy deployment, **the share of renewables in the global energy mix has remained constant since 1990 due to the growth in total energy consumption.**

Historically, there has been a lack of research and policy focus on the energy demand side despite its significant potential for transforming the energy system and the entire economy. **Most of the existing solutions within the clean energy transition (CET) have targeted the technological, supply-side domain.** In 2022, the full-scale Russian invasion of Ukraine and the unprecedented energy crisis in Europe led to European policymakers designing policies explicitly targeting energy demand reduction. These policies, however, focused on short-term energy demand, aiming to reduce the use of fossil fuels, primarily natural gas.

Energy demand reduction, along with its associated research and policies, should not focus solely on decreasing dependence on fossil fuels; instead, the aim should be to reduce total energy demand in the long run by integrating energy demand-reduction strategies into the CET in Europe. Despite the unprecedented speed of renewables deployment, numerous challenges related to the CET jeopardise achieving its goals in time, concurrently with climate mitigation objectives and the EU's strategic autonomy aims. In this regard, a strong strategy on demand reduction while continuing to support renewable energy technologies would be essential.

In developed economies, long-term structural energy demand reduction across all economic sectors is possible without compromising the level of wellbeing if it is carefully planned and implemented based on available knowledge and successful practices. Implementing energy demand reduction as part of the CET could mitigate risks and uncertainties associated with scaling up renewables while at the same time securing the EU's strategic autonomy. Moreover, energy demand-reduction strategies could alleviate risks such as creating dependencies for increasing amounts of materials and technologies for the CET in countries outside Europe, as well as environmental and social justice risks associated with the extensive deployment of renewables and rolling out environmentally harmful and energy-intensive processes such as mining.

An energy demand-reduction strategy implies that the focus should be on the main energy-consuming sectors, including households (buildings), industry and transport, as these sectors contribute the largest share of final energy consumption. The energy crisis of 2022 illustrated that crisis measures for reducing demand are primarily directed at households, which are also disproportionately affected by the crisis. Instead, a strategy focused on energy demand reduction should encompass all economic sectors and provide a combination of measures and tools applicable to various types of energy use and in different contexts.

The question of how energy demand can be reduced could be answered by combining different demand-reduction strategies, among which are **behavioural change**, **energy efficiency** and **energy sufficiency**.

Behavioural change is the cornerstone. The potential for behavioural change in energy consumption remains largely untapped due to multiple factors, including expectations of rational user behaviour, accessibility and affordability of energy-saving technologies, and often unaddressed cultural differences in how rules and incentives are designed for different user groups.

Energy efficiency is closely related to behavioural change. It is the demand reduction strategy most recognised by policymakers, explicitly present in policies and associated with corresponding targets. However, especially concerning the efficiency of industrial processes, energy efficiency measures and enabling technologies in Europe remain underinvested. **Despite being crucial for energy demand reduction and energy transition, energy efficiency measures per se do not guarantee an absolute reduction in energy use, as they target the amount of energy used per unit of goods or services produced, not the total number of those units.**

This limitation is addressed by **energy sufficiency**, another energy demand-reduction strategy with the highest transformative potential. It aims to address fundamental principles behind energy consumption, ensuring a sufficient level of wellbeing and limiting the absolute quantity of resources used to produce energy services. **Energy sufficiency has the potential to bring about long-term behavioural change and energy savings** by targeting such solutions as transforming infrastructure and offering alternative ways of achieving a similar level of comfort and services with minimal energy consumed. Despite many examples of national-level policies that are sufficiency-oriented in their goals, energy sufficiency is not explicitly mentioned in current EU policies. In this report, it is argued that **to truly intertwine energy use with wellbeing and to shift the paradigm from transitioning to net zero to achieving a low-energy society, transformative changes across our existing systems, infrastructure and governance should be boldly enacted**.

The report concludes with a series of policy recommendations aimed at integrating energy demand reduction into the EU's CET strategy by establishing specific reduction targets across all energy types and setting targets and indicators for energy demand reduction at EU and national levels. Moreover, it ultimately proposes integrating energy sufficiency by possibly elevating the "energy efficiency first" principle to "energy sufficiency first" and ensuring citizens actively shape energy demand-reduction measures by embodying the "citizen in the centre" principle.

1. Setting the scene

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HIGHLIGHTS OF THIS SECTION:

- Despite the global scaling up of renewable energy deployment, the share of renewables in the global energy mix has remained constant since 1990 due to the growth in total energy consumption.
- Energy demand reduction, along with its associated research and policies, should not focus solely on decreasing dependence on fossil fuels; instead, the aim should be to reduce total energy demand in the long run by integrating energy demand-reduction strategies into the clean energy transition (CET) in Europe.
- Evidence suggests that reducing energy demand does not compromise wellbeing in developed economies.
- Most of the existing solutions within the CET are to be found in the technological, supply-side domain, while the significant potential of demand-side mitigation remains largely untapped.
- Implementing energy demand reduction as part of the CET could mitigate the risks and uncertainties associated with scaling up renewables and secure strategic autonomy.

1.1. GENERAL CONTEXT

Historically, there has been a lack of research and policy focus on the energy demand side, despite its significant potential for transforming the energy system [7]. Especially lacking are research and policies on a system level and, ultimately, on the societal level as a whole. The opportunity to emphasise the crucial importance of addressing the demand side has arisen in Europe due to the energy crisis following the full-scale Russian invasion of Ukraine in February 2022, and the recognition of the adverse impact of fossil fuel dependence on energy security. A growing number of policy-relevant publications have highlighted the significance of research into demand reduction, attributing its importance to reducing reliance on fossil fuels and addressing the energy crisis (see, for example, [8], [9]).

In this report, we further expand the argument regarding the importance of interventions on the demand side. **We assert that energy demand reduction and the associated research and policies are crucial not only for addressing the energy crisis and ensuring energy security, but also for structurally integrating energy demand-reduction goals into the broader CET strategy in Europe.** This perspective holds true even in a hypothetical scenario with zero fossil fuel dependence and no energy crisis. Achieving the CET and climate goals in Europe by 2030 and 2050 should encompass comprehensive, long-term energy demand-reduction objectives, supported by corresponding policies.

The central argument of this paper is in line with the IPCC AR6 IWG3 report, which, for the first time, highlighted demand reduction as a central strategy for mitigating climate change [7].

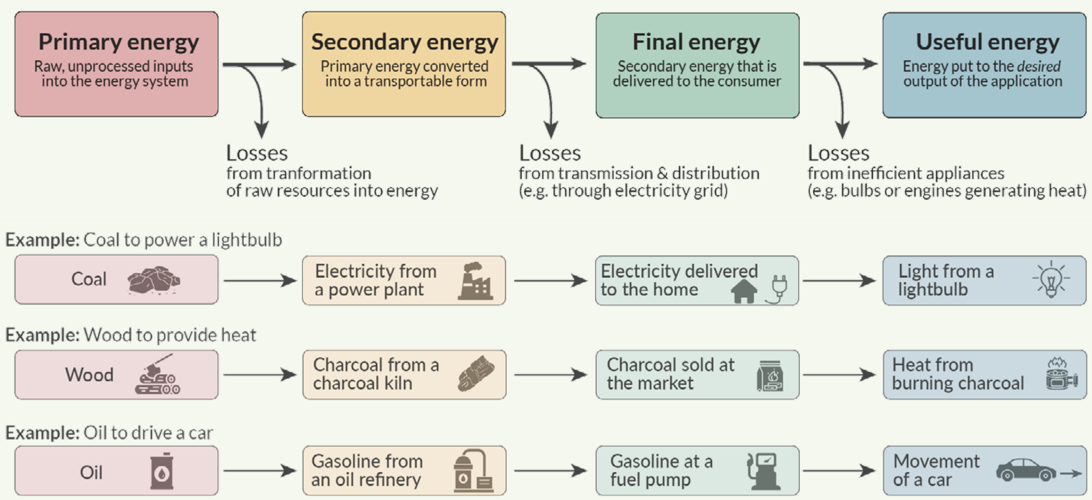
The present report starts by discussing how energy is consumed across different users, end-use sectors and energy services globally and within the EU. It also delves into available future scenarios for energy demand (Section 1). Subsequently, the report explores the state of play of three energy demand-reduction strategies: behavioural change, energy efficiency and energy sufficiency (Section 2). Following this is an examination of the discourse surrounding EU policies, particularly those specific to energy demand reduction. These policies are analysed in relation to the aforementioned demand-reduction strategies, their timelines and the sectors where energy is consumed (Section 3). Finally, the report concludes by proposing a set of key policy recommendations related to energy demand reduction (Section 4).

1.2. FINAL ENERGY CONSUMPTION IN THE EU AND GLOBALLY

This report focuses primarily on final energy consumption. In contrast to primary and secondary energy (Figure 1), final energy, as defined by Eurostat [10], is the total energy consumed by end-users. This pertains to the energy that reaches the ultimate consumer, excluding the energy used within the energy sector itself. The main energy user categories encompass private households, industry, transport, services, agriculture and other. This report narrows its focus to the following three consumer categories: households, industry and transport, since they are the top three responsible for final energy consumption in the EU [11]. However, it should be noted that in the future all these energy end-use sectors might become more and more integrated with each other and with centralised energy producers: household electricity may be used to charge electric vehicles, the service sector (e.g. data centres) might provide heat for households, and households may act as prosumers and provide power and heat to markets.

It is worth mentioning that, in this report, energy demand reduction in transport is discussed in less depth than energy demand reduction in households and industry. This is due to the fact that EERA Joint Programmes do not cover transport as a dedicated research area. The EERA research community therefore has limited knowledge of this topic compared with the other two sectors.

FIGURE 1:
The four ways of measuring energy [12]



(Icon source: Noun Project. Source: OurWorldinData.org - Research and data to make progress against the world's largest problems. Licensed under CC-BYby the author Hannah Ritchie.)

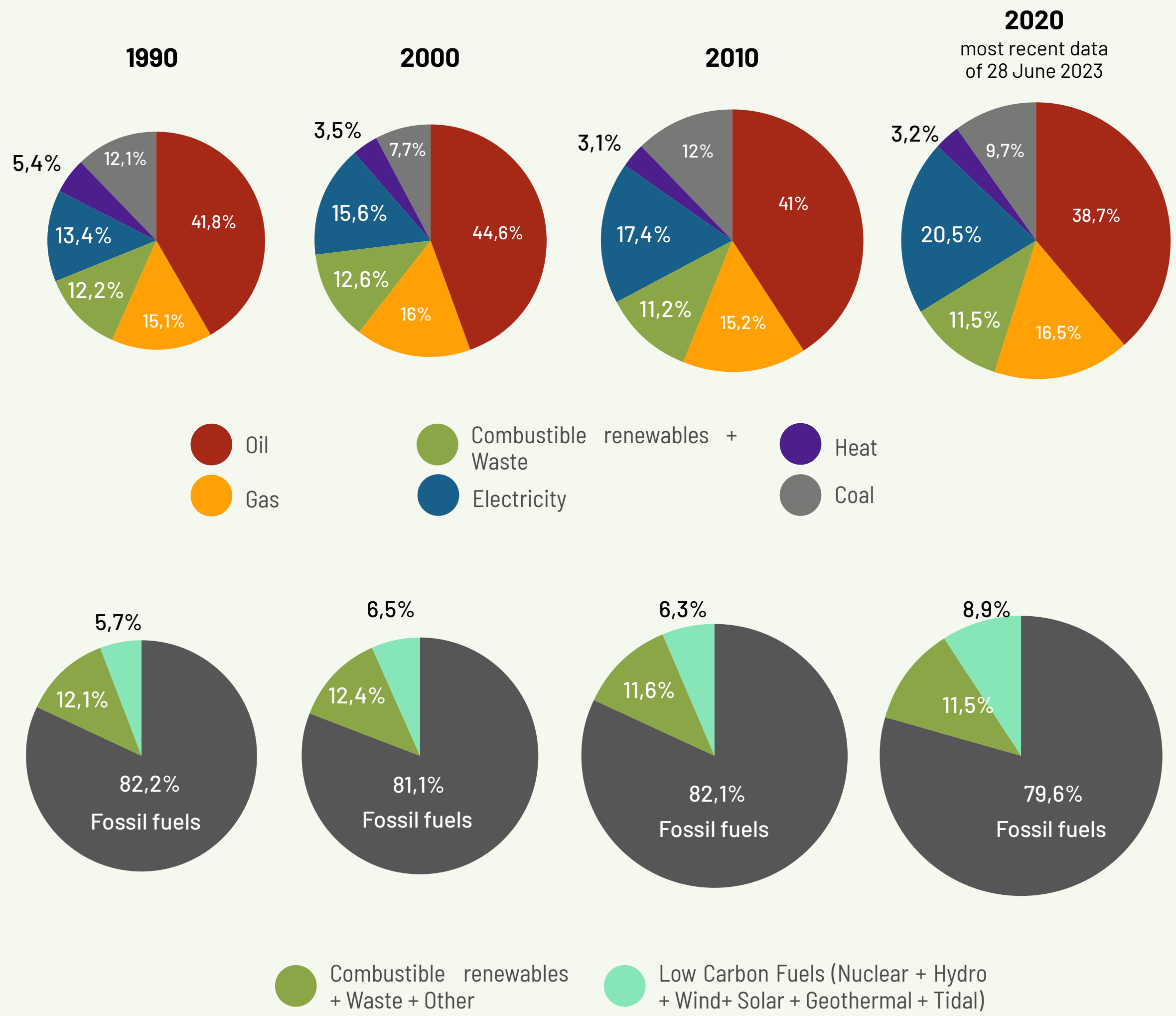
The main rationale for concentrating on final energy in the context of energy demand-reduction strategies is the fact that energy users do not inherently "demand" its intrinsic value but rather the services it provides, such as heating, lighting and motive power [7], [13].

Global statistics illustrate that global final energy consumption has increased by 54% since 1990, rising from approximately 261 EJ to over 400 EJ [14]. **Meanwhile, the proportion of fossil fuels and low-carbon energy remains almost unchanged from 1990 levels, despite progress in the CET and the expansion of low-carbon energy systems. In other words, the CET has predominantly covered the increase in energy demand rather than effectively replacing fossil fuels** (See Fig. 2).

FIGURE 2:

Global final energy consumption between 1990 and 2020 [14]

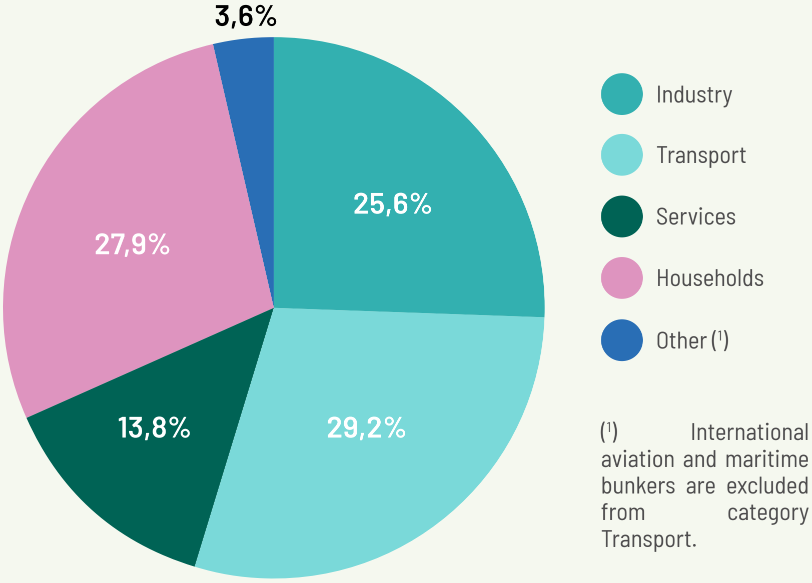
The area of each upper pie chart is proportional to total annual energy consumption of the respective year.



Regarding the European share (OECD-Europe) of global final energy consumption in 2020 in comparison with 1990, the percentage has decreased from 18% to 12%. The EU27 share in the global total final energy consumption in 2020 was 10.1% [15]. The absolute amount of final energy consumption in the EU rose in 2021 by 6% compared with 1990 – from 37 EJ (= 37,000 PJ) to 39.35 EJ (= 39,350 PJ) (Fig. 4). Structurally, in the EU, the final energy consumption in 2021 was distributed among households (27.9%), industry (25.6%), transport (29.2%) and services (13.8%), as illustrated in Figure 3. From 1990 onwards, several major disruptive events, including the economic downturn in 2008 and the COVID-19 lockdowns in 2020, temporarily reduced energy demand before it subsequently rebounded. Without 2022 statistics, it remains uncertain how primary and final energy consumption in the EU altered after the Russian invasion of Ukraine. However, IEA data suggests a 13% drop in natural gas demand in 2022 compared with 2021, marking the steepest decline on record [16]. According to the same IEA analysis, this decrease was mainly driven by the surge in energy prices, while the contribution of other factors such as behavioural change, remained marginal.

FIGURE 3:

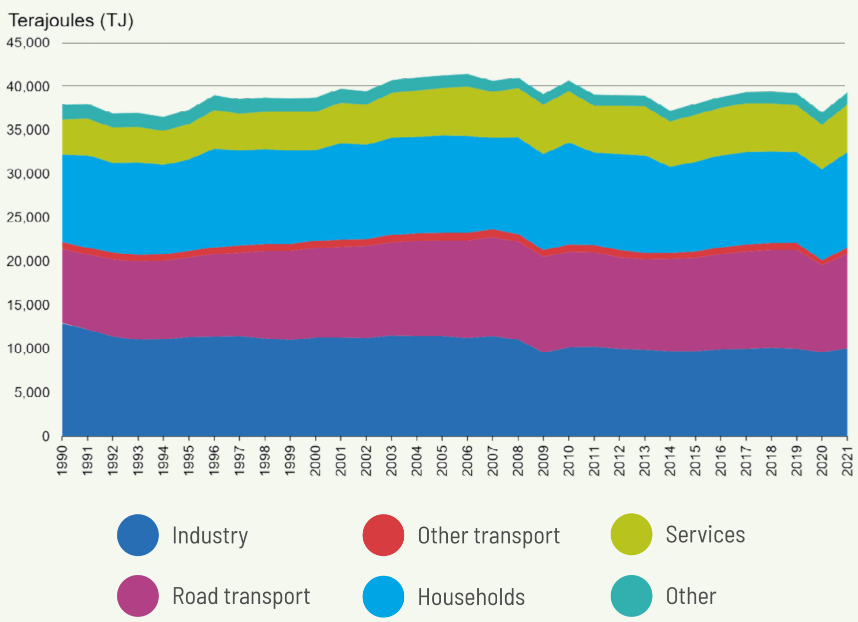
Final energy consumption by sector, EU, 2021 [11]
(% of total, based on terajoules)
(Source: Eurostat (online data code: nrg_bal_c))



(1) International aviation and maritime bunkers are excluded from category Transport.

FIGURE 4:

Final energy consumption by sector, EU, 1990-2021 [11] (terajoules)
(Source: Eurostat (nrg_bal_c))



Analysing the trend in changes in final energy consumption in the EU by end-use sector in 2021, compared with 1990, the transport sector's final energy consumption increased by 22%, while industry's decreased by 20%, and household consumption remained nearly the same (Figure 4). **Despite each of these sectors – households, industry and transport – contributing to roughly a third of total final energy consumption, the prevailing discourse regarding energy demand primarily targets households.** Allocating less priority to demand reduction in industry and transport compared with households significantly restricts the transformation potential of research and policies on the energy demand side. **Consequently, it becomes essential for both researchers and policymakers to equally prioritise understanding energy demand across all end-use sectors** [13].

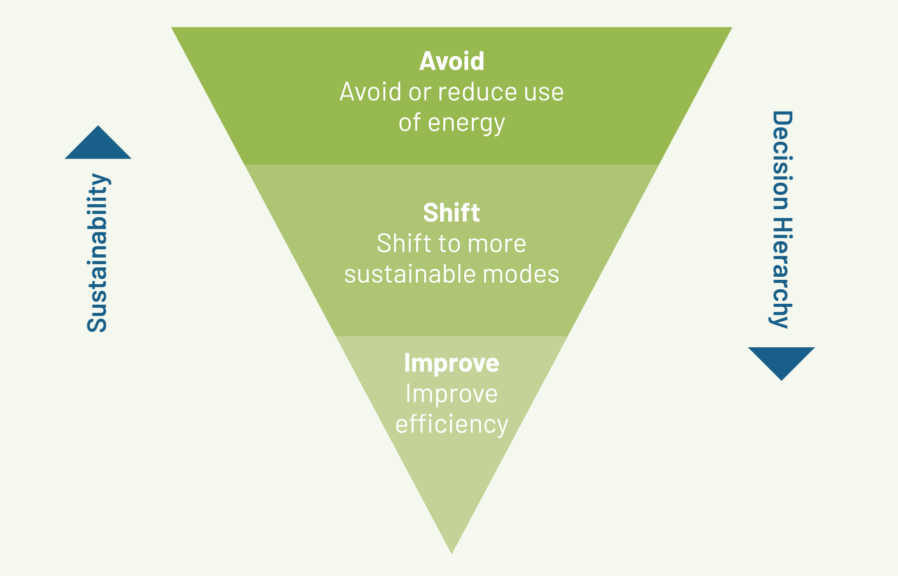
1.3. TRANSFORMATION POTENTIAL OF ENERGY DEMAND-SIDE MEASURES

Current scenarios within the energy system overwhelmingly lean towards supply-side solutions driven by technology [7]. This reflects an ingrained mindset where demand is typically modelled through demand drivers (such as GDP growth), and supply is managed to satisfy demand at minimum cost. As a result, the majority of energy system transformation is happening on the supply side. In energy scenario modelling, the major challenge lies in the lack of input data for the demand sectors and their development, as well as in finding methods that would realistically represent decision-making related to energy demand. At the same time, evidence indicates that significant untapped potential for transformation lies within the demand side of the energy system. **The IPCC emphasises** [7] **that curtailing energy demand is pivotal for swift and effective climate mitigation. Furthermore, reducing energy demand can alleviate challenges and uncertainties associated with the supply side of the CET**, eliminating the need for costly and risky technologies, as well as diminishing the requirement for raw material extraction.

Despite the enduring imbalance in research and policy attention between the demand and supply sides, there has recently been a growing effort to address this demand-side deficit [8], [17], [18]. Various theoretical frameworks have been employed in this context. Among these, the Avoid-Shift-Improve (ASI) framework stands out as being commonly employed [7], [19], [20]. For instance, this framework is integrated within IPCC's climate mitigation strategies. ASI categorises options for reshaping current energy systems into three types:

- **Avoid:** reducing energy demand by eliminating certain forms of consumption (e.g. teleworking reducing travel needs).
- **Shift:** transitioning to less carbon-intensive modes of consumption (e.g. using public transport, shared mobility schemes).
- **Improve:** enhancing energy technology or the carbon intensity of technology (e.g. improving energy efficiency in homes).

FIGURE 5: Graphical illustration of the Avoid-Shift-Improve framework. Adapted from [20].



From the description, it is clear that both "**Avoid**" and "**Shift**" have a strong focus on the demand side, with "Avoid" holding the highest potential for "deep demand reduction". In contrast, "**Improve**" mainly centres on supply-side transformations linked to technological solutions (Figure 5). The main message of the ASI framework underscores the fact that the most extensive transformation of the energy system arises only when all dimensions of ASI are addressed. This necessitates involvement in three areas: socio-cultural (where social norms, culture and individual choices have significant impact), infrastructure and technology. In terms of ASI, **the current approach to the CET predominantly highlights the "Improve" options, implying a technocentric approach**. The IPCC argues that the motivation and effort required to transition from "Improve" to "**Shift**" to "**Avoid**" decisions are challenging, as these changes involve shifts in "deeper values or mindsets" [7].

1.4. ENERGY DEMAND IN CONNECTION WITH WELLBEING AND PLANETARY BOUNDARIES

1.4.1. Energy demand in the energy models

Energy transition pathways are central in climate mitigation scenarios. Historically, most long-term mitigation scenarios employed normative technology-centric, bottom-up approaches, placing emphasis on supply-side solutions. Despite evidence of savings from sector-specific or issue-specific bottom-up studies [7], demand-side reductions linked with ASI strategies are rarely incorporated into these models [7], [21]. Given the significant role of integrated assessment modelling (IAM)[1] in climate change mitigation pathways to inform climate and energy policymaking, these technology-centric scenario assessments set a techno-centric

1. Integrated assessment models are used to assess the feasibility of climate goals, such as those of the Paris Agreement, which aims to limit global warming to well below 2°C, with efforts to restrict it to 1.5°C above pre-industrial levels.

policy agenda. In the EU, in view of the requirements set by the Governance Directive [22] on how to create and model policy scenarios, there is little room for innovative scenario assessment. For example, the EU has strict procedures for producing scenarios "with existing measures" (WEM) and "with additional measures" (WAM), scenarios for the national energy and climate plans (NECPs), long-term strategies (LTSs), etc. [22]. It is therefore essential that policymakers first set policy targets for the demand side to enable these targets to be modelled. Until this happens, demand-side mitigation strategies will remain underrepresented in the existing models informing the EU policymaking process and, as a result, absent from CET policies.

However, a growing body of work is now exploring the potential of profound demand-side reduction in energy and resource use, on both global and regional scales [7]. This new generation of models focus on long-term scenarios aiming to prioritise energy and resource demand reduction as key climate change mitigation strategies. One of the most notable scenarios, Low Energy Demand (LED), represents the lowest long-term global energy demand ever published. It incorporates the concept of decent living standards (DLSs) and delves into profound transformations in demand across food, energy, land and water uses. In its latest assessment report (AR6), the IPCC provides a comprehensive overview of the long-term model scenarios aimed at minimising service-level energy and resource demand [7].

1.4.2. Energy demand reduction and wellbeing

Globally, the primary targets for sustainable energy system development emphasise affordable and clean energy for all with the help of renewable energy resources and electrification (i.e. SDG 7). According to the UN 2023 Sustainable Development Goals Report [23], 675 million people lacked access to electricity in 2021. With current development and expected population growth, about 660 million people will still have no access to electricity by 2030, and close to 2 billion people will still rely on polluting fuels and technologies for cooking. It is thus understandable that the UN largely focuses on the supply side to ensure energy access for all. The UN also recognises that prioritising energy efficiency in policy and increasing investment can help the world achieve energy and climate targets [23], underscoring a supply-side focus. In pursuing the SDGs, by shifting the focus more towards demand, we reveal the inherent connection between energy consumption and human wellbeing – a link that is far less evident in approaches focusing on the energy supply side. Such a perspective prompts essential questions such as: *What amount of energy is sufficient for a good standard of living? How does energy consumption correlate with wellbeing?* Terms like "energy sufficiency", "energy needs" and "decent living standards (DLSs)" currently encapsulate this energy-wellbeing nexus.

Regarding the relationship between energy consumption and wellbeing, studies indicate a threshold beyond which increased energy use does not significantly increase wellbeing [24]. Current research examining low-emission demand-side scenarios indicates, on the contrary, that it is possible to sustain or even enhance wellbeing while reducing global final energy demand. Moreover, recent findings suggest that reducing energy consumption might not just be neutral but could actually boost wellbeing in developed economies. Though energy is indispensable for human development, a drop in energy consumption, especially when combined with improved services, leads to enhanced environmental quality and directly augments wellbeing [25], [26].

The concept of DLSs, which represent the bare minimum for human wellbeing, is especially relevant in the discourse on energy sufficiency. Research indicates that energy use needed for global wellbeing ranges from 20 to 50 GJ per person annually, depending on context [7]. These figures are rooted in the basic requirements for human life: nutrition, shelter, living conditions, clothing, healthcare, education and mobility [27], [28].

At the same time, it is important to recognise that methods aimed at reducing energy demand may affect the accessibility of energy services for some social groups, compromising individual wellbeing. For instance, low-income households, which typically reside in energy-inefficient properties, bear disproportionate energy costs that usually adversely affect their quality of life and health. If energy demand-reduction measures result in raising energy prices, without providing affordable alternative solutions or significantly impacting disposable income, inequality deepens, challenging the sustainability goal of preserving human welfare. In this regard, energy sufficiency, as one of the energy demand-reduction strategies discussed in this report (Section 2.1) provides the approaches to ensure that the goal of social equity is not compromised.

To truly intertwine energy use with wellbeing, and to shift the paradigm from transitioning towards a low-carbon society to transitioning towards a low-energy society, we must undertake a profound reassessment of our existing systems, infrastructure and governance, which are largely built on the historical assumption of cheap energy and abundant energy sources.

1.4.3. Other benefits of energy demand reduction

The focus on energy demand reduction offers a range of benefits beyond the direct positive impact on wellbeing:

- REDUCED ENVIRONMENTAL RISKS

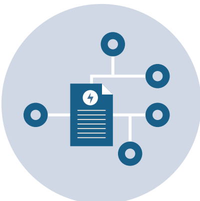
Demand-side solutions generally pose fewer environmental risks compared with many supply-side solutions [7], [29]. For example, in the IPCC's scenarios aiming to stabilise global warming at 1.5°C by 2050 [30], the Low Energy Demand (LED-19) pathway was the sole strategy out of four that did not include the need for uncertain technologies like bioenergy with carbon capture and storage (BECCS). **Reducing energy demand can yield a variety of environmental benefits, the nature and magnitude of which depend on the composition of the energy mix.** When fossil fuels dominate the energy mix, a reduction in demand primarily translates into a decrease in greenhouse gas (GHG) emissions and other pollutants. On the other hand, as the share of renewables in the energy mix increases, demand reduction will gradually mitigate the adverse environmental impacts associated with renewable energy technologies. Such impacts include those arising from the sourcing of critical raw materials (CRMs), land use and effects on bio-diversity.

- **REDUCED COST OF THE CET**

Relying on alternative energy supplies can be expensive. Infrastructure and lifestyle changes can considerably reduce the long-term economic cost of the energy transition [31].

- **REDUCED GEOPOLITICAL PRESSURES**

A shift from fossil fuels to renewables often trades one set of dependencies and geopolitical pressures for another [32], [33]. For the EU to attain long-term energy security and strategic autonomy, radical demand-side policy transformations are vital, given the CET ambitions in the EU, on the one hand, and the level of EU dependencies on critical material mining and processing overseas, on the other hand [34].



- **LIMITATIONS OF CIRCULARITY AND DIGITALISATION ARE ADDRESSED**

Digitalisation and circularity are both believed to be key enablers of a sustainable CET. However, evidence shows that circularity and digitalisation have only made a limited contribution to climate change mitigation. While digitalisation, through specific products and applications, holds the potential for improvement in service-level efficiencies, in the absence of dedicated public policies and regulations it also has the potential to increase consumption and energy. Similarly, claims about the benefits of the circular economy for sustainability and climate change mitigation are of limited evidential use [7]. Like digitalisation, circularity might also increase energy demand, especially in those cases where recycling processes are energy-intensive.

Research on energy demand reduction

2.

In this report, we explore the topic of energy demand reduction by delving into three demand-reduction strategies: *individual and collective behavioural change, energy efficiency and energy sufficiency* (Fig. 6). While each of these strategies has its own unique characteristics, they can broadly be conceptualised as being distinct yet complementary, collectively contributing to the overarching goal of energy demand reduction.

This section will discuss each of the three demand-reduction strategies, focusing on the policy-relevant research related to each.

FIGURE 6: The three demand-reduction strategies discussed in this report

- BEHAVIOURAL CHANGE
- ENERGY EFFICIENCY
- ENERGY SUFFICIENCY

2.1. INDIVIDUAL AND COLLECTIVE BEHAVIOURAL CHANGE

HIGHLIGHTS OF THIS SECTION:

- **Behavioural change is pivotal for demand reduction and must be useful, usable and desirable.**
- **Research guides policymakers in tailoring incentives, products and services to users' values, needs and desires to promote behavioural change.**
- **Multiple barriers hinder energy-saving behaviour, but extensive research provides solutions to address them.**
- **Targeted information and awareness-raising significantly enhance user engagement and the impact of behavioural changes for all user types.**

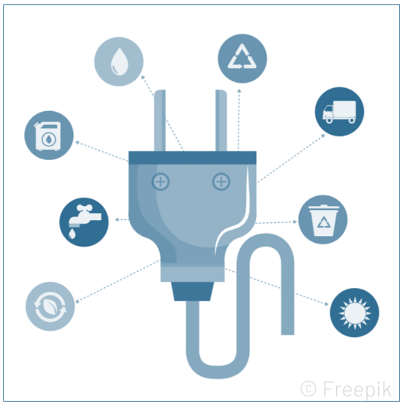
Section 2.1.1. provides a definition of behavioural change and discusses the main drivers and barriers that promote or hinder it. Additionally, the predominant challenges associated with both individual and collective behavioural change are outlined.

2.1.1. Definition

Sustainable energy practices are one of the main social goals of the green transition, but the implementation of transition requires an understanding of both individual and collective behavioural change. Energy behaviour is defined as a collection of individual actions influencing energy consumption and production [35]. This individual-centric perspective emphasises the role of human actions in utilising various energy sources to deliver desired services. For instance, the IEA defines energy behaviour as encompassing "all human actions that affect the way fuels (gas, petroleum, coal, etc.) and electricity are utilised to achieve desired services, including the acquisition or disposal of energy-related technologies and materials, how these are used, and the mental processes that relate to these actions" [32].

Often used in academic literature, policy documents and sustainability reports, the term "individual and collective behavioural change" refers to the need for both individual-level changes in behaviour (such as energy-saving actions taken by households) and collective-level changes (such as community-wide initiatives or policy measures) to effectively reduce energy consumption and promote sustainable energy practices [7], [35]–[37]. This term is strongly associated with the concept of energy conservation in the context of energy demand reduction. Energy conservation, initially introduced in the public agenda in the early 1970s to enhance energy security during the oil crisis in the OECD countries, has been defined by Bertoldi [38] as "end-users' actions resulting in a reduction of the energy service".

2.1.2. How behavioural change can contribute to energy demand reduction



Below are examples of how behavioural change can contribute significantly to energy demand reduction:

- **Energy conservation:** encouraging individuals to adopt simple yet effective energy-saving practices can lead to significant energy savings. For instance, promoting habits such as turning off lights when not needed or unplugging electronic devices when not in use [38]–[41].
- **Reduction in peak load demand:** encouraging individuals to shift energy-intensive activities to off-peak hours, when demand is lower, alleviates stress on the energy grid and promotes a more efficient utilisation of energy infrastructure and resources.
- **Energy-efficient practices:** encouraging individuals to adopt energy-efficient technologies in their households or transport use. Examples include weatherproofing[2], insulation, and implementation of smart technologies such as smart meters and energy monitoring systems.

2.1.3. Drivers and barriers

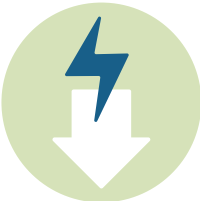
Understanding the drivers and barriers of behavioural change is essential for reducing energy consumption and gaining insight into the reasons behind the limited adoption of current energy reduction measures in society. **Several factors have proved influential in shaping individual energy behaviour, ranging from socio-demographic and psychological factors to external ones, such as economic incentives.**

Some of the most important *drivers* of energy behavioural change include the following:

- **Energy prices** particularly impact energy consumption patterns. Higher prices can incentivise individuals to adopt energy conservation practices. When energy prices rise, people are more likely to be motivated to reduce their energy consumption and seek more energy-efficient alternatives. The recent energy price surge resulting from Russia's invasion of Ukraine has driven a significant decline in energy demand. The higher energy prices prompted consumers to be more mindful of their energy usage and encouraged them to adopt energy-saving behaviour [16], [42].

2. Weatherproofing relates to actions to protect a building and its interior from the adverse effects of weather (sunlight, precipitation and wind), and to reduce energy consumption and optimise energy efficiency.

• **Environmental levies and green taxes** also affect energy consumption. Environmental levies such as carbon taxes are designed to compensate for negative environmental externalities created during the production and consumption of various products. Basic microeconomic theory postulates that a tax increases consumer prices, which lowers demand for the goods consumed. However, awareness of paying a carbon tax may change consumers' behaviour [43], [44]. Behavioural responses to green taxes might crowd out their demand-reduction effects if people think they have already done their fair share in taking responsibility; this "moral licensing" effect then leads them to engage in more carbon-intensive activities [45]–[50].



• **Incentives** can also lead to energy savings. When developing these incentives, usability, simplicity, clarity, predictability, attractiveness and understandability are important aspects to consider. In this connection, safeguarding privacy and data security should be taken into account. When incentives are designed, they should be implemented, tested and refined to maximise their effectiveness through the involvement of energy users [51].

• **Affordability and accessibility** of energy-saving technologies and infrastructure can also shape energy behaviour. If energy-saving technologies, energy-efficient appliances or renewable energy options are affordable and accessible, they become incentives for individuals to adopt energy-saving behaviour. Affordability and accessibility are also about making sure that energy-saving technologies and solutions are there for everyone, not just for those who are more privileged.

• **Feedback, real-time information and sharing best practices:** providing individuals with real-time feedback on their energy consumption through smart meters or energy monitoring systems can raise awareness and prompt behavioural changes. For instance, Jain et al. [52] investigated the impact of social pressure on the energy consumption behaviour of users provided with information about other users' behaviour. The research found that social pressure does affect the behaviour of users in a peer energy network. Sharing best practices among individuals also initiates and fosters a positive attitude towards energy demand reduction. For example, a study in Turkey [53] found that energy experts/managers in industrial firms perceive sharing best practices as one of the main drivers for energy efficiency measures at company level. Numerous empirical studies and meta-analyses have contributed to our understanding of the dynamics of peer influence and its implications for energy savings [54]. Several studies have also examined the willingness of consumers to pay a premium for higher-level energy-saving appliances. For example, a study conducted in North-East Italy [55] examined household preferences for ambient heating systems and found that people in the study group displayed different behaviours depending on individual willingness to adopt innovations, perceptions of heating system characteristics, social norms and communication channels.

- **Trust in energy-saving technologies:** the level of trust that consumers have in energy-saving technologies or services is also crucial. An individual's willingness to trust a new technology often stems from their existing knowledge of such innovations and their feelings about the company or organisation offering it. Trust is also strengthened when there is complete transparency about what the technology aims to achieve and how it works. For instance, if people have a high level of trust in the company selling an appliance, they are more likely to perceive high benefits and low costs and risks, and in turn develop a more positive attitude towards the appliance [56].

- **Positive attitude towards an energy-efficient technology** has been demonstrated to enhance acceptance and adoption of that technology [56], [57]. Several mechanisms account for this effect. For example, the technology acceptance model puts forward the idea that the perceived ease of use and perceived usefulness of a technology affect people's attitude towards it [58]. When the use of an appliance is perceived as straightforward and consumers expect to gain benefits from it, this positively affects people's attitude, which in turn has a positive effect on their intention to purchase the appliance [56], [57].

However, the intention to engage in energy-saving behaviour can be affected by other factors, such as communication methods oriented towards the short or the long term, where findings show that the promotion of new energy-efficient technologies should combine these communication methods to enhance consumers' intentions [59].

Some of the most important *barriers* include the following:

- **Lack of awareness** is one the main barriers to energy demand reduction, since limited knowledge about energy-saving practices and their benefits can stop individuals from adopting such behaviour. The study conducted by Brounen et al. [60] examines the energy literacy, awareness and conservation behaviour of residential households in the Netherlands through a case study survey of more than 1,700 households. The study revealed that the participants' energy literacy and awareness levels were low and that this lack of awareness was posing a significant challenge in fostering energy-saving behaviour, particularly in home heating and cooling practices. Furthermore, findings by Allcott and Mullainathan [61], who examined the effects of behavioural programmes implemented by Opower, a company employing home energy reporting approaches, revealed that their energy literacy initiatives resulted in significant changes in consumer behaviour. This suggests that if households were better informed and engaged in energy-saving behaviour, it could lead to potential annual electricity bill savings of approximately USD 2.2 billion for households in the United States.

As an illustration from industrial organisations, one study found that by treating energy use as a management issue and encouraging employees to save energy, up to 15% energy savings can be achieved at little or no capital cost [62]. However, the study also reveals that a reward mechanism is crucial for employees to pass on information that increases awareness. Moreover, a lack of awareness poses a significant barrier in the first step of the decision-making process for energy efficiency measures in industrial firms [63]. Respondents from more than 200 Italian companies were interviewed and it was found that about 40% of them consider lack of awareness a primary issue for implementing energy efficiency measures. Another study in an EU lighthouse project [64] reported that many citizens in several European cities said they needed more detailed insight into their energy consumption to be able to make choices and change their behaviour appropriately so that they would experience benefits from it (e.g. financial, in terms of comfort). The target audience's overall capabilities are also of major influence when trying to teach people how to make efficient use of services and technologies. Besides general usability requirements, the digital literacy and energy literacy of citizens/consumers dictates to what extent they can make use of new technologies and services that aim to create sustainable behaviour [65], [66].

• **Upfront costs of efficient technologies and renewable solutions** can also act as a barrier to behavioural change in energy consumption. A study conducted in the UK exploring households' willingness to pay (WTP) for renewable energy technologies [67] found that while households highly valued these technologies, the value attributed to them was not sufficient to cover the higher capital costs associated with their adoption and implementation. Thus, despite the benefits recognised by society, financial considerations pose a barrier to adopting renewable energy technologies and, therefore, act as important determinants of individual behaviour. On the other hand, a survey conducted in a Turkish industrial firm [68] found that energy experts/managers regard the cost of employee training in the use of energy-efficient technologies as a financial barrier to energy efficiency improvements at company level. The study also revealed many other financial challenges that prevent industrial companies from adopting energy-saving behaviour. These challenges include high market risk, the uncertainty of future energy prices and the high transaction cost of energy efficiency investments.

• **Habit and inertia:** lifestyle and habits are crucial in shaping energy-related decision-making [69]. As one study [70] observed, people tend to cling to familiar habits and resist change, even when provided with information about energy-saving options. The research found cyclical patterns of action and backsliding among households receiving home energy reports, showing the powerful influence of established habits and routines on energy-saving efforts. Moreover, habit and inertia can hinder the consistency of behavioural interventions, as initial energy-saving efforts may gradually wane over time. However, the study also provides evidence that continuous intervention can help establish a long-lasting impact on energy-saving behaviour.

• **Rebound effect:** this well-known phenomenon suggests that gains in energy efficiency might lead to less energy savings than expected, as the rebound effect can unintentionally increase energy use and related services. This effect is real and can be significant [71]. A wealth of literature on rebound effects discusses direct rebound effects (higher levels of energy consumption) and indirect rebound effects (direct energy-related cost savings lead to an increase in other consumption, which in turn leads to higher energy demand in other sectors) [72]. The reasons behind the rebound effect are socio-economic as well as psychological. While scientists agree on the existence of the effect, they have been struggling for decades to empirically quantify its size [73], [74]. Nevertheless, evidence shows that the rebound effect cannot justify abandoning the pursuit of efficiency improvements. In addition to the microeconomic effects, macroeconomic analyses of the rebound effect exist. While energy savings can reduce energy prices at a larger scale, this may inadvertently increase demand for services that use more energy, rather than those that are energy-efficient. There is, however, limited evidence about these macroeconomic impacts. Reports indicate that although renewable energy sources are rapidly expanding globally, they are not growing fast enough to meet the surge in global electricity demand. This has led to an increase in coal power usage, which in turn elevates CO_2 emissions in the electricity sector [75]. You can read more on the rebound effect in Section 2.2.3.2.

2.1.4. Main issues in individual and collective behavioural change

2.1.4.1. Influence of individual characteristics on behavioural choices

There are many studies grounded in theories and models that seek to understand determinants influencing individuals' energy behaviour. Socio-economic, socio-demographic and psychological factors play a role in shaping this behaviour. Some variations in determinants can be observed across different types of energy behaviours. For instance, investing in insulation or solar panels can be predicted by personal norms, knowledge and awareness, and the type of dwelling, while energy-saving behaviour is more related to the age of residents, the energy rating of their dwelling and their personal norms [76].

Personality traits or characteristics influence the processes that determine behaviour, leading each individual to exhibit a unique response [77]. Personality dimensions based on value orientations are commonly categorised [78] as openness-to-change, conservation, self-enhancement and self-transcendence.

Values and value orientations as characteristics of individuals can influence their tendency towards engaging in pro-environmental behaviour. For instance, openness-to-change and self-transcendence[3] have been

3. Self-transcendence is a personality trait that means that a person goes beyond their own limits or sees themselves as part of something bigger.

found to positively affect pro-environmental behaviour, while conservation and self-enhancement[4] are negatively related to such behaviour [79]. Biospheric values[5] lean towards the dimension of self-transcendence, and can include values such as preventing pollution. Whether people's personality is oriented towards biospheric values is a predictor of their motivation to reduce household energy use [80], [81]. On the other hand, people with egoistic value orientations are less likely to engage in energy-saving behaviour. Personal norms might possibly account for the effect of value orientations on energy behaviour. When people feel a moral obligation to save energy, the desire to avoid feelings of guilt can motivate them to engage in sustainable energy behaviour [81].

Socio-psychological and behavioural theories play a prominent role in explaining individual behaviour, by highlighting that consumers do not always behave rationally or act primarily as utility maximisers. There are numerous related theories. Here, we focus on those that have been most studied. One important psychological aspect is behavioural intention. According to the theory of planned behaviour (TPB), behavioural intention is shaped by people's attitude, subjective norms and perceived behavioural control [82]–[84]. People's intention to reduce household energy use is influenced by their perceived ability to save energy and their attitude towards energy saving [85]. Norms in the social networks to which people belong are also important drivers of their intention to reduce household energy consumption [76].

Another popular socio-psychological theory is the rational choice theory, which assumes that decisions and behaviours are based on autonomous, conscious and rational decision-making, subjective preferences and self-interest aimed at maximising personal utility. Information, technologies and financial incentives can play an important role in influencing simple purchasing/investment decisions by individuals. Providing information and education can help raise awareness and motivate people to take the right action in terms of both energy efficiency and investment decisions.

The VUX (Value-based User eXperience) framework, introduced in 2019 [86], aims to connect basic human needs with design. This helps in shaping products, services and transitions by considering the views and lives of end-users. The VUX framework helps identify which psychological needs or values users strive to improve and fulfil at a local level, in daily life (e.g. neighbourhood, street, apartment complex, work, family life). Based on this, the need for sustainable energy can often be identified by analysing users' needs and values. An example of this can be found in the BRIGHT project [54], [65] where adoption of demand-response (DR) mechanisms is lacking due to consumers not being knowledgeable and well-informed on what such products and services might mean to them when used.

4. Self-enhancement refers to the natural tendency we have to see ourselves in a positive light or to think highly of ourselves.

5. Biospheric value relates to individuals' concern for environmental issues and drives pro-environmental behaviour.

2.1.4.2. Impact of social norms and culture in energy demand reduction

As people tend to conform to behavioural standards, social norms can inform energy behaviour. **Norms have been shown to positively affect the adoption of energy-efficient technologies, retrofit investments, household energy conservation, and switching to more sustainable electricity sources** [57], [76]. Social norms can invoke a sense of responsibility to improve household energy use, which may lead to behavioural change. For instance, sending people social comparisons of their neighbours' energy use by post was found to reduce household energy consumption [61]. However, it is important to consider that social comparison feedback can also have adverse effects when sustainable energy behaviour is not the norm. In such cases, people might be less motivated to engage in sustainable energy behaviour [87].

Social comparison based on descriptive and injunctive norms[6] results in a significant reduction in energy consumption, especially for households where energy consumption is high. Here, descriptive and injunctive feedback is aligned: it reveals that other households perform better than they do and that their energy consumption is higher than what is perceived as good, and thus encourages energy saving [88]. For low-energy-use households, however, descriptive and injunctive feedback is at odds. Such households adhere to the injunctive norm, yet they perform better than the descriptive norm. Thus, social comparison feedback targeted at low-energy-use households results in smaller reductions than among high-energy-use households. **Strategies aimed at encouraging household energy savings should therefore be diversified, for instance by strengthening injunctive feedback for low-energy-use households** [88].

A novel study comparing 31 European countries found some cross-cultural variation in the extent to which social norms affect energy behaviour. This finding suggests that the effectiveness of social norm-based interventions for behavioural change can vary across countries [89]. Though it may seem paradoxical, social norms are a stronger determinant of support for the energy transition in cultures that are more individualistic and where the focus on norm compliance is less prominent. One possible explanation is that norms inform individuals of socially desirable behaviour, and adherence thereto can improve their self-image or help them achieve some other personal goal [89]. **While there is some research that discusses cultural effects on energy behaviour** [90]**, little is known about cultural variations in the effectiveness of interventions to encourage sustainable energy behaviour across Europe.**

Other strategies that rely on social influence to encourage sustainable energy behaviour include setting commitments and implementation inten-

6. Descriptive norms refer to what most people typically do in a given situation, showcasing common behaviours. In contrast, injunctive norms relate to what behaviours are generally approved or disapproved of in society, indicating what one ought to do. While descriptive norms describe actual behaviours, injunctive norms convey societal expectations.

tions. People are more likely to engage in sustainable energy behaviour when they have committed to doing so, as they have a desire to behave consistently; this is possibly related to personal norms [87]. For example, various types of gamification are often employed to motivate behavioural changes that result in demand reductions. These gamification elements often include cues (i.e. comparisons) from social environments such as neighbourhoods or others linked to a flexibility service. While these social cues can be very effective, they can also negatively affect social structures, especially if the information that is shared concerns money [65], [91].

Social cohesion can also be a driver for community engagement and service provisioning. In several EU projects, energy communities (ECs) are involved in different ways: they may align with the citizen energy community (CEC) or renewable energy community (REC) definitions, or they may be initiated by external partners. In terms of social cohesion, a difference in the engagement of members in top-down developed ECs (initiated by external partners) can be observed compared with that in bottom-up developed ECs (initiated by a collective of citizens or neighbours). **When an EC is created bottom-up, the members are actively engaged from the start** [92]. **In contrast, when created top-down, the urgency and relevance come from external stakeholders, and households need to be made aware, interested and engaged.** The amount of social cohesion and member engagement in a local EC also seems to be an indicator for the adoption rate of energy-related products and services put forward by ECs. Social cohesion within an EC depends on geographical spread, group size, group composition, method of communication and culture [86]. **The results of a survey of 206 collective action initiatives across six European countries (Belgium, the Netherlands, Italy, Poland, Estonia and Spain) point to the role of collective initiatives such as ECs as vehicles to promote and increase citizen participation in energy transitions, encourage social change and foster social innovation.** The social aims of these initiatives include financially promoting local projects, empowering young people and fostering social inclusion of all genders in the initiative [93].

ECs are not only driven from the bottom up, but also enabled through institutional frameworks, such as the Energy Efficiency Directive (EED). Consumer ownership or co-ownership in renewable energy is seen as the cornerstone of the overall success of the CET, and is expected to be embedded in ECs that bring together a wide variety of actors [94]. **A recent European Commission staff working document has highlighted the need to combine user-led initiatives and top-down regulatory activities, clarifying the use of regulatory sandboxes, testbeds and living labs to support regulators and innovators in their approach to experimentation in the context of the New European Innovation Agenda and the REPowerEU Plan** [95].

2.1.4.3. Collective demand-reduction approaches

Despite the fact that collective energy action initiatives – such as energy cooperatives, community energy groups, associations of consumers, and collective purchasing groups – have long been a feature of the European energy system, EU legislation has only recently recognised jointly acting renewable self-consumers and active consumers, as well as CECs and RECs, as an effective and necessary way to contribute to inclusive energy transition [96]. **The contribution of RECs to reducing demand has been explored less than their capability to generate renewable energy** [36].

The flexibility provided by local ECs could enable locally produced energy (and possibly storage) to be better balanced. Here, again, social cohesion, the governance structures of RECs and CECs and the way these are designed are an essential part of doing this successfully. **For flexibility and better balancing or demand reduction, ECs provide many more opportunities compared with individual households or individuals.** Scalable solutions also have the advantage of being adjustable and practical, ensuring they are not only functionally effective but also feasible and affordable to implement. A neighbourhood battery is in many instances a better option compared with individually owned home batteries, especially when used in conjunction with other stakeholders such as industry, offices, grocery stores, etc.

Recent studies have highlighted the supporting role of ECs in demand reduction. A survey of 3,988 members of a Belgian cooperative showed a positive correlation between membership of an EC and reductions in energy demand [97]. Another study reported that 38.7% and 64.7% of the members of two ECs in Belgium and France claimed to have saved energy by joining the cooperative, but only 18% and 37% of respondents recognised the relationship between energy saving and EC measures such as an awareness-raising campaign or a change in socio-technical infrastructure [98]. A multiple case study of nine European ECs [36] analysed their potential to develop demand-side solutions to reduce energy demand and foster demand-side flexibility. The authors conclude that ECs have the capacity to develop demand-side solutions that are distinct from government- and business-led approaches, but that this presents some challenges. First, ECs would need to prioritise demand reduction in the pursuit of their other objectives. Second, opportunities are scarce to create and capture value from demand reduction, and third, the authors argue that creating innovative social configurations through network formation processes is challenging. All in all, the authors emphasise the need for ECs to operate at meso-scale level to build innovative socio-technical configurations capable of fostering demand reduction and increasing demand-side flexibility.

As with individuals, communities' actions are influenced by their values. A Dutch study [54] looked at nine different local ECs and analysed what human values [99] they address or planned to address with their EC products and services. Table 1 reports an example of how the value-based approach can help in identifying interesting propositions for a community and its members as well as what propositions will be effective, efficient and adopted by members, and why. The activities of the ECs can be related, for example, to generating, storing or saving energy, as well to other areas, such as, for example, increasing the number of local jobs.

TABLE 1: Value-based approach for identifying interesting propositions for energy communities

Socio-economic factor (value)	Energy community activity
Improving the local labour market (money-luxury)	ECs can increase the number of local jobs.
Proving autonomy and independence (autonomy-independence)	Generating and storing energy locally increases independence from external supply.
Providing a feeling of competence for members (competence-confidence)	Combining complementary competences increases reliability within the community.
Providing a feeling of relatedness (relatedness-belongingness)	Shared assets, decision-making processes and problem solving support a sense of community.
Providing a feeling of influence (influence-popularity)	Small community size enables greater influence on the governance of the community.
Providing means for pleasure and stimulation (pleasure-stimulation)	Additional services improve housing, recreation, communication opportunities and the living environment.
Safety and control (security-control)	Higher financial autonomy for investments can contribute to security of supply and cost control.
Providing financial means and security (money-luxury and security-control)	Joint revenues enable cheaper or more reliable products/services (e.g. reimbursement for providing flexibility).

Overall, the existing literature underscores the need to consider individual, socio-economic, socio-demographic and psychological traits when analysing energy behaviours, aiming to encourage energy-saving actions. Below, we have highlighted the research areas that are key for ensuring the desired impact of behavioural change policies:

1. **Understanding energy community dynamics:**
   - → Conduct research into EC characteristics, cultural dimensions and household characteristics to strengthen social cohesion.
   - → Utilise existing data resources on ECs in Europe to facilitate this research.

2. **Investigating global perspectives on energy demand reduction:**
   → Adopt a global view of energy demand reduction, integrating the "innovation for need" perspective, often prevalent in the Global South, with the "innovation for comfort" approach, typical in developed economies.

3. **Incentive analysis for energy consumers:**
   → Investigate to better understand what incentives, especially non-monetary ones, are effective, under what circumstances, and for which groups of energy consumers.

4. **Dynamics and impact of environmental movements:**
   → Study the dynamics and power of environmental movements, including activists and social media, to ascertain how they can better bridge the value-action gap.

5. **Cross-cultural effectiveness of demand reduction strategies:**
   → Examine cultural variations in the effectiveness of demand-reduction strategies across Europe to inform more culturally sensitive and effective policymaking at regional and local levels.

2.2. ENERGY EFFICIENCY

HIGHLIGHTS OF THIS SECTION:

- **Advances in energy efficiency do not necessarily result in reduced consumption owing to increased energy services.**
- **A holistic approach, from design to operation, is crucial for optimal energy efficiency, particularly in buildings.**
- **Limited investments, particularly in energy efficiency of industrial processes, hinder the realisation of full potential in energy efficiency.**
- **Scattered R&D for industrial heating and cooling technologies hinders the acceleration of energy efficiency and decarbonisation in industry.**

2.2.1 Definitions of energy efficiency

This section provides definitions of energy efficiency in different sectors and discusses how changes in energy efficiency impact energy demand. The goals or targets set in policies are compared with actual energy use in the three main energy consumption sectors: buildings (including households), industry and transport. Finally, barriers and drivers for efficiency improvements are briefly discussed before identifying the prominent issues for the selected areas.

Energy efficiency in different sectors is defined as follows:

- Energy efficiency **in buildings** refers to the practice of designing, constructing and operating buildings in a way that minimises the energy consumption required for heating, cooling, lighting and powering various building systems while maintaining or improving comfort, functionality and performance. From an end-user (i.e. citizen) perspective, energy efficiency is the ratio between the final energy consumption and the energy service that is provided by an end-use technology.

- Energy efficiency **in industry** refers to minimising energy use in the production of a product. It can be enhanced by refining processes or by transitioning to alternative energy sources. Additionally, it encompasses the potential recovery and utilisation of excess energy, such as residual heat and other by-products.

- Energy efficiency **in transport** refers to the use of energy to move an object from point A to point B using a given mode of transportation.

2.2.2. Current state of energy efficiency in different sectors

The EU's energy efficiency targets for the year 2020 were set by the Energy Efficiency Directive 2012/27/EU (EED) [100] and the Energy Performance of Buildings Directive 2010/31/EU (EPBD) [101]. Article 3 of the EED states that the EU shall reduce primary energy consumption (PEC) and final energy consumption (FEC) by 20% by 2020 compared with the energy consumption projected in the 2007 PRIMES model scenario for 2020.

According to the EU's 2022 report (ref. COM(2022) 641 final) [102], both the PEC and FEC targets were achieved. However, the COVID-19 pandemic and the consequential lockdowns resulted in lower energy demand in 2020, which was an important factor in reaching the 2020 targets.

The recast EED mandates that EU countries must now achieve cumulative end-use energy savings for the period 2021-2030. This is equivalent to new annual savings of at least 0.8% of FEC from 2021 to 2023, at least 1.3% from 2024 to 2025, 1.5% from 2026 to 2027 and 1.9% from 2028 to 2030 [100].

FIGURE 7:
Final and primary energy consumption trends in the EU27 and the 2020 PEC and FEC targets (red and blue dots) [102]

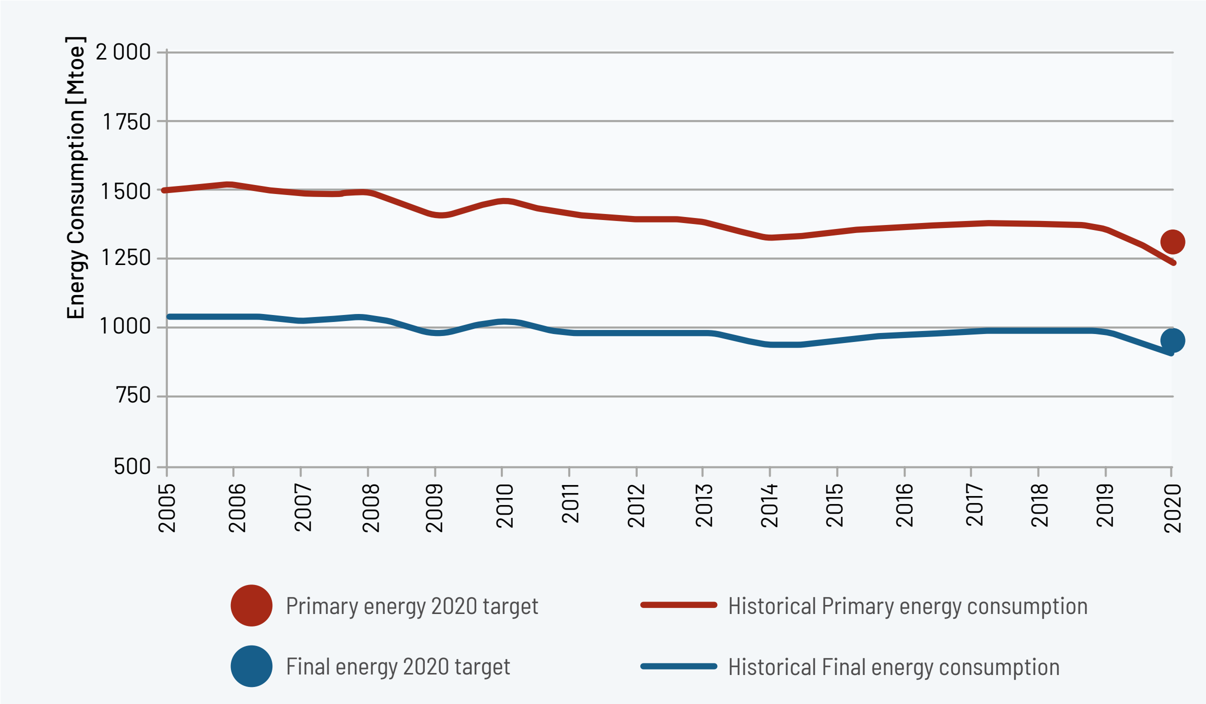
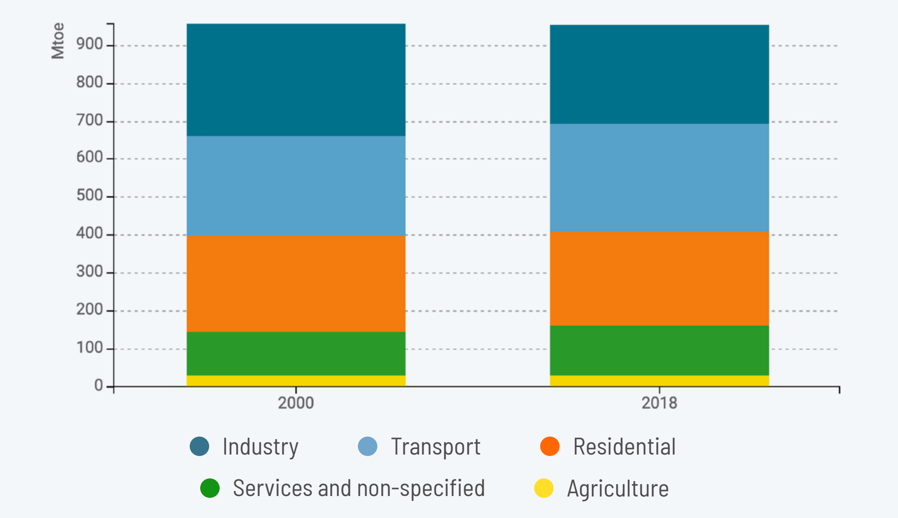


Figure 7 illustrates the primary and final energy consumption trends in the EU27 from 2005 to 2020. There is a clear downward trend in the PEC (top line in red), while the FEC remains relatively stable over the same period (bottom line in blue). The reason behind this is the improvement in technical energy efficiency, which is measured by the ODEX index, indicating the overall energy efficiency progress for each end-use sector and for the entire economy (see Figure 8).

FIGURE 8:
ODEX – technical energy efficiency index in the EU from 2000 to 2018 [103]

FIGURE 9:
Final energy consumption in the EU by sector in 2000 and 2018 [103]



While it is crucial to acknowledge that enhancements in energy efficiency do not necessarily lead to reductions in final energy consumption, in numerous instances, increased efficiency is counterbalanced by a corresponding increase in energy service. For example, improved energy efficiency in buildings can be nullified by increased heated surface area per person; in transport, advances in engine efficiency can be countered by larger, heavier vehicles such as SUVs, and the proliferation of domestic appliances negates the efficiency improvements made on individual units.

This phenomenon is vividly depicted in Figure 9, demonstrating that despite the efficiency improvements in all end-use sectors, as indicated in Figure 8, final energy consumption has largely remained stable since 2000.

This highlights the inherent limitations of relying solely on energy efficiency as a strategy to reduce demand and emphasises the vital roles of energy sufficiency and behavioural change. These are complementary components of energy efficiency initiatives necessary to achieve energy demand-reduction goals.

2.2.2.1. Energy efficiency in buildings

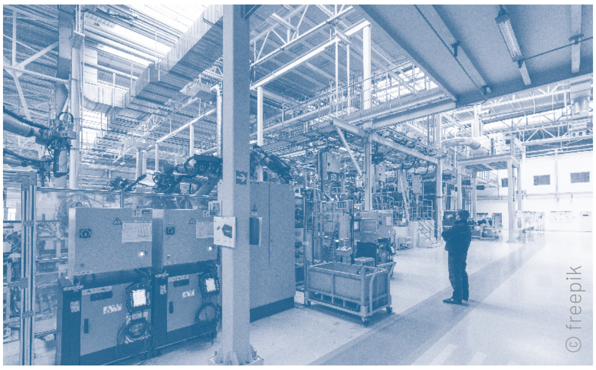
Currently, 75% of the EU's existing building stock has poor energy performance and accounts for about 40% of EU energy consumption and 36% of energy-related GHG emissions [104]. With clear targets for nearly zero-energy building (NZEB) renovation, energy-efficient measures are the first step to achieving better performance and consistently reducing energy demand. The second step towards NZEB renovation is the maximisation of renewable energy generation on-site. An efficient building operation and optimal use of renewables could be achieved through energy flexibility solutions and strategies such as effective monitoring, ICT and smart technologies, providing direct interaction with building occupants and the buildings' environment [105].

Improving energy efficiency in buildings can best be implemented by starting at the design stage. Energy efficiency measures can save up to 36% by combining shape factor, orientation, heating solutions, level of insulation, etc. On the other hand, energy-efficient building elements may not perform efficiently if poorly constructed.

At the building operation stage, the actual energy consumption in buildings can be up to as much as 2.5 times higher than the predicted energy use despite a growing supply of newly built energy-efficient housing and energy-efficient renovations. Studies suggest that this unexpectedly high energy use may be explained by rising expectations of occupant thermal comfort. Maintaining a satisfactory thermal environment for occupants is an important part of the built environment, affecting not only health and wellbeing but also the productivity of building occupants [106]. Although building systems rely on standards to define occupant comfort ranges, these standards do not always reflect the preference of users, and, thus, users may interact with building systems and significantly increase energy consumption [107].

Consequently, a **holistic approach to the built environment that includes the design, construction and operation stages is critical for energy efficiency in buildings.**

2.2.2.2. Energy efficiency in industry



Energy efficiency in industry is intrinsically linked to decarbonisation. While it is possible to move towards decarbonisation in industry using renewable fuels and carbon capture and storage (CCS) technology, and improving the energy efficiency of industrial processes, it is vital to understand the pivotal role of energy efficiency. By enhancing this, the need for renewable energy inputs and the use of CCS can be directly reduced. This would mean direct cost savings; additionally, fewer resources would be required in terms of space and raw materials essential for renewable technologies such as wind turbines and PV panels, concurrently reducing the need to expand gas storage facilities and lowering the associated costs and energy demands of CCS. **The current challenges with large-scale electrification of industrial processes, such as limited renewable electricity availability and grid constraints, can be significantly alleviated through energy efficiency.** Reducing overall energy requirements for electrification makes it cheaper and easier to electrify processes.

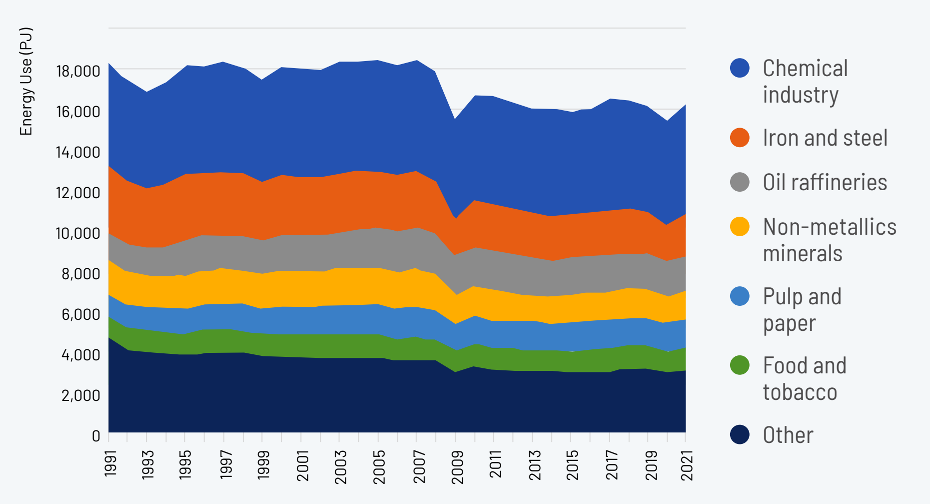
Essentially, prioritising energy efficiency makes the subsequent steps towards decarbonisation using renewable generation and CCS more attainable. This is why the "energy efficiency first" principle should be a cornerstone of climate strategy and the CET.

Industrial energy use in the EU as a proportion of overall energy use fell slightly from around 31% in 1990 to 27% in 2018 [108]. Due to high reliance on fossil fuels, the share of GHG emissions from industry is substantial, accounting for 25% of the EU's emissions in 2020 [109]. This excludes indirect emissions from the electricity purchased by industry.

The mix of energy carriers used in industry is important for understanding the huge decarbonisation challenge for industry. **On average, fossil fuel consumption accounts for 67% of industrial energy use, while electricity consumption is at 22%** [110]. The chemical industry and oil refineries consume mainly oil and natural gas, while the iron and steel sectors use the highest share of coal among other industries.

Figure 10 shows the trend in industrial energy use per sector in the period 1991-2021. **From 2010 until 2021, energy use in industry in the EU did not change significantly, despite all the policy efforts directed at increasing energy efficiency. This is even more remarkable given that a significant share of energy-intensive industry was offshored to non-EU countries during this period.**

FIGURE 10: Industrial energy use in PJ in the EU27, including feedstocks [110]



It is important to highlight that some of the recent EU policies, such as the Critical Raw Materials Act (CRMA) and the Net Zero Industry Act (NZIA), are most likely going to increase energy demand in the EU's industrial sector in the years ahead. Indeed, as will be discussed in more detail in Section 3, by aiming to shorten the value chains for CRMs on the one hand and clean tech on the other, both of these Acts are expected to contribute to reshoring in Europe energy-intensive mining and industrial activities that have long been outsourced by the EU to other parts of the world, and thus will most probably lead to an increase in EU energy demand.

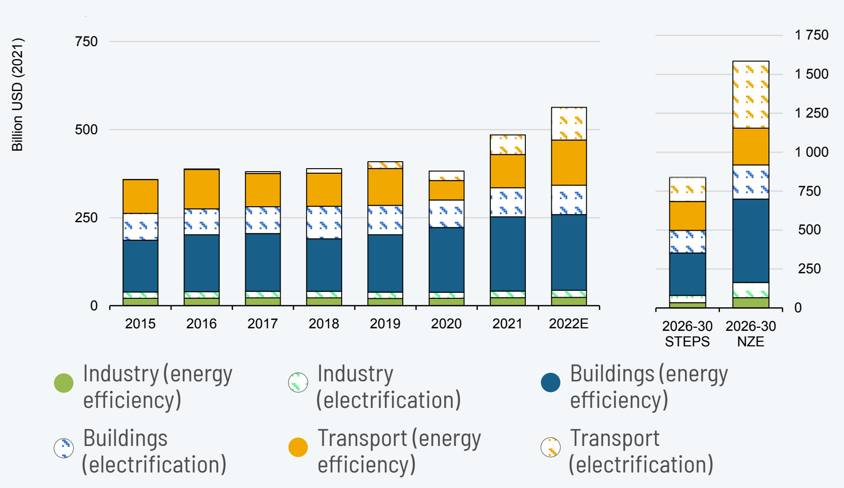
2.2.3. Barriers to energy efficiency improvements and ways to address them

This section discusses the main barriers and ways to address them in order to enhance energy efficiency. As a result of the Russian invasion of Ukraine, Europe faced a significant disruption in gas supply, which triggered skyrocketing energy prices in 2021-2022. This situation underscored two important findings. First, it showed that price signals had a more pronounced and rapid effect on energy demand than initially expected. Second, it highlighted the inherent inertia of the energy system, emphasising that significant shifts in demand or transitions to alternative energy sources are not instantaneous processes. These two insights form the basis for the barriers discussed in this section.

2.2.3.1. Investment

Access to adequate funding is one of the main barriers to capital-intensive energy efficiency improvements. Figure 11 shows the IEA estimates of how much more investment in energy efficiency per sector will be needed to reach net-zero goals in comparison to current investments. It can be seen that the global yearly investment level increased by about 70% between 2015 (USD 350 bn/year) and 2022 (USD 600 bn/year). In terms of proportion, both the building and transport sectors significantly outpace the industry sector in receiving investments, leaving the latter substantially underfunded.

FIGURE 11: Global energy efficiency-related end-use investment, 2015-2022, and averages by scenario, 2026-2030 [108][7]



Note: Energy efficiency investment comprises the incremental spending on new energy efficient equipment as well as the full cost of refurbishments that reduce energy use, which allows for capturing all spending that leads to reduced energy consumption. Investment in energy efficient transport comprises additional spending on efficient road vehicles and road electric vehicles, including plug-in hybrid vehicles.

7. STEPS (Stated Policies Scenario) is the IEA scenario exploring where the energy system might go with the current policy commitments and without a major additional steer from policymakers. NZE (Net-Zero Emissions Scenario) is a normative IEA scenario that shows a pathway for the global energy sector to achieve net-zero CO_2 emissions by 2050, with advanced economies reaching net-zero emissions in advance of others.

2.2.3.2. Rebound effect

The rebound effect (RE) is recognised as one of the most significant barriers to achieving the intended energy savings resulting from energy efficiency measures.

It is a complex phenomenon that arises when energy consumption evolves differently than expected after energy efficiency improvements have been implemented. Rebound effects explain the unexpected energy savings percentage after efficiency improvements [111]–[115].

The RE, which traces its origins back to Jevon's seminal work in 1865, has been explored extensively in multiple studies [73], [116]–[121]. This effect has been examined in households, transport and industry [53], [121], [122].

There are two primary causes of REs:

1. **Direct rebound effect** occurs when energy services become more affordable due to efficiency improvements; their demand might rise, leading to higher energy use. This effect is driven by the reduced real unit price of these services.

2. **Indirect rebound effect (income effect)** occurs when the savings from these cheaper services allow consumers to invest in other energy-related goods or services, causing an indirect increase in energy consumption.

Additionally, REs are also influenced by psychological factors, particularly "moral self-licensing" [123]. After implementing energy-saving measures, consumers may feel morally justified in using more energy elsewhere, a behaviour seen in other contexts as well [124].

Size-wise, REs can vary extensively, from more than +100% to less than -100% [125]. Here is how they break down:

- **Backfire effects (> 100% RE):** energy use rises above its original level after implementing efficiency measures.
- **Partial conservation (0-100% RE):** actual savings are less than expected, but still positive.
- **Zero rebound (0% RE):** expected and actual energy savings align perfectly.
- **Prebound effects (negative RE):** actual energy savings exceed expected savings [126].
- **Negative rebound (< -100% RE):** energy consumption drops far more than expected, resulting in even more significant savings [68].

Essentially, while energy efficiency improvements aim to reduce consumption, they do not always yield the expected energy savings. Indeed, energy use may even increase if energy efficiency measures are implemented without proper management of REs. It is therefore crucial that these measures are designed and implemented with full consideration of the potential implications of possible REs.

2.2.3.3. Barriers and enablers related to energy efficiency specifically in buildings

Various studies emphasise the variety of barriers preventing optimal energy efficiency in buildings. These range from financial to behavioural and informational challenges. To promote a more energy-efficient future, it is vital to understand these barriers and actively work towards implementing enablers. A summary of the most relevant is provided below.

1. **Complexity barrier:**

✗ Energy efficiency potentials vary based on location and end-user category, making it challenging to standardise incentives. The variety of available technologies can make it difficult for households to identify the best choices.

✓ Enablers: simplified guidelines and recommendations for households based on their specific needs and locations can help address the complexity challenge.

2. **Existing inefficient buildings:**

✗ A significant proportion of existing buildings have poor energy efficiency levels and require significant retrofit.

✓ **Enablers**: retrofitting and upgrading can be encouraged by leveraging the following measures:

- *Building envelope enhancements:* the foundation of energy efficiency lies in prioritising elements such as walls, roofs, windows and insulation. By using advanced techniques involving superior insulation and phase-change materials, temperature can be effectively regulated and heat transfer can be reduced.
- *Sustainable retrofits:* a circular economy approach is gaining traction, especially during renovations. Use of sustainable materials not only reduces environmental footprint but also ensures the longevity and efficiency of the retrofitted structures.
- *Net-zero energy designs:* the future of building design is aiming for a balance, with structures producing as much energy as they consume. Passive house design principles are at the forefront of this shift, pushing the boundaries of what buildings can achieve in terms of energy self-sufficiency.
- *Innovative techniques for energy-use optimisation:* a mix of nature-based solutions, dynamic shading systems and advanced glazing technologies is being widely adopted. These techniques not only enhance aesthetic appeal but also optimise light infiltration and thermal performance, ensuring a comfortable and energy-efficient indoor environment.

- *Maximising the capabilities of building energy management systems (BEMS) and smart appliances within the Internet of Things (IoT)* can substantially improve energy efficiency by optimising building operations and energy use, fostering more sustainable energy management practices.

3. User behaviour:

✗ Energy wastage often results from user negligence (e.g. forgetting to turn off lights or HVAC systems during unoccupied hours), poor usage or incorrect energy regulation system settings.

✓ **Enablers**: human-centric design principles applied in building architecture can enhance comfort and reduce energy wastage. Studies that focus on psychological and sociological drivers can trigger design interventions and promote energy-saving behaviour.

4. Unregulated energy consumption:

✗ Up to 50% of a building's energy use can come from unregulated sources, such as lifts, security and server rooms. Poor maintenance, extended hours in service and lack of occupant awareness exacerbate the issue.

✓ **Enablers**: to overcome this obstacle, building regulations can be enacted to mandate energy efficiency standards for systems linked to unregulated energy consumption. Furthermore, launching educational campaigns can help promote energy-saving habits.

5. Techno-economic analysis limitations:

✗ Techno-economic analysis may overestimate the adoption of energy efficiency measures due to non-rational user decision-making processes.

✓ **Enablers**: interdisciplinary collaboration incorporating models such as agent-based modelling (ABM) can simulate human behaviour more accurately.

6. Access to information:

✗ The gap between predicted and actual energy consumption in buildings hampers effective policy decisions.

✓ **Enablers**: advanced modelling and simulation tools, AI and integration of IoT sensors can aid in designing energy-efficient buildings. BEMS can optimise energy consumption in real time.

7. **Infrastructure and grid limitations:**

The infrastructure may not be equipped to integrate local/distributed energy storage solutions effectively.

Enablers: holistic approaches and strategies to upgrade infrastructure, backed by strict building codes and regulations.

8. **Public sector opting for "low-hanging fruit":**

Public authorities often favour simpler, cheaper and shorter-term energy efficiency measures.

Enablers: to resolve these issues, energy efficiency strategies should harmonise technical and economic innovations with social considerations [127], [128] and incorporate intelligent, criteria-based decision-making to ensure a balanced focus on short-, medium- and long-term impact measures, preventing overemphasis on immediate impacts.

9. **Policy-related barriers:**

Several barriers affect efficient policymaking relating to energy efficiency and result in government programmes often delivering well below expectations. These include: 1) lack of public leadership concerning green procurement practices; 2) inadequate energy poverty policies; 3) failure to protect vulnerable groups in the population; 4) insufficient consideration of the impact of specific regional characteristics; 5) inefficient or outdated building codes and standards.

Enablers: a number of strategies can alleviate these barriers and support better policymaking. These include:

- Continuous assessment and iterative refinement of existing government programmes to make them more effective.
- Fostering stronger leadership from the public sector, implementing green procurement strategies, promoting green initiatives and setting a standard for others to follow.
- Creating a standardised energy performance certification system with consistent benchmarks, providing a reference framework for energy users to assess and improve their energy efficiency practices.

Understanding the intricate web of barriers and enablers associated with energy efficiency in buildings is paramount not only for designing effective solutions but also for directing future research and policy. Each identified barrier and its corresponding enabler should be viewed as a priority for both research and policy.

2.2.3.4. Barriers and enablers related to energy efficiency specifically in industry

In this section, we discuss barriers to adopting energy efficiency measures in industry and suggest corresponding enablers that alleviate these barriers.

1. **Insufficient focus on energy efficiency in industry**

This is the most important barrier. The potential impact of energy efficiency measures within the industrial sector has long been undervalued in both national and European policies and R&D strategies. Given that the majority of industrial energy (69%) is used for heating and cooling, these areas deserve the highest priority.

Enablers: researchers in energy efficiency have highlighted gaps in European policies and R&D agendas. In particular, the white papers published by the EERA Joint Programme on EEIP, "Strengthening Industrial Heat Pump Innovation: Decarbonizing Industrial Heat" [129] and "Industrial Thermal Energy Storage: Supporting the Transition to Decarbonise Industry" [130], offer targeted and concrete proposals to increase the efficiency of energy-intensive industrial processes. EERA's recent policy brief on the recast EED suggests a series of actions for the European Commission to boost energy efficiency in industry and fast-track EU-wide R&D on energy-efficient technologies [105]. The recommended actions and topics are detailed below.

- **Investment and collaboration**
  - Increase investments in energy efficiency in the industrial sector in Europe and target a 15% reduction in global energy demand by 2040.
  - Showcase industry demonstrations with lighthouse projects[8].
  - Enhance collaboration between energy-intensive industries and power companies to utilise surplus heat.
- **R&D and technology advances**
  - Push R&D to develop technologies reducing specific energy consumption needs: efficient separation, process intensification, energy-efficient drying solutions, and heat-to-power technologies.
  - Prioritise thermal energy storage solutions to stabilise waste heat supply.
- **Create demand for energy efficiency solutions in industry**
  - Implement energy management systems for better consumption analysis and efficiency gains.
  - Establish energy efficiency regulations, possibly including import taxes on high carbon footprint products.

8. Lighthouse projects are strategic initiatives developed to implement technologies aimed at resolving universally shared concerns within a sector. They act as demonstrative guides, or "lighthouses", for other companies in the sector, facilitating standardisation and aiding the adoption of technology to tackle societal challenges.

- **Engage all parts of the value chain**
  - Promote energy efficiency partnerships across different industries and locations.
  - Develop sectoral plans for energy reduction in industry targeting 2050.

- **Prioritise heating and cooling innovations**
  - Develop and showcase next-generation heating and cooling technologies for a climate-neutral future by 2050.
  - Reduce costs and enhance integration of heat pumps in industrial processes.
  - Advance electrical heating technologies with a focus on capital expense reduction and energy efficiency.
  - Digitise and reduce costs of solar thermal heating applications.
  - Promote projects integrating renewable heat and fuels, emphasising heat storage technologies that address both short- and long-term needs.

- **Support R&D on industrial heat pumps**

Current heat pump technologies have limitations for higher-temperature applications, significantly preventing their large-scale use in industrial processes. A number of possible solutions have been analysed in the EERA JP EEIP white paper [129], including:
  - Create an EU-wide programme promoting cutting-edge R&D and demonstration projects on industrial heat pumps.
  - Develop and demonstrate heat pump technologies targeting supply temperatures between 100°C and 200°C.
  - Conduct research on technologies aiming above 200°C.
  - Enhance performance and devise a strategy for the transition to renewable process heat systems.
  - Encourage cross-industry collaboration.

- **Support thermal energy storage (TES) technologies**

There are many limitations in exploiting the potential of TES technologies. These include the absence of accessible materials databases and standard metrics and the lack of awareness and knowledge-sharing on the benefits and applications of TES (white paper on "Industrial Thermal Energy Storage: Supporting the Transition to Decarbonise Industry" [130].

The main solutions to alleviate limitations include:
- Initiating targeted TES R&D programmes at regional, national and EU levels.
- Prioritising techno-economic studies and demonstration projects with open-access results.
- Developing a uniform TES materials database and establishing an independent testing institute.
- Building a community involving industry, policymakers and stakeholders to share best practices and disseminate the benefits of TES in industry. This would also aim to reduce financial risks through standardised systems and information-sharing.

2. High upfront costs and limited access to financing

Implementing energy efficiency measures requires significant upfront investment and this often constitutes a barrier to implementation. Most energy efficiency upgrades require substantial capital investment, which can be challenging for companies to justify in the absence of immediate returns and/or guaranteed payback time. This particularly affects SMEs, which, more so than large firms, usually struggle with an inability to allocate time and resources for energy efficiency improvements. Furthermore, even when companies recognise the benefits, accessing the necessary financing remains a hurdle. This is especially a problem for SMEs. Additionally, many smaller companies, particularly SMEs with limited technical expertise, are often unaware of the potential benefits of energy efficiency and of available funding schemes [68]. This knowledge gap is a major obstacle to adopting energy efficiency measures.

Enablers: some of the potential enablers alleviating this barrier could be governments providing tax breaks, subsidies or grants for businesses that invest in energy efficiency upgrades. This could significantly reduce the initial financial burden on organisations. Additionally, financial institutions could offer tailored financing options, such as low-interest loans or longer-term repayment schemes specifically designated for energy efficiency projects. This can make such projects more attractive and attainable for companies wary of the upfront investment cost. Organising training programmes can inform businesses about the long-term financial benefits of energy efficiency measures. A well-informed decision-making process is more likely to result in energy efficiency investment.

3. Organisation-level barriers

Organisational structure and culture can also hinder implementation of energy efficiency measures. For example, employees might resist changes to their routines, and there could be communication gaps between departments. Organisational characteristics are key to unlocking the full potential of industrial energy efficiency, as pinpointed by Thollander et al. [131].

Enablers: organisations should further emphasise energy efficiency strategies, in particular by embedding energy efficiency goals within their management and operational structures.

4. Broad scale of energy efficiency solutions

Energy efficiency technologies and solutions vary significantly by industrial sector and often even by individual industrial site. Specific technological developments that can reduce energy consumption in industrial processes include: 1) efficient separation technologies; 2) process intensification; 3) implementation of industrial heat pumps; 4) energy-efficient solutions for drying and dewatering; 5) heat-to-power technologies and TES solutions for peak shaving and better utilisation of fluctuating heat losses.

✓ **Enablers:** to address this issue, tailored solutions should be adopted for each industrial sector and/or industrial site.

5. Limits of electrification of industrial processes

✗ While electrification through renewable energy technologies is pivotal for decarbonising industry, its main application remains in low-temperature industrial processes. High-temperature process applications remain challenging and hard to decarbonise.

✓ **Enablers:** to address this barrier, incorporation of digitalisation, process automation and circular principles is important. These can enhance flexibility in manufacturing plants and optimise energy consumption, thereby reducing GHG emissions. To truly enhance efficiency, a comprehensive understanding of the industrial production life cycle is imperative. A prominent example is the harnessing of waste heat. Here, circularity goes beyond merely reusing waste. Instead, it encompasses a holistic approach to planning design, production and renovation processes in both the industrial and building sectors [105].

By tackling these barriers using the corresponding enablers, industry can make significant energy efficiency improvements. Combined with the decarbonisation agenda, this can substantially reduce energy consumption within the industrial sector.

2.3. ENERGY SUFFICIENCY

HIGHLIGHTS OF THIS SECTION:

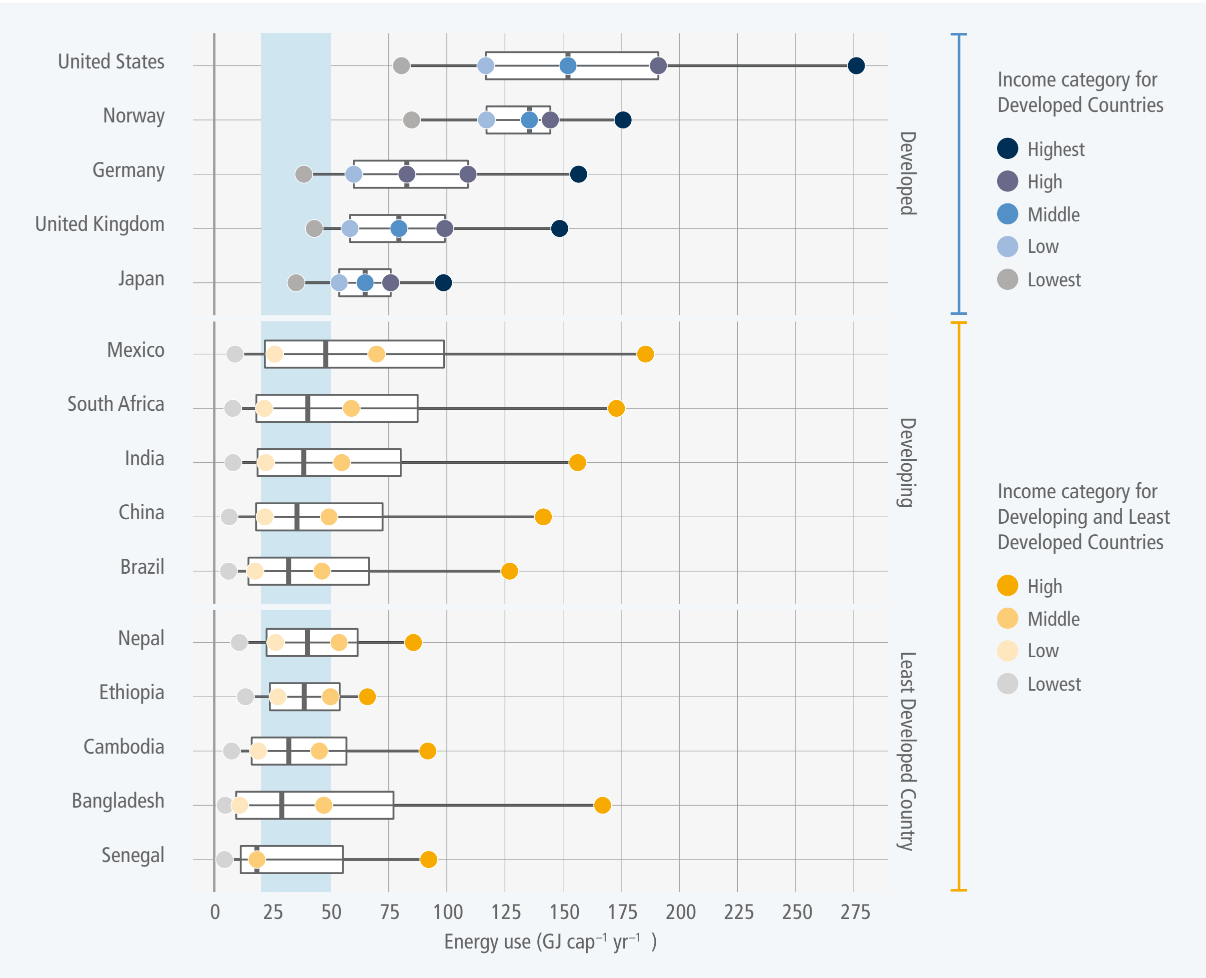
- Energy sufficiency has significant potential for long-term energy reduction and is crucial for Europe's strategic autonomy.
- Achieving sufficiency requires changing deep-rooted social practices related to energy consumption.
- Although complex, integrating energy sufficiency into policy-making is possible with existing conceptual tools and theories.
- Current EU and national frameworks incorporate sufficiency elements but do not label them as such. The Sufficiency Policy Database [132] is a key resource, cataloguing diverse sufficiency-focused strategies.
- Interdisciplinary research is pivotal in forming effective energy-sufficiency policies and altering unsustainable growth patterns.

2.3.1. Energy sufficiency: definition and related concepts

2.3.1.1. Energy sufficiency and human wellbeing

Among the various energy demand-reduction strategies, energy sufficiency is the concept most closely and conceptually interconnected with wellbeing. The decent living standard (DLS) framework mentioned in Section 1 is especially relevant in relation to energy sufficiency, because it provides not only a conceptual but also a quantifiable foundation for it. Research on DLSs concludes that a universally accessible, efficient infrastructure – primarily in the form of public services – is crucial in maintaining or attaining wellbeing levels that are in harmony with climate objectives. Figure 12 is a good illustration of what the difference between sufficient and actual energy consumption might look like. It illustrates the stark contrast between the energy use of the world's richest and poorest nations against the DLS benchmark (20-50 GJ/capita/year), shown as the area in blue. This disparity, both across and within countries, intensifies concerns about justice and challenges our collective endeavour to attain global wellbeing within our planet's boundaries [133]–[135].

FIGURE 12:
Yearly energy use per capita in different countries against a DLS benchmark [7]



2.3.1.2. Difference between energy sufficiency and energy efficiency

The concept of a "sufficiency economy", which means ensuring there is enough for everyone, has been gaining traction as an essential alternative to mainstream ideas like green growth, efficiency and technology-driven solutions. While these popular approaches have struggled to fully address pressing environmental and social issues, climate change being the most urgent of them [136], the sufficiency model offers an alternative perspective.

Energy sufficiency, a relatively newer concept compared with energy efficiency, offers a unique perspective on energy demand reduction. In contrast to the conventional efficiency model, which gives priority to minimising resource use per unit of output, sufficiency instead emphasises reducing the quantity of output to be produced and consumed. This approach aims to reduce overall consumption to sustainable levels while simultaneously achieving a sustainable level of wellbeing for individuals. The broader aim is to curtail the resources our societal and economic systems consume, thus mitigating the total outputs produced. Even though there are various definitions of sufficiency and several unanswered questions about its implementation, all emphasise a transformative change in our production and consumption habits.

Although there is some overlap between the two concepts, they are not identical. At times, this distinction becomes blurred in policy conversations. Table 2 clarifies the differences, highlighting the contrasts between energy efficiency and energy sufficiency across five essential categories.

TABLE 2:
Comparison between energy efficiency and energy sufficiency

Criterion	Energy efficiency	Energy sufficiency
Goal	Reducing energy input per output (relative reduction)	Reducing the aggregated use of energy (absolute reduction) without compromising the level of wellbeing
Assumption	Reduction in energy demand can be achieved through technological improvements increasing energy productivity	Reduction in energy demand can be achieved by avoiding or shifting energy services (both direct and indirect)
Scope	Targeting specific sectors such as: - Industrial and production processes - Domestic energy uses (heating, lighting, etc.) - Transport (e.g. electric vehicles replacing conventional cars)	Focus on energy services and needs, as well as social practices that encompass several energy-consuming sectors
Type of innovation	Primarily technological, but also digitalisation and business models	Social and socio-technical innovation
Operational timeframe	Short to medium term	Medium to long term

2.3.1.3. Approaches to define energy sufficiency and its "building blocks"

Energy sufficiency, a paradigm increasingly prevalent in the discourse on sustainable practices, has been explored and defined by numerous scholars and institutions in recent years. According to the IPCC [7], it encompasses "a set of measures and daily practices that avoid demand for energy, materials, land and water while delivering human well-being for all within planetary boundaries". This perspective is echoed by Zell-Ziegler and Thema [137], who emphasise the strategy's pivotal role in achieving absolute reductions in the consumption of energy-based services. This is achieved notably by endorsing intrinsically low-energy activities, aiming for a level of "enoughness" that guarantees sustainability. Furthermore, Saheb [138] stresses the importance of adapting lifestyles to remain within planetary confines. This involves tweaking policy measures and everyday behaviour to curtail demand for energy, materials, land, water and other resources. The ultimate goal is to maintain quality of life for all populations without overstepping our planet's boundaries. Lage [139] offers a double-sided approach to energy sufficiency. The first addresses the quantitative limitations of consumption and production, targeting both overconsumption and deprivation. The second highlights the significance of social innovations crafted to transform societal practices. Moreover, Darby and Fawcett [140] conceptualise energy sufficiency as a state wherein individuals' fundamental requirements for energy services are met equitably, while ecological constraints are observed. They regard it not merely as a state but as an organising principle vital for attaining this balance. Lastly, Dufourunet et al. [141] stress the need to rethink and restructure both collective and individual practices. The objective is to champion intrinsically low-energy activities and services, ensuring alignment with the planet's ecological limits. They advocate comprehensive reflection on diverse aspects, including human needs, social equity, economic growth, urban configurations, social norms and consumption habits.

Based on the definitions provided, **energy sufficiency emerges as a ground-breaking social innovation. It harmonises energy resources and consumption by thoughtfully re-evaluating human needs, prompting profound systemic shifts**. These shifts foster diverse practices and activities to fulfil these needs, all within planetary boundaries (termed "consumption corridors" [142]). While energy sufficiency promotes an overarching reduction in energy demand, it is essential to stress that this reduction should not be regarded as being universally applicable, as the true essence of sufficiency lies in ensuring a dignified life for everyone. This implies that certain parts of global society (e.g. countries, regions or specific groups) might need to reduce their energy consumption. In contrast, others might maintain or potentially increase theirs. From the literature and practices on energy sufficiency, we have identified its "building blocks" as follows:

1. Focus on energy services and final uses
   - Questioning the final purpose of the uses of energy instead of focusing on maximising energy generation efficiency.
   - Ensuring availability and accessibility of energy services to social actors such as families, businesses and the public sector.

2. Absolute reduction of energy use
   - Prioritising absolute energy consumption reduction instead of relative reductions due to efficiency gains.
   - Eliminating activities and processes requiring excessive energy.
   - Avoiding energy use instead of enhancing it.

3. Harmonising planetary wellbeing and social sustainability
   - Promoting "ecological" change, with lower consumption also reducing use of other finite resources (water, soil, critical minerals, carrying capacities of ecosystems, etc.).
   - Satisfying needs through social processes and human interactions, while keeping material consumption within environmental limits [136], [143], [144].
   - Balancing minimum requirements for basic needs with maximum consumption levels, considering both justice and environmental impacts [145].
   - Emphasising structural and infrastructural shifts to ensure feasibility, fairness and environmental consideration.

4. Focus on social practices and social innovation
   - Implementing disruptive and systematic changes in social practices.
   - Recognising environmentally friendly behaviour as the type to be ingrained in daily routines.
   - Moving beyond solely individual determinants of energy consumption towards understanding societal determinants.
   - Viewing sufficiency as a dynamic process, necessitating innovative approaches.
   - Requiring fundamental shifts in valuation systems (e.g. the valuation of natural resources and services), organising principles and consumer society infrastructure [145].
   - Adopting a holistic perspective to ensure interaction with domains such as living, mobility, work organisation and food.

5. Going beyond "traditional" growth paradigm towards "enoughness" and wellbeing
   - Recognising the unsustainability of current energy and resource consumption trends triggered by the growth paradigm.
   - Championing sufficiency as an alternative to the "faster, further, more" orientation of the consumer society.
   - Defining decent living standards as full satisfaction of fundamental human needs.

2.3.2. Integrating energy sufficiency into policy

Understanding how to integrate energy sufficiency principles into policy-making is not straightforward. In this section, we discuss conceptual tools and theories that could be instrumental for designing energy sufficiency policies. The proposed tools aim to help ensure that energy sufficiency policies address the societal complexity of energy use and assist in achieving a structural and long-term reduction in energy demand at the societal level. There are many theories and approaches available to aid in energy sufficiency policymaking. The primary purpose of this section is to provide examples of how research can offer valuable tools for guiding energy sufficiency thinking and policy design in Europe.

2.3.2.1. Energy sufficiency policy through the social practice theory

Finding effective approaches to implement energy sufficiency, which involves radical structural changes in societal energy consumption, requires a thorough understanding of the factors driving energy consumption within society. Here, conventional approaches based on individual behavioural assumptions and simplified views about the role of energy in society become limited. One theory that can be useful in addressing these limitations is the social practice theory.

Originating from sociological debates in the 1970s, with significant contributors like Bourdieu and Giddens, this theory has gained traction over the past two decades in sustainability debates, aiming to understand and foster shifts in resource consumption [146].

Social practice theory sees three main problems with the conventional approach to energy consumption practice and offers corresponding solutions to them.

(1) Problem with the way the energy-society interconnection is conceptualised

There is a deeply intertwined relationship between energy (both its production and consumption) and the socio-economic system. Energy systems both influence and are influenced by the broader context in which they operate. Various factors, be they economic, institutional or cultural, play a role in defining how energy systems differ across time and regions.

The social practice approach insists that energy should be viewed not just as a component of society, but more specifically as an integral element of the practices that define that society.

(2) Perception of energy consumption in isolation, disconnected from other social practices

According to the social practice theory, energy use, like all resources in social practices, gains significance only within the context of those practices. Energy is not consumed for its own sake but to carry out these practices.

Thus, to alter energy consumption, we must address and modify the associated practices. This means that the focus should not be just on "how much" energy we use, but on "why" we use it and for what specific practices.

(3) Problem with applying individual behavioural approach to understanding energy consumption in society as a whole

According to social practice theory, traditional behavioural models, such as the "portfolio model" [147], can oversimplify human behaviour. These models often assume that people consistently act based on a fixed set of values and beliefs. The driving factors behind these actions can vary, from social norms and attitudes to economic interests, depending on the academic discipline. Yet these models have their shortcomings. For example, while someone might advocate sustainable living, their actions may not always align with that belief [148].

Social practice theory therefore suggests that, rather than overly focusing on conscious decisions, it is essential to consider the strong influence of habits, routines, values and societal norms on our behaviour, as well as the socio-technical structure within which it is adopted that might enable or hamper certain courses of action.

As a summarised response to the three above-mentioned limitations, social practice theory defines social practices (e.g. driving, cooking) as routinised types of behaviour and breaks them down into three main components [149], [150]:

- **Materials:** these include objects, tools, technologies and infrastructure.

- **Competence:** this pertains to skills and know-how.
- **Meanings:** these encompass norms, cultural conventions and expectations [151].

From this viewpoint, individuals are more than just decision-makers; they are "carriers" of activities. These activities stem from wider social practices largely unaffected by personal intentions. **Thus, to achieve energy sufficiency, we must modify these deep-rooted social practices associated with energy consumption. This means creating policies that encompass all elements of social practice: materials, competence and meanings.** The core insight of the social practice theory is that efforts to change behaviour should not be narrowly focused on energy use or individual motivations. Instead, it is crucial to understand the reasons behind energy use and how various factors – material, cultural and social – shape routine actions like cooking, driving or office work, where individual choices are often limited.

A practical example of policies informed by the social practice theory emphasises strategies that avoid placing responsibility solely on individuals for sustainable choices. Instead, it recognises the complexities of larger societal structures that may encourage unsustainable habits. Such strategies may include the following [152]:

- **Re-crafting practices:** this strategy suggests focusing on enhancing skills and awareness. For example, offering cookery courses to improve culinary skills.

- **Substituting practices:** this strategy involves re-evaluating the current needs fulfilled by specific habits and finding alternatives. One example would be promoting other forms of transportation as a shift in mobility.

- **Interlocking practices:** this strategy seeks to better coordinate various habits to optimise their combined benefits. For instance, scheduling activities to avoid peak times.

2.3.2.2. Energy sufficiency policy through the dimensions of scale, time and technology

In this section, a framework is proposed for integrating sufficiency into policies. Three main dimensions of energy sufficiency are framed as three policy criteria to be carefully considered: scale, time and technology. Each has its own nuanced set of challenges and opportunities. Table 3 presents the three main domains and the associated sub-domains that can help guide policymaking processes when the aim is to incorporate an energy sufficiency policy mindset.

TABLE 3:
Energy sufficiency policy through the dimensions of scale, time and technology

Domain	Sub-domain	Associated questions and examples
Scale	Defining the boundaries	How are regional or local ecosystem conditions integrated with the broader planetary boundaries?
	Sufficiency at various levels	Is the scale of consideration a neighbourhood, city, nation or continent? Where is sufficiency most effectively implemented?
	Importance of context	Within the EU, although air quality standards apply universally, regional and local bodies craft their unique air quality plans. For instance, Austria's Climate and Energy Model Regions, envisioned by locals, aim for energy self-sufficiency using regional resources.
Time	Temporal dimensions of energy	What energy-consuming activities are more time-sensitive in terms of energy consumption, and how does this factor into the flexibility of energy systems?
	Peak times for energy demand	Energy systems are designed to manage peak demand. Shifting away from peak times can be beneficial at the system level but may impact energy service levels [153].
	"Time of use" & "Use of time"	"Time of use" becomes more important as variable renewable energy sources become integral to energy systems. The coordination of demand, storage and supply should consider time. "Use of time" refers to the pace of human activity. Here, "non-energy energy policy" has potential, such as a change of working hours, school holidays, public holidays or daylight saving [154]–[156].
Technology	Dynamic landscape	Given the constant evolution of technology, how can sufficiency policies address product and system developments effectively?
	ICT and energy demand	ICT began "smartening" electricity systems at high-voltage level decades ago and is now being used more widely to improve demand flexibility via direct load control or demand response. This raises many issues, including accessibility of ICT for different groups of users, demand-side infrastructure, tariffs, privacy, security and regulation [157].
	Limitations and uncertainties of smart technology	• Studies on intelligent technology often rely on positive presumptions, frequently overlooking the environmental consequences [140], [158]. • The expected growth of the Internet of Things may significantly increase energy consumption [159]. • Smart technologies can produce outcomes far from original intentions in both domestic and commercial settings [160]–[162].

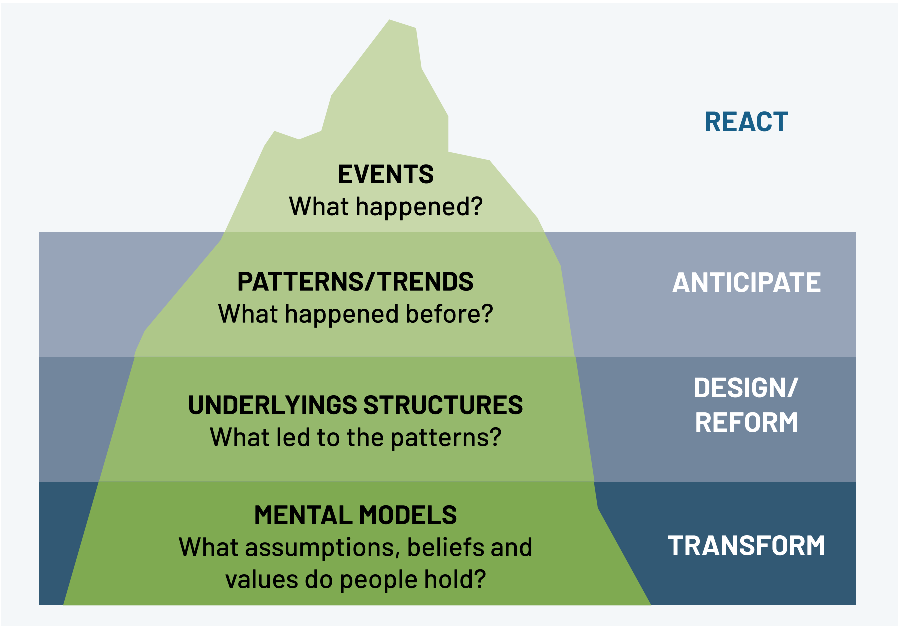
2.3.2.3. Energy sufficiency policy through a systems thinking perspective

Unlike many energy demand-reduction strategies that may merely adjust the existing system, energy sufficiency critically evaluates and challenges the entire system's design across multiple domains. More than any other energy demand-reduction strategy, energy sufficiency requires a systems thinking approach.

A system, in the context of systems thinking, is a cohesive ensemble of interconnected elements that produce patterns of behaviour over time [163]. These systems operate on various scales, from molecular interactions to universal phenomena, and span both tangible realms (e.g. economies) and intangibles (e.g. societal norms).

While systems might produce both intentional and unexpected outcomes – be they positive or negative – their interconnectedness often makes it challenging to change a system. Altering one aspect could inadvertently lead to new challenges elsewhere. Complex socio-techno-ecological systems, such as energy systems, often challenge easy predictions, which can result in less-than-optimal decision-making. Take the built environment as an example. Here, the aim of constructing buildings can also foster employment and shape culturally significant landscapes. However, the same system might inadvertently contribute to biodiversity loss, urban heat island effects, social divide or increasingly sedentary lifestyles. Thus, before altering a system or addressing its inherent issues, it is crucial to first understand its operation and the rationale behind its functions. The behavioural patterns of systems, as observed in consumers, organisations, industries or policymakers, can often be traced back to system structures. These structures, influenced by mental models, needs and perceptions, determine behaviour [164], [165].

FIGURE 13: Systems thinking "iceberg" model. Adapted from [165].

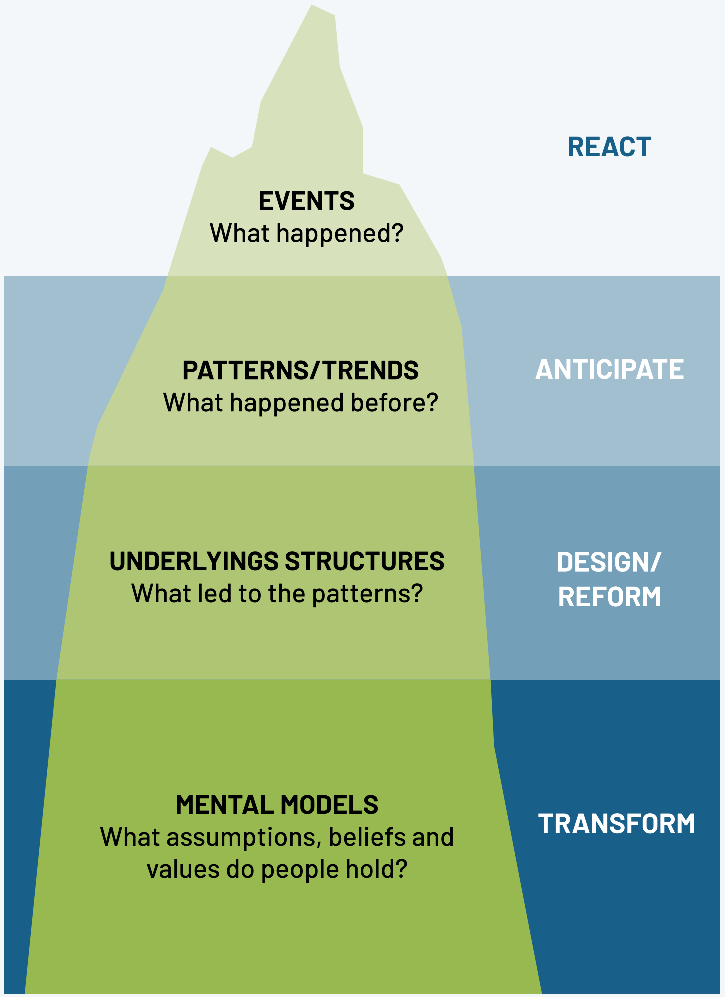


In explaining this link between behaviours and system structures, some scholars have proposed the "four levels of thinking" model, represented as an iceberg (Figure 13). This model introduces a hierarchy within any system: events, patterns, underlying structures and mental models. Events – the visible "symptoms" or outcomes – are akin to the iceberg's tip. Much of policy work targets this visible layer, suggesting remedies for apparent issues. Energy sufficiency policies, however, would delve deeper, challenging the underlying structures and mental models that shape the energy system's core principles and objectives. From a systems-thinking viewpoint, policy can be an instrument for reshaping existing systems. Hence, different policies can impact varying system levels, from the superficial to the deeply rooted. In this context, Meadows [166] introduced a system of 12 leverage points: (12) constants, parameters, numbers; (11) buffers; (10) stock-and-flow structures; (9) delays; (8) balancing feedback loops; (7) reinforcing feedback loops; (6) information flows; (5) rules; (4) self-organisation; (3) goals; (2) context paradigms; (1) transcending paradigms.

Today, these 12 leverage points are widely used by system analysts, researchers, policymakers and practitioners. This hierarchical system elucidates where interventions are likely to have the most significant impact. Meadows highlighted the inherent intricacy of systems and advocated a humble approach to systemic change, emphasising the absence of a one-size-fits-all formula.

Figure 14 illustrates how the concept of the 12 leverage points relates to the system's "iceberg" and the types of policies relevant to different leverage points. **When applied to energy sufficiency, it becomes evident that most related actions affect the system's deeper levels, addressing core leverage points for change.**

FIGURE 14:
System leverage points with specific examples



Leverage points level	Leverage point name	Examples
Events	Constants, parameters, numbers	• Raising the minimum wage. • Offering subsidies of different amounts.
	The structure of material stocks and flows	• Building new roads. • Increasing efficiency of supply chains.
Patterns/ Trends	Strengthening desired feedback processes in the system. Weakening undesired feedback processes in the system.	• Introducing the "polluter pays" principle.
Underlying structures	The structure of information flows	• Giving communities the possibility to compare their consumption data with others.
	The rules of the system	• Imposing a carbon tax, charging rates for excess energy use.
Mental models	The mindset or paradigm out of which the system – its goals, structure, rules, delays, parameters – arises	• Creating a new system in which GDP is replaced by wellbeing indicators and goals. • Aiming for a low-energy-demand energy system instead of a net-zero energy system.
	The power to transcend paradigms	• Recognising planetary boundaries and using them as limiting guidelines for the CET.

2.3.2.4. Energy sufficiency policy through a multi-level perspective

Another complementary tool supporting effective energy sufficiency policymaking is the multi-level perspective. While leverage points might pertain to any segment of a system, a multi-level perspective assists in structuring the system into more digestible, hierarchical components.

In steering society's transformation towards sufficiency, the application of systems thinking can benefit from a multi-level approach. Geels [167] proposed such an approach to probe the dissemination of sufficiency lifestyles and the evolution of social norms and values within society.

According to the multi-level perspective, systems can be dissected at three distinct levels:

1. **Micro-level:** this focuses on individual behaviour and lifestyle choices. It delves into how values, attitudes and habits influence consumption patterns, exploring potential shifts towards more sustainable lifestyles. Additionally, it considers the impact of social norms, peer influence and individual motivations on behaviours.

2. **Meso-level:** this examines the role of communities and organisations in championing sufficiency. It evaluates how social networks and community organisations, among other intermediaries, can aid in the spread of sufficiency practices at an organisational scale. For instance, it might consider appropriate adaptive reuse practices in the construction sector. Furthermore, the meso-level perspective contemplates the influence of institutions, policies and regulations on the conduct of organisations and communities.

3. **Macro-level:** this focuses on how cultural and national backdrops influence the propagation of sufficiency. It scrutinises the impact of historical occurrences, energy cultures, institutional path dependencies and political leanings on the dissemination of sufficiency strategies. Moreover, the macro-level approach examines how a nation's historical and cultural lineage, specific to a country or community, can pave the way for the development, execution and acceptance of meso-level strategies such as policies, regulations and other institutional frameworks.

2.3.3. Overview of existing energy sufficiency policies and existing gaps

Although the EU currently lacks policies specifically mentioning "energy sufficiency", the concept is not novel in the policy domain. One particularly prominent example is the oil crises of the early 1970s. To bolster energy security, nations introduced policies to save energy. Measures included reducing room temperatures and driving speeds, and moderating heating and lighting in public areas. Notably, Finland even planned to stop TV broadcasting on Mondays. Echoes of these strategies were seen during

Europe's 2022 energy crisis (see Section 3 for a more detailed discussion). Globally, however, dedicated energy sufficiency policies remain absent. SDG 7 – Affordable and clean energy – establishes a framework for providing sufficient energy for all, emphasising the need to ensure that everyone has access to affordable, reliable, sustainable and modern energy. Through this, SDG 7 implicitly aims to provide everyone with a minimum baseline level of energy services but does not specify the upper threshold for sufficiency.

The 1970s oil crises catalysed the development of energy-efficient technologies. Yet post-crisis, from the 1980s onwards, global energy consumption has more than doubled (Section 1.2). Modern societies have evolved, assuming access to a consistent supply of affordable energy. While the EU has implemented numerous policies emphasising the significance of energy savings and energy efficiency, such as the "energy efficiency first" principle [105], achieving sustainability within planetary boundaries requires policies that go beyond these notions. It necessitates the introduction of maximum consumption thresholds that align with the concept of "energy sufficiency".

Increasing number of scholars are discussing and analysing energy sufficiency policies. For instance, Burke and Melgar [17] explore policies aimed at changing behaviours and technologies, while curbing excessive energy consumption. Their suggestions include fossil fuel taxation or bans, recognising that while such moves could raise energy costs (a politically sensitive issue), they would be in line with long-term sustainability. Such policies must, however, safeguard vulnerable population groups from a disproportionately high financial burden. The same paper also notes that non-price rationing, in connection with restrictions, can range from energy and water to luxury goods. For successful implementation of such policies, democratic procedures and inclusive dialogue are especially crucial.

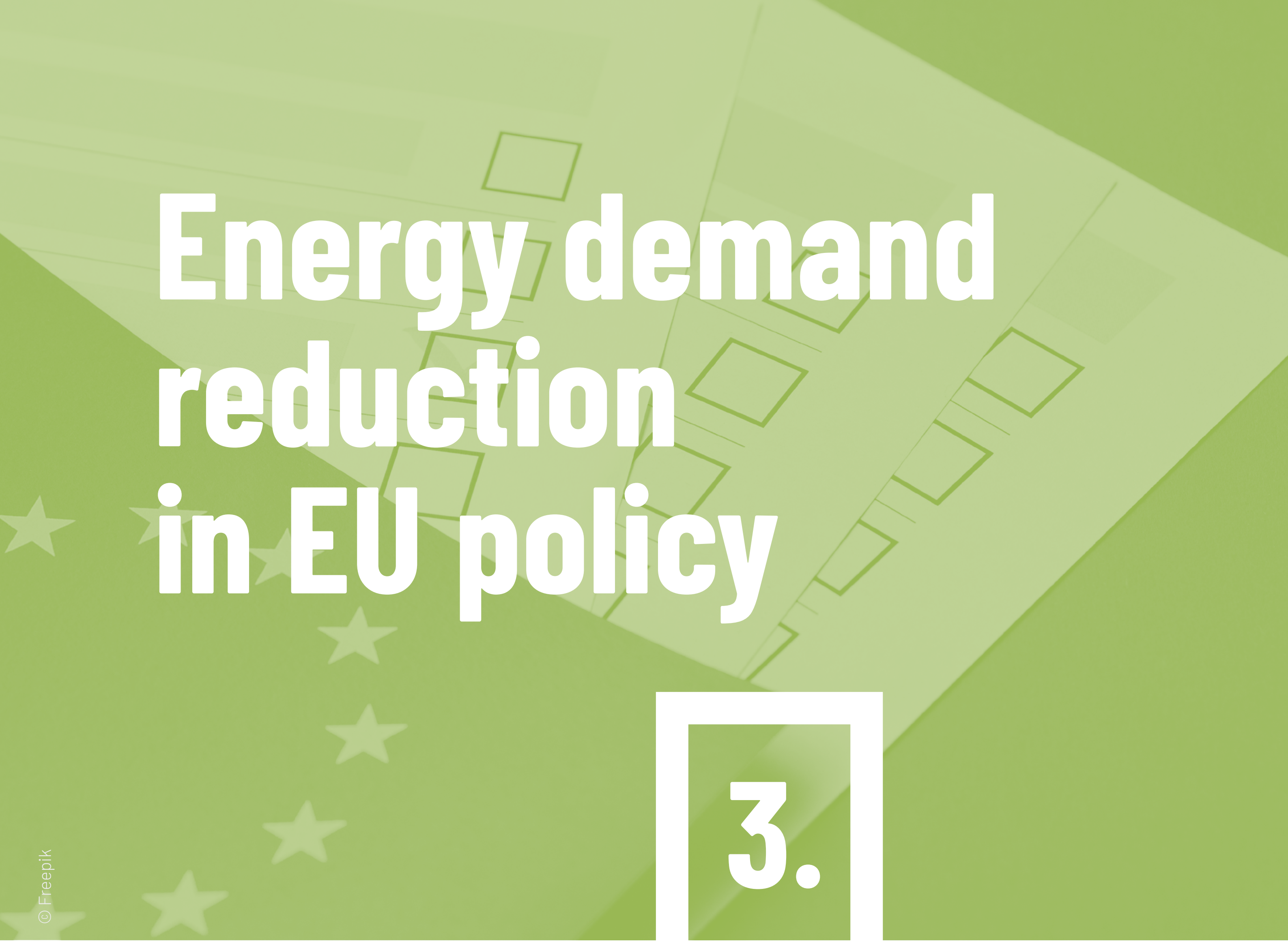
In contrast, Bertoldi [41] believes that energy conservation and sufficiency policies should complement energy efficiency initiatives, especially when targeting consumer behaviour and lifestyle changes.

One significant resource on European energy policies is the Sufficiency Policy Database [132], cataloguing over 300 policy strategies across various sectors. Common strategies promote behavioural changes, such as optimising living spaces, encouraging teleworking or increasing local food production. In cross-sectoral policy strategies, many policies focus on the internalisation of external costs and setting limits on the externalisation of negative environmental impacts through tax reforms, including carbon taxes or tax incentives. To date, establishing a unified carbon tax on a global scale or even within the EU remains politically challenging. Instead, we have the established ETS (Emissions Trading System), which exists alongside cross-border taxes. The primary goal of these measures, however, is not to reduce energy consumption but to promote clean energy production and safeguard domestic industries.

Zell-Ziegler et al.'s research [168] explores the role of energy sufficiency in the NECPs and LTSs of EU Member States. Their findings highlight significant national and sectoral differences, with the transport sector being a leader in terms of sufficiency-related policies, which primarily target individual behaviour.

As highlighted earlier, sufficiency policies suggest a holistic approach to sustainability, going beyond conventional energy and climate policies. **Current EU and national frameworks, while containing some sufficiency elements, do not label them as such. This highlights a gap that future policies will have to bridge by explicitly prioritising long-term energy demand reduction.** For affluent nations, prioritising energy sufficiency over technical energy efficiency and renewable targets can promote equitable distribution of resources while simultaneously ensuring that planetary boundaries are not transgressed.

Research on energy sufficiency remains limited, with important gaps still to be addressed. Despite numerous existing sufficiency-related measures, building a comprehensive policy framework emphasising sufficiency is vital. Currently, there is no integrated sufficiency strategy, but future studies can address this, identifying key policies and potential implementation challenges. **More interdisciplinary research can help shape energy sufficiency policies and drive a shift away from unsustainable growth patterns. Investing in energy sufficiency research is also a way to mitigate future risks of unsustainable investments. Sufficiency should also be an integral part of building Europe's strategic autonomy.**



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Energy demand reduction in EU policy

3.

HIGHLIGHTS OF THIS SECTION:

- Recent crises, notably the Russian invasion of Ukraine and subsequent energy security concerns, have driven the EU to devise responsive legislative packages.
- The EU has explicitly prioritised energy demand reduction in response to energy crises and security threats.
- Many energy demand-reduction policies are presently short term, emphasising immediate results; a shift towards policies focusing on enduring, structural reduction is imperative.
- Active awareness of current EU policies, which may inadvertently escalate energy demand, such as the NZIA and the CRMA, is essential.

3.1. GENERAL CONTEXT

The reduction of energy demand is a topic that started to gain prominence in the EU political debate quite recently. In the wake of the economic rebound following the COVID-19 pandemic, and due to Russia's manipulation of the EU's energy markets (starting in 2021 with Russia reducing gas supply volumes to the EU), the EU began experiencing substantial energy supply problems. These problems escalated into a full-blown energy crisis subsequent to Russia's full-scale invasion of Ukraine in February 2022. This led the EU and its Member States to urgently adopt a range of mitigating measures, including some aimed at reducing energy demand.

Until then, when dealing with energy consumption, European policies had mainly focused on *demand management*[9], also known as *demand-side response* – a concept that does not directly involve a reduction in energy demand. As a matter of fact, before 2022, "energy demand reduction" is mentioned only once in an official EU policy document, namely the Energy Efficiency Directive (EED) [105]. Moreover, that directive[10], dated 2012, sets EU reduction of energy consumption to 20% by the year 2020 and at least to 32.5% by 2030 compared with baseline projections[11]. Over the past two decades, both primary and final energy consumption have fluctuated (peaking in 2006), influenced by economic developments, structural changes in industry, the implementation of energy efficiency measures, and variations in weather conditions. In more recent years, both primary and final energy consumption significantly decreased in 2020 due to the COVID-19 pandemic. Although there was a rebound in 2021, consumption levels remained below those of 2019. To elaborate, in 2021, primary energy consumption was 0.2% below the 2020 target, while final energy consumption exceeded the 2020 target by 0.9% [171].

To complete the overview of energy consumption in the EU, two aspects should be emphasised. Firstly, the progressive reduction in the EU's domestic energy consumption registered in the past few decades was largely due to the gradual shift away from heavy industrial production (which is the most polluting and energy-intensive part of the economy) recorded in Europe during the same period [172]. **In absolute terms, this does not mean that less energy was consumed but rather that it was consumed in those countries from which the EU imports heavy-industry products.** A similar consideration applies in the case of delocalisation of European industries. Indeed, the amount of energy that the latter no longer consume in Europe is consumed in less developed economies to which Europe has offshored its manufacturing processes. Such offshoring of industrial processes might result in even higher amounts of consumed energy (due to, for example, less advanced technologies, less stringent

9. Demand management refers to strategies and actions taken by consumers to manage and control their energy usage in an efficient and optimised manner.

10. Directive 2012/27/EU on energy efficiency was adapted by Council Directive 2013/12/EU of 13 May 2013, by reason of the accession of the Republic of Croatia to the EU [170].

11. Taking into account the withdrawal of the UK from the EU, this results in a primary energy consumption target of no more than 1,312 Mtoe in 2020 and 1,128 Mtoe in 2030, and a final energy consumption of no more than 959 Mtoe in 2020 and 846 Mtoe in 2030 [171].

environmental regulations, longer supply chains, etc.) than could have been consumed in Europe. At the same time, econometric studies have indicated that there is no robust evidence of carbon leakage[12], highlighting how difficult it is to make such estimates [173]. Secondly, when projecting future changes in energy demand in Europe, it should be taken into account that, for about the past 10 years, there has been a noticeable trend of EU industries reshoring in Europe [174]. In addition, one of the aims of the Net Zero Industry Act (NZIA) [175] proposed by the European Commission on 16 March 2023 is to create more favourable conditions for investment in Europe. This is expected to encourage further reshoring of industries in Europe. This trend might be further encouraged in the future against the backdrop of Europe's efforts to secure its strategic economy amidst escalating geopolitical tensions.

In the EU research-and-policy landscape, several actors have recently voiced positions on the issue of energy demand reduction and EU energy policies. The Coalition for Energy Savings [176], for instance, calls for a long-term strategy to structurally reduce energy demand in the EU. Indeed, although short-term energy-saving measures are essential to quickly address the emergency and increase the EU's energy security, they need to be integrated into a comprehensive approach to structurally reduce European energy demand in the long term.

Similarly, in the building sector, the Buildings Performance Institute Europe (BPIE) has pointed out that reducing energy demand in residential buildings should be prioritised because it contributes to securing energy independence and supports EU climate targets of reducing overall GHG emissions by 55% by 2030 and achieving climate neutrality by 2050 [177].

Regarding energy sufficiency, the Jacque Delors Institute, for example, has highlighted that sufficiency policies are the only policies that enable immediate reductions in energy demand to be achieved, as part of a strategy to tackle the energy crisis as well as the climate emergency [9].

3.2. EU DEMAND REDUCTION-RELATED POLICY ANALYSIS

Within the EU energy governance framework, demand reduction has mainly been viewed as a secondary outcome of energy efficiency, with the latter being the main policy goal. Indeed, as already mentioned, energy demand reduction remained a rather marginal issue in the wider energy policy framework until the Russian invasion of Ukraine in February 2022. That moment in

12. Carbon leakage refers to the situation that may occur if, for reasons of cost related to climate policies, businesses were to transfer production to other countries with laxer emission constraints. This could lead to an increase in their total emissions. The risk of carbon leakage may be higher in certain energy-intensive industries.

time can thus be considered a turning point in the EU's approach to energy saving. **In fact, the energy crisis led to a change on two different levels: on the one hand, it compelled the European Commission to rethink the relationship between energy efficiency and demand reduction; on the other hand, it resulted in a shift in the balance between measures based on improving energy efficiency and measures aimed at behavioural change.**

Regarding the second point, the urgency of drastically reducing imports of fossil fuels and gas from Russia led the European Commission to refocus its approach from medium-/long-term energy efficiency policies to short-term measures, with a strong preference for initiatives aimed at individual or collective behavioural change.

In this section, the discussion will initially concentrate on established energy policies that have undergone revision over time, and subsequently on the newer energy policies instituted in response to the energy crisis sparked by Russia's invasion of Ukraine.

As highlighted above, energy efficiency policies play a pivotal role in the overall EU energy policy framework. The current framework for energy efficiency relies on two main directives: the Energy Efficiency Directive [105] and the Energy Performance of Buildings Directive (EPBD) [101]. Introduced in the 2010s and providing targets for 2020, the directives were revised for the first time in 2018, in the light of the 2030 climate and energy strategies. Then, as a part of the "Fit for 55" plan [178], the European Commission issued two recast proposals to align energy legislation with the targets set by the European Climate Law [179]. While these proposals were still under examination by the co-legislators, the Russian invasion of Ukraine led the Commission to redefine its energy efficiency objectives. These measures, along with those provided for in the "renovation wave strategy" [180], are characterised by a medium-/long-term scope and a particular focus on households and buildings, as the decarbonisation of the heating and cooling sector is perceived as one of the key action areas.

The latest version of the EED [105] was adopted on 25 July 2023. It has further increased the EU's ambition for energy demand reduction by tightening the energy consumption targets, aligning them with the European Green Deal and the new 2030 and 2050 climate goals set by the European Climate Law [179]. Specifically, the revised EED aims to reduce primary and final energy consumption by 11.7% at EU level by 2030 (the target for primary consumption is indicative), compared with the projections of the 2020 EU

Reference Scenario[13]. This target results in a binding EU final energy consumption of no more than 763 Mtoe and an indicative EU primary energy consumption of no more than 992.5 Mtoe in 2030. The approved target is slightly below that proposed by the Commission in the REPowerEU Plan [182] of May 2022, which envisaged a 13% reduction in final energy consumption (2020 EU Reference Scenario).

As regards the national level, the new EED establishes that EU Member States shall set an indicative national contribution based on final energy consumption to meet, collectively, the EU's binding final energy consumption target and shall make efforts to contribute to the EU's indicative primary energy consumption target. To this end, EU Member States are required to set indicative national energy efficiency contributions and trajectories towards reaching the target in their integrated NECPs, using a combination of objective criteria that reflect their national circumstances (e.g. energy intensity, GDP per capita, energy savings potential and fixed energy consumption reduction). By doing so, Member States must achieve an annual saving of 1.3% of final energy consumption by 2024, rising to 1.9% by 2028, up from the 2023 level of 0.8%[14]. Compared with its previous version, the new EED amends the way in which Member States should express their national contributions to the EU's target, i.e. in terms of primary energy consumption and final energy consumption to ensure consistency and monitoring of progress. Moreover, the latest version of the EED includes an enhanced "gap-filling mechanism", which will be triggered if countries fall behind in delivering their national contributions. Member States are also asked to provide the shares of primary energy consumption and final energy consumption of energy end-use sectors, including industry, buildings and transport, in their national energy efficiency contributions.

In terms of energy demand reduction, understood as an absolute decrease in energy consumed, the new EED – similarly to its previous version – does not devote significant attention to this topic. However, the updated EED mentions new regulations to implement the "energy efficiency first" principle. In energy efficiency policy, energy efficiency ambition should be promoted and likewise measured, leading directly to energy savings. In large energy investments (e.g. new electricity or road transport infrastructure) and policymaking, specific energy-saving solutions and demand reduction need to be assessed as first possible alternatives (including behavioural change).

13. The EU's energy efficiency target was initially set and calculated using the 2007 EU Reference Scenario projections for 2030 as a baseline. The change in the Eurostat energy balance calculation methodology and improvements in subsequent modelling projections call for a change of the baseline. Thus, using the same approach to define the target, i.e. by comparing it with future baseline projections, the ambition of the EU's 2030 energy efficiency target is set compared with the 2020 EU Reference Scenario projections for 2030, reflecting national contributions from the NECPs. With that updated baseline, the EU will need to further increase its energy efficiency ambition by at least 11.7% in 2030 compared with the level of efforts under the 2020 EU Reference Scenario. The new way of expressing the level of ambition for the EU's targets does not affect the actual level of efforts needed and corresponds to a reduction of 40.5% for primary energy consumption and 38% for final energy consumption when compared with the 2007 EU Reference Scenario projections for 2030 [181].

14. Exceptions exist for Cyprus and Malta.

Other medium-/long-term measures, established by REPowerEU and based on energy efficiency, are the update of the EU ecodesign and energy labelling legislation [183], and the reform of the Single European Sky Regulation [184] to enable the modernisation of air traffic management. Both pieces of legislation are still under discussion.

With regard to more recent energy policies adopted as an immediate reaction to the energy crisis and the Russian invasion of Ukraine, the "EU Save Energy" plan [185] (May 2022), a Communication from the Commission under the REPowerEU [182], is the first EU policy document that makes explicit and meaningful reference to energy demand reduction, introducing at the EU level a demand-based approach to complement existing supply-side measures, as a way of helping reduce fossil fuel imports and avoid abrupt shortages and the ensuing economic and social consequences.

The plan identifies a series of actions to achieve immediate energy savings through voluntary choices intended for households and industry (such as fuel switching, the establishment of joint actioning and tendering systems, and awareness-raising campaigns for savings in heating and cooling) and to accelerate and strengthen structural, mid- to long-term energy efficiency measures. **It is relevant to underline that, as was the case in the 1970s with the rise in oil prices, similarly in 2022 the direct and explicit call for the need to reduce energy demand came only when significant energy security concerns emerged.**

In July 2022, the European Commission presented another Communication, "Save gas for a safe winter" [186], which proposes a new European Gas Demand Reduction Plan and a list of possible demand-reduction measures. This was followed by a Council Regulation [187] (August 2022) on coordinated demand-reduction measures for gas, envisaging an immediate recommendation for a voluntary gas demand reduction of 15% in all Member States over at least the next eight months, and introducing a process to trigger a binding demand-reduction target should it become necessary, at any time during the coming weeks or months. Then, in March 2023, the Council issued a new Regulation [188], amending the previous one, extending the period for gas demand-reduction measures until March 2024 and reinforcing the reporting and monitoring of their implementation.

In October 2022, the Council adopted another Regulation, on an emergency intervention to address high energy prices [189], this time focused on electricity demand reduction (by 5-10%) as part of efforts to bring down electricity prices. In this case, the call for demand-reduction measures is therefore mainly related to the goal of reducing energy prices rather than to energy supply concerns.

In light of the above, it is important to emphasise two aspects. **First, until now, the EU has invoked energy demand-reduction measures only in relation to its dependence on fossil fuels, and in particular, on Russian gas. Thus, there was no call for an overall more structural reduction in energy demand. Second, despite the fact that the EU has begun to explicitly talk**

about the concept of "energy demand reduction" in the past two years, there is no shared and agreed definition of what it entails.

As a result of the emergency policies put in place at the EU and national levels, the increased awareness of many EU citizens but also the particularly favourable weather conditions, EU gas demand in Q4 2022 fell by 21.4% (-25 bcm) in a year-on-year comparison, after decreasing by 7.9% in Q3 2022, and by 16.5% in Q2 2022. As far as electricity is concerned, EU consumption fell by 9% in Q4 2022 compared with the same period in 2021. Throughout the year, demand dropped by an average of 3% compared with 2021, due to the unprecedented electricity prices in 2022, which supported a decrease in energy demand in households, and even more so in industry. In particular, major industry, responsible for the greatest share of the demand, struggled with high energy prices, resulting in a considerable decline in consumption [190].

In conclusion, we can argue that the shift towards an explicit call for energy demand reduction through the promotion of behavioural change policies can be partially attributed to the urgent nature of such measures. Since most aspects of energy policy, indeed, fall within the shared competence of the EU and Member States, there is a clear preference for target-setting and soft governance tools so as to give national governments the freedom to decide what specific strategies to adopt. In this context, each Member State has the discretion to decide the conditions for exploiting its own energy resources, choose between different energy sources and organise the general structure of its energy supply. As a result, the EU energy governance framework was not optimally suited to respond to the sudden crisis brought about by the Russian war in Ukraine. In this context, the shift in the Commission's approach can be seen as seizing a window of opportunity to advocate measures that, under different circumstances, would have encountered resistance from Member States. Serving in a role akin to that of an entrepreneur, the European Commission converted indicative targets to be met into actionable tools for achieving them.

3.3. RECENT EU POLICIES STIMULATING INCREASE IN ENERGY DEMAND

Through the green and digital transitions, the EU is aiming to profoundly transform the way in which we use energy, from individual consumption to industrial production. **While energy efficiency has long been a key element of the EU decarbonisation strategy, and more and more efforts have been made lately to incorporate the principle of "energy efficiency first" into EU policies, the recent shift towards strategic autonomy could increase energy demand on European shores.**

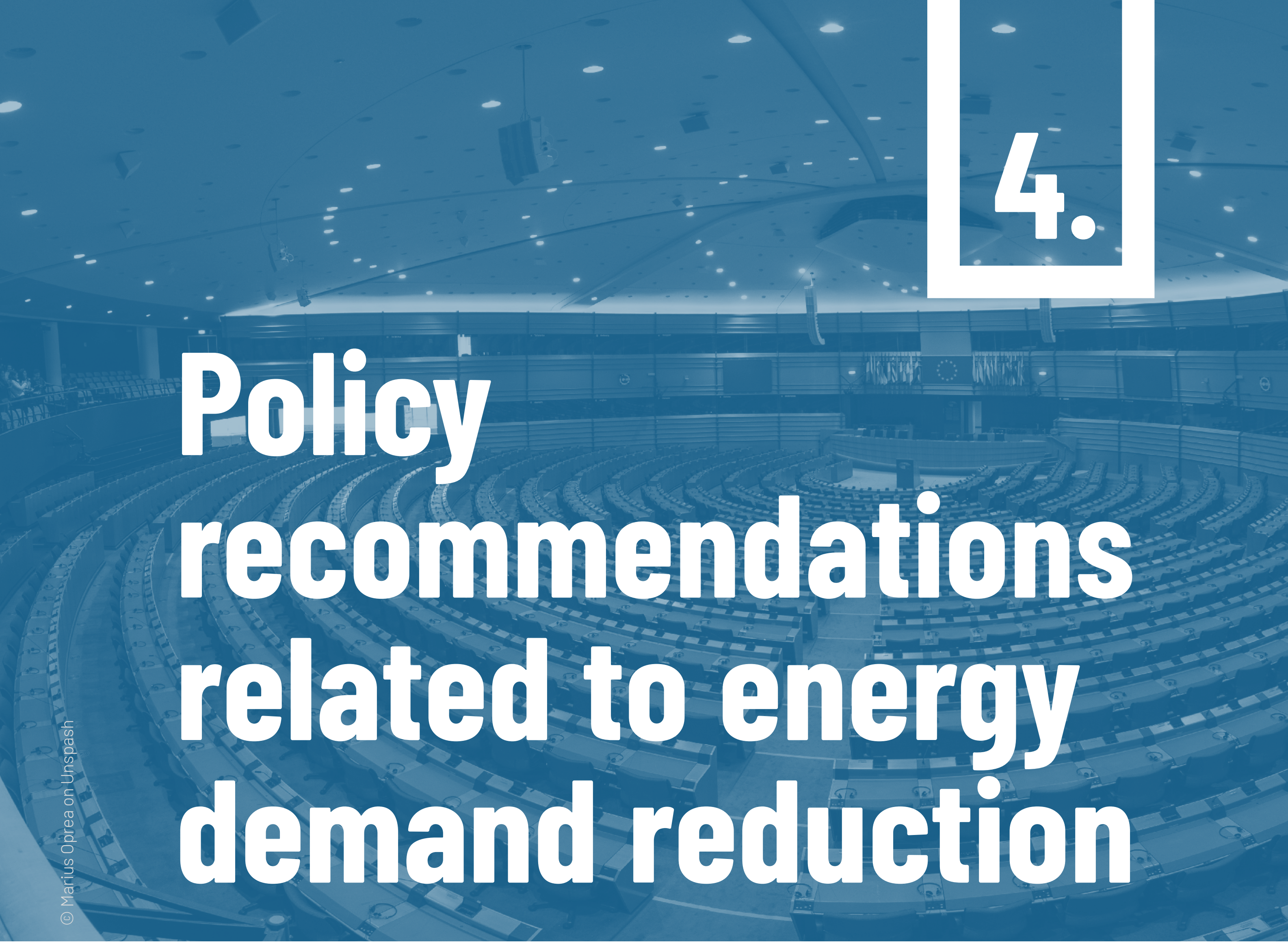
This is the case, for instance, for the Green Deal Industrial Plan [191], a package of measures designed to respond to the American Inflation Reduction Act [192]. In the Plan's three key proposals, i.e. the Electricity Market Design (EMD) reform [193], the CRMA [194] and the NZIA [175], the concept of demand reduction has almost disappeared, apart from some rare mentions in the EMD. The latter two Acts, instead, could have a huge potential to increase energy demand in Europe.

The CRMA, in fact, set targets for EU extraction, processing and recycling capacity. This will entail setting up energy-intensive industries within Europe, ranging from mining to processing facilities. A similar effect can be hypothesised regarding the NZIA, which provides a benchmark for the manufacturing capacity of clean technologies within Europe of at least 40% of the EU's annual deployment needs by 2030. This Act is creating a regulatory environment to facilitate the scaling-up of the European net-zero industry. Since both the CRMA and the NZIA aim to shorten the value chains for CRMs and clean tech by scaling up energy-intensive activities in Europe, it is most probable that this legislation will, as a side effect, increase EU energy demand.

The trend towards reducing EU dependence on energy imports by reshoring energy-intensive industrial activities on the continent will in fact inevitably lead to an increase in energy demand.

Additionally, the decarbonisation of particularly energy-intensive sectors or processes may increase energy demand in the short term, as also stated in the RED III proposal [195]. This is the case for policies that promote a shift to hydrogen, either as a fuel or in the decarbonisation of industrial processes. Indeed, the EU targets for hydrogen production, as set down in the REPowerEU, are to produce 10 million tonnes of renewable hydrogen domestically by 2030. The Communication on the European Hydrogen Bank (COM/2023/156) [196], published on 16 March 2023, aims to accelerate renewable hydrogen production.

Lastly, the massive digitalisation that will support both the digital and the green transition will also increase demand for energy in Europe. Currently, the ICT sector is responsible for 5-9% of the world's total electricity use and this is set to increase further as our economies rely on digital markets and services. Hence, policies concerning technological transition, from semiconductor production to digital services, are not exempt from considerations about energy demand.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4. Policy recommendations related to energy demand reduction

The following policy recommendations are derived from the analysis provided in this report, which encompasses insights from three energy demand-reduction strategies: *behavioural change*, *energy efficiency* and *energy sufficiency*. Integrating energy demand reduction into the EU's CET strategy is crucial for transforming the EU energy system. This transformation is vital not only for achieving climate goals but also for enhancing the EU's energy security, bolstering its strategic autonomy and ensuring the wellbeing of European citizens.

1. INTEGRATE LONG-TERM ENERGY DEMAND REDUCTION INTO THE EU'S CLEAN ENERGY TRANSITION STRATEGY

- The importance of long-term energy demand reduction in the EU should be acknowledged. Long-term energy supply and long-term energy demand are closely interconnected. For the CET to meet its goals, energy demand reduction should be ingrained as a foundational element of energy policies in the EU and should target all energy demand, not just demand for fossil fuels. Energy demand reduction should therefore be structurally integrated into the EU's CET strategy and given the same priority as the energy-supply side. This emphasises the importance of establishing specific targets for energy demand reduction in a manner comparable with the provisions established for energy supply.

- Currently, EU policies primarily target energy demand reduction at the household level. However, for a comprehensive energy demand-reduction strategy, policies should encompass all economic sectors and address all main end-users of energy, including households, industry, transport, services and agriculture.

- It is crucial to be aware of the EU policies that might create incentives for increasing energy demand. Some recent EU policies could potentially stimulate growth in energy demand, particularly those relating to the reshoring industry and those relating to increasing mining activities in Europe. It is essential to be aware of the potential trade-offs; increasing the EU's strategic autonomy could lead to higher energy demand, potentially undermining that strategic autonomy.

2. SET TARGETS FOR ENERGY DEMAND REDUCTION

- At the EU level, targets for energy demand reduction should be incorporated into various strategic frameworks, including, most importantly, the EED. Targets relating to absolute demand reduction should be explicitly added to the EED.

- At national level, NECPs and LTSs should include energy demand-reduction targets to stimulate long-term structural demand-reduction policies and, in parallel, to encourage researchers to advance energy models that would incorporate comprehensive demand-reduction strategies.

- Digitalisation and circularity are vital enablers for the CET. However, data indicates that activities associated with them can lead to increased energy consumption. EU policies on digitalisation and circularity facilitating the CET should therefore include energy demand-reduction targets to ensure the promotion of energy demand reduction.

3. INTEGRATE ENERGY SUFFICIENCY INTO LONG-TERM DEMAND-REDUCTION POLICY

- Currently, EU demand-reduction policies address energy efficiency and behavioural change. However, there are no EU policies that explicitly address energy sufficiency. As a strategy explicitly aimed at reducing energy demand, energy sufficiency targets long-term energy consumption. In contrast, energy efficiency alone does not guarantee a reduction in final energy consumption. Effective long-term demand-reduction strategies should therefore include both energy efficiency and energy sufficiency. One way of implementing this is to ensure that the "energy efficiency first" principle is elevated to the "energy sufficiency first" principle in the EED.

- The Sufficiency Policy Database [132], which provides a comprehensive list of policy strategies and instruments, can be used to develop sufficiency policies across different economic sectors and governance levels.

- Introducing energy sufficiency indicators may be challenging within the existing system of indicators that encourage the growth of all economic activities. One solution to this dilemma is to introduce alternatives complementary to GDP indicators. This could reduce dependence on escalating economic activities that invariably increase energy consumption, even with enhanced energy efficiency.

4. ENCOURAGE INVESTMENT IN ENERGY DEMAND REDUCTION

- Energy-saving solutions and demand reduction should serve as guiding principles for infrastructure investments. For instance, when investing in new electricity or road transport infrastructure, the potential for energy savings should be a criterion for prioritising among alternative investment projects.

- Energy efficiency is crucial for achieving a carbon-neutral Europe by 2050. Despite its significance, investments in energy efficiency, particularly in industrial processes, are highly insufficient and under-prioritised. The recast EED aims to stimulate more investments in energy efficiency; however, further details are needed there, particularly regarding enhancement of the efficiency of industrial processes.

- A substantial barrier to investments in energy efficiency is the uncertainty surrounding return on investment. Enhancing collaboration between research organisations and companies can offer mutual benefits and facilitate improved data collection and utilisation.

5. MAKE CITIZEN ENGAGEMENT AND COMMUNITY EMPOWERMENT PRINCIPLES WORK

- To ensure that demand-reduction measures promote citizen wellbeing, citizens should be actively involved in shaping energy demand-reduction solutions. The EU's policy documents emphasise placing the "citizen in the centre"; however, there is a disparity between this principle and its actual implementation in practice. The “citizen in the centre” principle should be integrated into both supply and demand aspects of the CET strategy.

- Current policies often oversimplify consumer decisions and choices, assuming rational economic behaviour. At the same time, there is ample research evidence providing a detailed and contextual understanding of energy users’ behaviour. Incorporating such research evidence into policies is especially relevant in the context of energy demand reduction.

- It is crucial to ensure that EU CET policies encourage community experimentation regarding energy demand reduction. For instance, implementing local community sandboxes for energy demand-reduction policies could lead to more efficient local energy production-consumption systems. Engaging with energy users is vital to understand their values, needs and preferences in order to customise incentives, products and services accordingly.

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