Study on promoting energy system integration through the increased role of renewable electricity, decentralised assets and hydrogen

Final Report

Written by the consortium of Trinomics, DNV, LBST, E3M and Schönherr
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LIST OF ABBREVIATIONS

AC	Alternating Current
ACER	European Union Agency for the Cooperation of Energy Regulators
AFID	The Alternative Fuels Infrastructure Directive
AFIR	Alternative Fuels Infrastructure Regulation
aFRR	Automatic Frequency Restoration Reserve
API	Application Programming Interface
ATR	Autothermal reforming
BEV	Battery electric vehicle
BMS	Battery Management System
BtM	Behind-the-meter
CAN	Controller Area Network
CAPEX	Capital Expenditures
CBAM	Cross-border adjustment mechanism
CCS	Combined Charging System
CCU	Communication Control Unit
CCU/S	Carbon Capture, Utilisation and Storage
CBA	Cost-Benefit Analysis
CEER	Council of European Energy regulators
CfD	Contract-for-differences
CHP	Combined Heat and Power
CIM	Common information model
CPO	Charging Point Operator
CSV	Comma Separated Values
D4E	Data for Energy
DC	Direct Current
DEP	Data Exchange Platform
DER	Distributed Energy Resources
DG ENER	Directorate General of Energy
DHC	District Heating and Cooling
DR	Demand Response
DSO	Distribution System Operator
EC	European Commission
ECJ	European Court of Justice
ECU	Energy control units
EED	Energy Efficiency Directive
EHPA	European Heat Pump Association
EMD	Electricity Market Design
EMS	Energy Management Systems
EMSP	E-Mobility Service Provider
ENISA	The European Union Agency for Cybersecurity
ENTSO-E	European Network of TSOs for electricity
ENTSOG	European Network of TSOs for natural gas
EPBD	Energy Performance of Buildings Directive
ESABCC	European Scientific Advisory Board on Climate Change
ESCOs	Energy Service Companies
ESI	Energy System Integration
ETD	Energy Taxation Directive
ETS	Emission Trading System
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
EU	European Union

FCEV	Fuel cell electric vehicle
FCR	Frequency Containment Reserve
FSP	flexibility service provider
FTP	File Transfer Protocol
GDPR	General Data Protection Regulation
GHG	Greenhouse Gas
GPS	Global Positioning System
HEMS	Home Energy Management System
HMI	Human Machine Interface
HP	Heat pump
HVAC	Heating, Ventilation, and Air Conditioning
ICT	Information and Communications Technology
IEC	International Electrotechnical Commission
IRENA	International Renewable Energy Agency
JRC	Joint Research Centre
LCOH	Levelised cost of hydrogen production
mFRR	Manual Frequency Restoration Reserve
MS	Member State
MW	Megawatt
MWh	Megawatt-hour
NCCS	Network Code on Cyber Security
NRA	National Regulatory Authority
OBD	On-board Diagnostics
OCPI	Open Charge Point Interface
OCPP	Open Charge Point Protocol
OEM	Original Equipment Manufacturer
OPEX	Operational Expenditures
PEF	primary energy factor
PEM	Proton Exchange Membrane
PPA	Power Purchase Agreement
RCF	Recycled Carbon Fuels
RED	Renewable Energy Directive
RES	Renewable Energy Resource
RFNBO	Renewable Fuels of Non-Biological Origin
RR	Replacement Reserves
SMR	Steam Methane Reforming
SOC	State of Charge
SOE	Solid oxide electrolyser
SOH	State of Health
SOP	State of Power
SOX	State of X
tbc	To be confirmed
TEN-T	Trans-European Transport Network
TLS	Transport Layer Security
TP	transparency platform
TPA	third-party access
TSO	Transmission System Operator
USA	United States of America
V2G	Vehicle to Grid (bi-directional charging and discharging capability based on the standardised protocol)
V2H	Vehicle to Home
V2L	Vehicle to Load
V2X	Vehicle to everything
WHU	Waste Heat Utilisation

WH/C	Waste heat and cold
XML	Extensible Markup Language

ABSTRACT

Full decarbonisation of the EU economy will require a significant transformation of the energy system. System integration can help achieve this in a cost-efficient manner. The EU Energy System Integration Strategy[1] "proposes concrete policy and legislative measures at EU level to gradually shape a new integrated energy system." The main objective of this study is to assess the progress of energy system integration in the EU by looking into existing barriers as well as identifying solutions and providing recommendations to address these barriers. The assessment analyses three topics in-depth, namely electrification of end-uses (with a specific focus on transport, industry, buildings) and decentralised renewable energy integration, uptake of renewable and low-carbon hydrogen (but also biogas and biomethane), and utilisation of waste heat. The assessment also covers cross-cutting topics such as energy infrastructure, energy storage, and digitalisation.

RÉSUMÉ

La décarbonisation complète de l'économie de l'UE nécessite une transformation profonde du système énergétique. Une intégration optimale de ce système peut contribuer à atteindre cet objectif de manière plus efficace. La stratégie d'intégration du système énergétique de l'UE[2] "propose des mesures politiques et législatives concrètes au niveau de l'UE pour développer progressivement un nouveau système énergétique intégré". L'objectif principal de cette étude est d'évaluer les progrès dans le domaine de l'intégration des systèmes énergétiques dans l'UE en examinant les obstacles existants, en identifiant des solutions et en proposant des recommandations pour surmonter ces obstacles. Le rapport analyse trois sujets en profondeur, à savoir l'électrification des utilisations finales (avec un accent particulier sur les transports, l'industrie, les bâtiments) et l'intégration des énergies renouvelables décentralisées, le déploiement de l'hydrogène renouvelable et à faible teneur en carbone (mais aussi le biogaz/biométhane), et l'utilisation de la chaleur résiduelle. L'évaluation couvre également des sujets transversaux tels que l'infrastructure énergétique, le stockage de l'énergie et la numérisation.

[1] COM(2020) 299 Final, page 2. Powering a climate-neutral economy: An EU Strategy for Energy System Integration
[2] COM(2020) 299 Final, page 2. Alimenter une économie neutre sur le plan climatique : Une stratégie européenne pour l'intégration des systèmes énergétiques

EXECUTIVE SUMMARY

Full decarbonisation of the EU economy will require a significant transformation of the energy system. System integration can help achieve this in a cost-efficient manner while providing the needed flexibility to the energy system. Net decarbonisation will require a reduction in energy demand, further electrification of energy needs, and the deployment of renewable and low-carbon fuels for the sectors where electrification is not an option. Renewable heat is also important for decarbonisation, even though it is not the focus of this study. Flexibility needs to accelerate at the same pace as renewable rollout by 2030, as both demand and supply must react to changing conditions to keep the system constantly in balance. Accordingly, decarbonisation will require deeper integration between sectors, greater involvement of consumers, greater utilisation of assets for demand-side flexibility and adequacy services as well as energy trade across all markets, and a more innovative and enabling regulatory framework.

The EU Energy System Integration (ESI) Strategy was published by the European Commission in July 2020 and "proposes concrete policy and legislative measures at EU level to gradually shape a new integrated energy system," with various actions addressing all elements mentioned above which are necessary for the decarbonisation of the EU energy system in line with the European Green Deal.

The objective of this study is to conduct an assessment of the progress of energy system integration in the EU. This is done by looking into existing barriers as well as providing recommendations to address these barriers. The assessment of barriers was conducted based on a literature review and extensive stakeholder consultations (through a survey, interviews, and workshops). This study is structured as follows:

- ✓ Chapter 1 presents the structure of the analysis, including an overview of the EU Energy System Integration Strategy;
- ✓ Chapter 2 presents the analysis for **topic 1: electrification of end-uses and decentralised renewable energy integration;**
- ✓ Chapter 3 presents the analysis for **topic 2: uptake of hydrogen;**
- ✓ Chapter 4 presents the analysis for **topic 3: utilisation of waste heat;**
- ✓ Chapter 5 presents the **assessment of cross-cutting topics** which were not analysed in the previous chapters (notably infrastructure, energy storage, and digitalisation & innovation)**.**

Implementation challenges towards electrification of end-uses and integration of decentralised resources.

The barriers for advancing the electrification of end-uses and integration of decentralised renewable energy were identified, along with recommendations to address these barriers. Regarding electrification, the scope includes the direct electrification of end-use applications for: (i) heating in buildings, (ii) industrial processes, and (iii) transportation using electric vehicles (EVs). The addition of decentralised renewable energy assets and storage, including EVs, will also allow for bi-directional electricity flows, which is an additional challenge for ESI.

Electrification brings multiple benefits, including increased energy savings, as electricity is more efficient than other energy carriers and cleaner, as electricity is produced increasingly from renewable energy. Furthermore, electricity empowers consumers with access to cleaner energy options. Electricity injected into the grid and

taken from the grid can adjust to specific load profiles as needed by the grid to reduce variability, backup capacity needs and costs. Moreover, combined with decentralised renewable energy generation and various local storage systems, electricity can bring higher benefits to the energy users, the energy system, and decarbonisation. When both electrification and decentralised renewable electricity generation increases, the synergy can mitigate grid congestion, reduce the need for scarce -centrally procured- power reserve capacity, and increase the efficiency of investments in the grids, eventually reducing per unit investment needs. In this manner, decentralised renewables with storage and demand response can become a source of high-value flexibility services for the grid and the energy system in general.

Significant technical, economic & financial, legislative & regulatory, and societal barriers remain for either electrification of end-uses or integration of decentralised renewable energy or both:

- **Technical barriers** mainly stem from the increasing balancing needs between power supply and demand due to the further penetration of variable renewable energy sources and the complexity they bring to networks' operation. The integration of distributed energy resources poses operational challenges and benefits to the electricity grid, requiring a revised approach on the way distribution systems are designed, developed and operated, employing innovative technical solutions. On the demand-side, technical interventions and upgrades required on the building stock (i.e., electric panels, wiring, etc.) face limited space availability for new equipment in urban areas.
- **Economic and financial barriers** can be seen as the main barriers, rather than technical, which is consistent with the literature and the survey results. Energy prices and differences in the capital expenditures (CAPEX) of equipment are the chief determinants of the relative economics of electric compared to non-electric technologies. The additional investment to the already massive investments needed to upgrade ageing networks, may put pressure on consumers due to the increased costs. These are supplemented by large-scale competitive investments in new storage facilities, further increasing the costs for consumers. From the consumers' point of view, high upfront cost, including long project lead times, are slowing down the electrification process. Innovative approaches to electricity supply (i.e., dynamic tariffs, multiple suppliers, combination of products to better manage supply cost, remuneration of flexibility) are not yet widely offered, affected by delayed smartening of the grid. Taxation and existing policies that favour fossil fuels can impede progress towards electrification and decarbonisation.
- **Legal and regulatory barriers** cause delays implementing detailed market rules for the active participation of distributed energy resources (DERs) in market operation. Furthermore, they are enabling them to offer flexibility and balancing services, affect their operational efficiency, hindering the opportunities to generate revenues from market products and services offered. Permitting processes related to the installation of infrastructure, such as grid extensions and reinforcements, solar PV, wind and storage facilities, or even charging points can also be a challenge as implementation of simplified and accelerated permitting processes at national level lags behind. The revised REDII sets specific requirements regarding the acceleration of the permit-

granting process for installation of renewable energy production, co-located storage, and heat pumps as well as the related grid connections. Most of the permitting-related rules will have to be transposed into national law by 1 July 2024. Until then, Council Emergency Regulation 2022/2577 is already accelerating permitting, and the validity of several of its stipulations has been prolonged until mid-2025.

- **Societal barriers** need to be overcome for the success of electrification and renewable energy integration. Lack of public support can lead to opposition to infrastructure projects and policies that support electrification and renewable energy. Raising people's awareness is a critical prerequisite for the effective scaling up of electrification and decentralised energy generation. The limited availability of a properly trained workforce is another key barrier as electrification and local energy management require new skills and qualifications.

Several new provisions to advance the electrification and decentralised renewable energy integration in the EU have been introduced in the revised Renewable Energy Directive (REDII), Energy Performance of Buildings Directive (EPBD), Alternative Fuels Infrastructure Regulation (AFIR) and in the revised Energy Efficiency Directive (EED). These new provisions already address some of the recommendations from stakeholders put forward in the survey as well as in various studies and policy papers and are expected to address partially or fully some of the barriers identified. The Wind Power Package and the Grid Package published end 2023 also contribute to address these topics.

However, some barriers potentially remain, and grid users, such as consumers and DERs, should be able to benefit from further initiatives to alleviate the main barriers. The lack of adequate grid capacity to timely connect new load and injection facilities remains a key barrier. The implementation of the EU Action Plan for Grids will help in this regard, notably to incentivise anticipatory development of the electricity networks at distribution level. In line with the aspects highlighted in the EU Action Plan for Grids in this regard, national authorities could mandate electricity TSOs and DSOs to properly anticipate expected developments at supply and demand side and take them into account in their investment plans.

A key recommendation for electrification is to provide guidelines for maximising the benefits from smart metering networks. Providing guidelines on how to enable different value propositions for the utilisation of smart meter networks and maximise benefits for consumers and energy systems, will make more efficient use of the lessons learned from the implementation of rollout programmes to date.

Another key recommendation emerging from the stakeholder engagement process is to formulate an actionable Strategy for Electrification. There is a need for a dedicated Electrification action plan to accelerate the uptake of direct, smart electrification in Europe. According to stakeholders, concrete actions would include a reform of grid planning both for transmission and distribution networks to improve coordination and political oversight, programmes to attract skilled workers, the prioritisation of direct and smart electrification in the EU's funding and financing programmes, and the empowerment of end-users to utilise the full potential of demand side management. It was recommended the strategy also include specific regulatory and price-based incentives and mechanisms to further increase the rate of electrification.

Uptake of renewable and low-carbon hydrogen

The uptake of renewable and low-carbon hydrogen to address the decarbonisation in hard-to-abate sectors and the increased system flexibility is an essential pillar of the energy transition. Significant technical, economic & financial, legislative & regulatory, and societal barriers remain for the uptake of hydrogen:

- **Technical barriers** include inadequate hydrogen infrastructure, i.e. the pipeline network and the lack of storage facilities. In addition, a hydrogen import infrastructure (from overseas) is still dependent on technical issues to be resolved in all the options discussed. Further, a rapid introduction of hydrogen may face production bottlenecks for electrolysers. The lack of experience and infrastructure for CCS in Europe could significantly delay the use of low-carbon hydrogen.
- **Economic and financial barriers** are identified as most important and include the cost gap and bankability issues. Despite activities to address the cost gap, e.g. through the European Hydrogen Bank, stakeholders emphasise the remaining gap with fossil alternatives. This leads to competitiveness challenges and consequently bankability remains difficult to achieve for many projects.
- **Legislative and regulatory barriers** remain for low-carbon hydrogen, and a lack of clarity on how to interpret the requirements of the Delegated Acts to define renewable hydrogen creates barriers to imports. And permitting remains a challenge for hydrogen projects across Europe.
- **Societal barriers** are the lack of trained personnel and potentially low acceptance of some derivatives as well as CCS.

The regulatory framework is considered to be almost complete, and measures are being implemented tackling both major and minor barriers, however the effectiveness of the respective measures remains to be assessed individually. A significant number of recommendations (22) emerged from both the literature and stakeholders, the majority of which addresses hydrogen independent from its production route (14). Important overarching recommendations are:

1. Towards 2040 a high-level hydrogen ambition could further foster the uptake of renewable and low-carbon hydrogen.
2. The measure of highest impact to address the cost gap between renewable/ low-carbon hydrogen and current fossil-based hydrogen is to phase out subsidies for fossil fuels;
3. To address bankability issues for projects, differentiated and more ambitious demand quotas are seen as an appropriate lever to provide the required offtake certainty financiers seek;
4. The lack of existing infrastructure can be addressed through appropriate risk-sharing and comprehensive integrated infrastructure planning, potentially including storage targets, while ensuring third party access to transport and large-scale storage infrastructures.

The uptake of low-carbon hydrogen from natural gas with carbon capture and storage (CCS) is especially dependent on the build-out of CCS infrastructure, while renewable hydrogen needs even higher acceleration of renewable electricity deployment, as well as access to water.

Detailed recommendations range from improving IT systems on permitting procedures for encouraging the EU to engage globally in harmonising GHG calculation methodologies. Two detailed paragraphs on the feasibility and costs for reaching the targets in the short term by 2030 and on the GHG footprint of hydrogen imports, conclude that the above-mentioned barriers need to be addressed to reach the ambitious national targets by 2030, and that the imports should focus on renewable hydrogen or low-carbon hydrogen with certified lifecycle analysis.

Utilisation of waste heat

This section identifies barriers to and provides recommendations on advancing the utilisation of waste heat and cold in the EU. The scope of waste heat sources and applications considered differ from the definition in the revised REDII and is detailed in the chapter. In addition, four in-depth case studies have been developed to analyse barriers, best practices and recommendations in specific waste heat and cold applications.

There is significant waste heat and cold potential in the EU (from industrial as well as non-conventional sources). The better use of this potential could allow to decarbonise a significant portion of the EU's current heating and cooling needs. Total waste heat potential (as defined by the REDII) could exceed 3000 TWh/year, with industry and power generation responsible for much of it (even considering a significant decrease in thermal inputs for power generation towards 2040), but with non-conventional sources such as data centres, wastewater treatment facilities, and tertiary buildings offering an important potential. Future sources of waste heat will also arise, including electrolysis and methanation among others. Moreover, while waste heat utilisation is usually focused on district heating applications (including industrial use), indirect applications such as waste heat to power should also be considered.

Significant technical, economic & financial, legislative & regulatory, and societal barriers exist for waste heat utilisation:

- **Technical barriers** are driven by the temporal, locational, and temperature quality mismatch between waste heat and cold sources and potential, which will always exist to a certain extent. These mismatches can however be managed through existing technical solutions and appropriate policies and measures. Moreover, how waste heat is represented in energy system models and scenarios could be improved;
- **Economic and financial barriers** are related to internal factors that affect the costs of projects and reduce their revenues (such as capital intensiveness of assets for waste recovery and district heating and cooling networks, and low valuation of waste heat), as well as external factors which distort the competition with other heating options (particularly the non-internalisation of negative externalities of competing heating sources). Moreover, project uncertainty, complexity and the risk aversion of actors compound these factors;
- **Legislative and regulatory barriers** are related most of all to the lack of appropriate governance and planning frameworks in the geographical (from the EU to the national and local levels) and planning dimensions (with heating and cooling, broader energy & climate, and spatial planning). The limited replicability of solutions and gaps in the accounting of climate and environmental footprints of waste heat also impact its competitiveness;

- **Societal barriers** include the lack of knowledge and/or acceptance of various stakeholders, including authorities (EU, national and local), waste heat suppliers, heat network operators and consumers. In this category the lack of sufficient skills to plan and implement waste heat and cold projects is also included.

A main recommendation of this chapter is for policymakers to give higher priority to waste heat and cold. Recently adopted policies such as the revised REDII and EED should already address (fully or partially) many of the barriers. These new legal provisions are in the phase of implementation. However, stakeholders can benefit from further clarity regarding policy principles for waste heat and cold recovery and utilisation in the long run.

Member States should be at the forefront of actions to advance waste heat utilisation. In this regard, many of the recommendations to the Commission concern providing assistance and exchanging best practices so the Member States can implement relevant measures (with a number of related initiatives already ongoing). More concrete actions remain, such as improving the representation of waste heat in energy system models, including it specifically in energy statistics, providing funding for planning and feasibility studies, improving skills-related initiatives, and expanding the energy source mix disclosure obligation from electricity to also gas and heat suppliers. At national level, in general Member States should improve their planning of the energy system and support to waste heat recovery and utilisation, while removing market distortions.

Cross-cutting aspects of energy system integration

An additional analysis focuses on challenges that are not covered in detail in the analysis of specific aspects but are considered as important challenges. These need to be addressed to further advance energy system integration in the EU. The following aspects are focused on:

1. Integrated energy infrastructure planning and operation
2. Energy storage;
3. Digitalisation and innovation;
4. Monitoring and frameworks;
5. Other aspects, particularly critical raw materials and skills.

Overall findings show that for integrated energy infrastructure, issues such as the currently insufficient utilisation of interconnector capacities and the lacking interoperability of grid technology solutions need to be addressed. Overall better coupling of different energy vectors is needed. The recommendations also emphasise the importance of addressing the increasing complexity of balancing distribution systems, necessitating improved coordination between DSOs and TSOs. The need to accelerate the expansion and reinforcement of the electricity networks, and to enable investments in decentralised renewable electricity generation as well in demand-side assets, is identified as a key factor to tackle delays to further electrification and DER integration. Additional integration benefits can be reaped in collaboration is fostered between ENTSO-E and ENTSOG (and in the future ENNOH), with a focus on revising their respective models to include short and long-term resolutions.

To facilitate cross-border trading and create a level-playing field for market participants, the harmonisation of regulatory frameworks is needed, including rules on grid access, tariffs, trading, and capacity allocation; as well as rules for compliance, permitting and licensing for cross-border projects. The Commission should also support

Member States in the implementation of regulatory frameworks and investments into dedicated cross-border CO_2 transport infrastructure.

Concerning energy storage, the most important barriers are the long permitting procedures, the lack of consideration of the double role of storage and inadequate capacity mechanisms. An update of existing regulatory frameworks combined with lifting economic barriers for energy storage is recommended. As an economic driver, the value of storage could be more transparent if adequate assessments and valuations of storage needs would be undertaken.

While digitalisation in the energy sector is already underway and a series of actions have been defined on EU level, the implementation of these can benefit from the harmonisation of legislative acts, standards and regulations on the EU and MS level. This will help to create a safe European-level data-sharing infrastructure to support a vast integrated energy system.

For many topics of the study as well as for the cross-cutting issues, the focus should be on an adequate implementation and follow-up of policies and measures. A monitoring framework to assess the effectiveness of the measures is recommended, with indicators that focus on electricity grids, energy storage and digitalisation. Periodic reports could be distributed to aid stakeholders in understanding progress and identifying required actions. As many of the specific recommendations of this study, e.g. regarding the deployment of distributed energy resources, will have socio-economic impacts – positive or negative – further attention from the Commission is necessary to ensure public acceptance and accelerate the deployment of the technologies while minimising potential negative impacts.

RÉSUMÉ EXÉCUTIF

La décarbonisation complète de l'économie de l'UE nécessite une transformation profonde du système énergétique. Une intégration optimale de ce système peut contribuer à atteindre cet objectif de manière plus efficace tout en apportant la flexibilité nécessaire au système énergétique. La décarbonisation nécessite une réduction de la demande d'énergie, la poursuite de l'électrification des usages énergétiques et le déploiement de vecteurs énergétiques renouvelables ou à faible teneur en carbone dans les secteurs où l'électrification n'est pas envisageable. La chaleur renouvelable est également importante pour la décarbonisation, même si elle ne fait pas l'objet de la présente étude. La flexibilité dans le système électrique doit être développée au même rythme que les énergies renouvelables intermittentes; tant la demande que l'offre doivent en effet s'adapter aux conditions changeantes pour que le système reste à tout moment en équilibre. En conséquence, la décarbonisation nécessite une intégration plus poussée entre les secteurs, une plus grande implication des consommateurs, une plus grande utilisation des ressources permettant de fournir des services de flexibilité et d'adéquation du côté de la demande, ainsi que l'échange d'énergie sur tous les marchés, et un cadre réglementaire plus innovant et plus propice.

La stratégie de l'UE pour l'intégration du système énergétique (ESI) a été publiée par la Commission européenne en juillet 2020 et "propose des mesures politiques et législatives concrètes au niveau de l'UE pour développer progressivement un nouveau système énergétique intégré", avec diverses actions portant sur tous les éléments mentionnés ci-dessus qui sont nécessaires pour la décarbonisation du système énergétique de l'UE conformément au Green Deal européen.

L'objectif de cette étude est d'évaluer les progrès dans le domaine de l'intégration des systèmes énergétiques dans l'UE. Pour ce faire, elle examine les obstacles existants et propose des recommandations pour y remédier. L'évaluation des obstacles a été réalisée sur la base d'une analyse documentaire et d'une vaste consultation des parties prenantes (par le biais d'une enquête, d'entretiens et d'ateliers). Ce report est structuré comme suit:

- ✓ Le chapitre 1 présente la structure de l'analyse, y compris une vue d'ensemble de la stratégie d'intégration du système énergétique de l'UE;
- ✓ Le chapitre 2 présente l'analyse du **thème 1 : électrification des utilisations finales et intégration des énergies renouvelables décentralisées;**
- ✓ Le chapitre 3 présente l'analyse du **thème 2 : déploiement de l'hydrogène;**
- ✓ Le chapitre 4 présente l'analyse du **thème 3 : utilisation de la chaleur résiduelle;**
- ✓ Le chapitre 5 présente l'**évaluation de thèmes transversaux** qui n'ont pas été analysés dans les chapitres précédents (notamment les infrastructures énergétiques, le stockage de l'énergie, la numérisation et l'innovation)**.**

Défis liés à l'électrification des utilisations finales et l'intégration des ressources énergétiques décentralisées.

Les obstacles à l'électrification des utilisations finales et à l'intégration des énergies renouvelables décentralisées ont été identifiés, et des recommandations ont été formulées pour les surmonter. En ce qui concerne l'électrification, l'analyse porte sur l'électrification directe des applications d'utilisation finale pour : (i) le chauffage des bâtiments, (ii) les processus industriels, et (iii) le transport par le biais de véhicules électriques (VE). Le déploiement d'installations de production d'énergies renouvelables décentralisées et de stockage, y compris les VE, permettra également des flux d'électricité bidirectionnels, ce qui constitue un défi supplémentaire pour l'ESI.

L'électrification présente de multiples avantages, notamment des économies d'énergie accrues, l'électricité étant plus efficace que les autres vecteurs énergétiques, et plus durable, l'électricité étant de plus en plus produite à partir de sources d'énergies renouvelables. En outre, l'électricité permet aux consommateurs d'accéder à des options énergétiques plus appropriées. L'électricité injectée dans le réseau et prélevée du réseau peut s'adapter à des profils de charge spécifiques, selon les besoins du système, afin de réduire la variabilité, les besoins en capacité de secours et les coûts. En outre, combinée à une production décentralisée d'énergie renouvelable et à divers systèmes de stockage locaux, l'électricité peut apporter des avantages importants aux utilisateurs d'énergie, au système énergétique et à la décarbonisation. Lorsque l'électrification et la production décentralisée d'électricité renouvelable augmentent, la synergie entre les différentes composantes du système peut atténuer la congestion du réseau, réduire le besoin de capacité de réserve d'énergie – contracté au niveau central par le TSO - et augmenter l'efficacité des investissements dans les réseaux, tout en réduisant les besoins globaux d'investissement par unité. De cette manière, les énergies renouvelables décentralisées couplées avec le stockage et la gestion de la demande peuvent devenir une source de services de flexibilité de grande valeur pour le réseau et le système énergétique en général.

D'importants obstacles techniques, économiques et financiers, législatifs et réglementaires, et sociétaux subsistent pour l'électrification des utilisations finales ou l'intégration des énergies renouvelables décentralisées, ou les deux :

- **Les obstacles techniques** découlent principalement des besoins croissants d'équilibrage entre l'offre et la demande d'électricité en raison de la pénétration accrue des sources d'énergies renouvelables variables et de la complexité que celles-ci apportent à l'exploitation des réseaux. L'intégration des ressources énergétiques distribuées pose des défis opérationnels et présente également des avantages pour le réseau électrique, ce qui nécessite de revoir la manière dont les systèmes de distribution sont conçus, développés et exploités, en recourant à des solutions techniques innovantes. Du côté de la demande, les interventions techniques et les mises à niveau nécessaires dans le parc immobilier (panneaux électriques, câblage, etc.) se heurtent au manque d'espace disponible pour les nouveaux équipements dans les zones urbaines.
- **Les obstacles économiques et financiers** ont un impact plus important que les obstacles techniques et peuvent donc être considérés comme les principaux obstacles, ce qui est cohérent avec la littérature et les résultats de l'enquête. Les prix de l'énergie et les différences dans les dépenses d'investissement (CAPEX) des équipements sont les principaux déterminants de la compétitivité des technologies électriques par rapport aux technologies non électriques. Les investissements supplémentaires, qui s'ajoutent aux investissements déjà massifs nécessaires pour moderniser les réseaux vieillissants, peuvent exercer une pression sur les consommateurs en raison de l'augmentation des coûts. En plus des investissements requis dans les équipements et réseaux, des investissements importants sont nécessaires dans de nouvelles installations de stockage, ce qui augmente encore les coûts globaux pour les consommateurs. Du point de vue des consommateurs, les

coûts initiaux élevés, y compris les longs délais d'exécution des projets, ralentissent le processus d'électrification. Les approches innovantes en matière de fourniture d'électricité (tarifs dynamiques, fournisseurs multiples, combinaison de produits pour mieux gérer les coûts d'approvisionnement, rémunération de la flexibilité) ne sont pas encore largement proposées, ce qui s'explique notamment par le retard pris dans la mise en place d'un réseau intelligent. La fiscalité et les politiques existantes qui favorisent encore l'utilisation des combustibles fossiles peuvent entraver les progrès vers l'électrification et la décarbonisation.

- **Les obstacles juridiques et réglementaires** entraînent des retards dans la mise en œuvre de règles de marché appropriées pour la participation active des ressources énergétiques distribuées au fonctionnement du marché, ce qui ne leur permet pas d'offrir des services de flexibilité et d'équilibrage, affecte leur efficacité opérationnelle et entrave les possibilités de générer des revenus à partir des produits et services offerts sur le marché. Les processus d'autorisation ou de permis pour de nouvelles infrastructures, telles que les extensions et les renforcements de réseaux, les installations solaires photovoltaïques, éoliennes et de stockage, ou même les bornes de recharge, peuvent également constituer un défi, car la mise en œuvre de procédures simplifiées et accélérées au niveau national doit être renforcée. La REDII révisée fixe des exigences spécifiques concernant l'accélération du processus d'octroi de permis pour des 'installations de production d'électricité sur base d'énergies renouvelables, des systèmes de stockage et de production d'électricité couplés et des pompes à chaleur, ainsi que les raccordements concernés au réseau. La plupart des règles relatives aux autorisations devront être transposées dans le droit national d'ici le 1er juillet 2024. D'ici là, le règlement d'urgence 2022/2577 du Conseil accélère déjà l'octroi des autorisations et la validité de plusieurs de ses dispositions a été prolongée jusqu'à la mi-2025.
- **Les obstacles sociétaux** doivent être surmontés pour assurer le succès de l'électrification et de l'intégration des énergies renouvelables. Le manque de soutien public peut conduire à une opposition aux projets d'infrastructure et aux politiques qui soutiennent l'électrification et le déploiement des énergies renouvelables. La sensibilisation de la population est une condition préalable essentielle à l'extension effective de l'électrification et de la production d'énergie décentralisée. La disponibilité limitée d'une main-d'œuvre correctement formée est un autre obstacle majeur, car l'électrification et la gestion locale de l'énergie requièrent de nouvelles compétences et qualifications.

Plusieurs nouvelles dispositions visant à faire progresser l'électrification et l'intégration des énergies renouvelables décentralisées dans l'UE ont été introduites dans la directive révisée sur les énergies renouvelables (REDII), la directive sur la performance énergétique des bâtiments (EPBD), le règlement sur les infrastructures pour les carburants alternatifs (AFIR) et la directive révisée sur l'efficacité énergétique (EED). Ces nouvelles dispositions répondent déjà à certaines des recommandations formulées par les parties prenantes dans l'enquête ainsi que dans diverses études et documents d'orientation, et devraient permettre de lever partiellement ou totalement certains des obstacles identifiés. **Le paquet "European Wind Power" et le "Grid Action Plan"**

publiés fin 2023 contribuent également à alléger certains problèmes évoqués dans cette étude.

Toutefois, certains obstacles peuvent subsister, et les utilisateurs du réseau, tels que les consommateurs et les producteurs décentralisés d'électricité, devraient pouvoir bénéficier de nouvelles initiatives visant à réduire les principaux obstacles. Le manque de capacité adéquate du réseau pour connecter en temps voulu les nouvelles charges et les installations d'injection reste un obstacle majeur. La mise en œuvre du plan d'action de l'UE pour les réseaux sera utile à cet égard, notamment en encourageant le développement anticipé des réseaux électriques au niveau de la distribution. Conformément aux aspects soulignés à cet égard dans le plan d'action de l'UE pour les réseaux, les autorités nationales pourraient demander aux GRT et GRD d'électricité d'anticiper correctement les développements attendus du côté de l'offre et de la demande et d'en tenir compte dans leurs plans d'investissement.

Une recommandation clé pour l'électrification est de fournir des lignes directrices pour maximiser les avantages des réseaux et compteurs intelligents. En disposant de lignes directrices sur les différentes possibilités pour valoriser et optimiser l'utilisation des réseaux et des compteurs intelligents et pour maximiser les avantages pour les consommateurs et les systèmes énergétiques, les parties prenantes pourront utiliser plus efficacement les leçons tirées de la mise en œuvre des programmes de déploiement à ce jour.

Une autre recommandation clé issue du processus d'engagement des parties prenantes est de formuler une stratégie d'électrification appropriée. Il est nécessaire de mettre en place un plan d'action dédié à l'électrification afin d'accélérer le déploiement de l'électrification directe et intelligente en Europe. Selon les parties prenantes, les actions concrètes devraient comprendre une réforme de la planification des réseaux de transport et de distribution afin d'améliorer la coordination et la supervision politique, des programmes visant à attirer des travailleurs qualifiés, la priorisation de l'électrification directe et intelligente dans les programmes de financement de l'UE, et la responsabilisation des utilisateurs finaux afin d'utiliser le plein potentiel de la gestion de la demande. Il a été recommandé que la stratégie comprenne également des incitations et des mécanismes réglementaires et tarifaires spécifiques afin d'augmenter le taux d'électrification.

Déploiement de l'hydrogène renouvelable et à faible teneur en carbone

Le déploiement de l'hydrogène renouvelable et à faible teneur en carbone pour faire face à la décarbonisation des secteurs difficiles à décarboner et à l'augmentation des besoins en flexibilité du système est un pilier essentiel de la transition énergétique. D'importants obstacles techniques, économiques et financiers, législatifs et réglementaires, et sociétaux subsistent pour le déploiement de l'hydrogène:

- Les **obstacles techniques** comprennent l'inadéquation de l'infrastructure de l'hydrogène, c'est-à-dire le manque d'un réseau de gazoducs et d'installations de stockage. En outre, une infrastructure d'importation d'hydrogène reste tributaire de questions techniques à résoudre dans toutes les options examinées. En outre, une introduction rapide de l'hydrogène pourrait se heurter à des goulets d'étranglement dans la filière de production d'électrolyseurs. Le manque d'expérience et d'infrastructure en matière de capture et stockage du carbone (CSC) en Europe pourrait retarder considérablement l'utilisation de l'hydrogène à faible teneur en carbone.

- **Les obstacles économiques et financiers sont** considérés comme les barrières les plus importantes et comprennent notamment les coûts élevés et le financement des projets. Malgré les initiatives visant à combler l'écart de coût, par exemple par le biais de la Banque européenne de l'hydrogène, les parties prenantes soulignent l'écart qui subsiste avec les solutions conventionnelles basées sur l'utilisation de combustibles fossiles. Cela entraîne des problèmes de compétitivité et, par conséquent, le financement reste difficile pour de nombreux projets.
- **Des obstacles législatifs et réglementaires** subsistent pour l'hydrogène à faible teneur en carbone, et le manque de clarté sur la manière d'interpréter les exigences des actes délégués pour définir l'hydrogène renouvelable crée des obstacles aux importations. De plus, l'octroi de permis reste un défi pour les projets d'hydrogène dans toute l'Europe.
- Les **obstacles sociétaux** sont le manque de personnel formé et l'acceptation publique potentiellement faible pour l'utilisation de certains dérivés ainsi que du CSC.

Le cadre réglementaire est considéré comme quasiment complet et des mesures sont mises en œuvre pour remédier aux obstacles majeurs et mineurs, mais l'efficacité des mesures respectives doit encore être évaluée individuellement. Un nombre important de recommandations (22) ont été formulées dans la littérature et par les parties prenantes, la majorité d'entre elles portant sur l'hydrogène indépendamment de son mode de production (14). Les principales recommandations sont les suivantes :

1. À l'horizon 2040, une ambition de haut niveau en matière d'hydrogène pourrait favoriser le déploiement de l'hydrogène renouvelable et à faible teneur en carbone ;
2. La mesure la plus efficace pour combler l'écart de coût entre l'hydrogène renouvelable/à faible teneur en carbone et l'hydrogène actuel d'origine fossile consiste à supprimer progressivement les subventions aux combustibles fossiles ;
3. Pour résoudre les problèmes de financement des projets, des quotas de demande différenciés et ambitieux sont considérés comme un levier approprié pour garantir une demande certaine telle que recherchée par les financiers ;
4. Le manque actuel d'infrastructures existantes peut être résolu par un partage approprié des risques et une planification globale et intégrée des infrastructures, incluant éventuellement des objectifs de stockage, tout en garantissant l'accès des tiers aux infrastructures de transport et de stockage à grande échelle.

Le déploiement de l'hydrogène à faible teneur en carbone issu du gaz naturel avec CSC dépend particulièrement de la mise en place de l'infrastructure CSC, tandis que l'hydrogène renouvelable nécessite une accélération encore plus forte du déploiement de l'électricité renouvelable, ainsi que l'accès à l'eau.

Les recommandations détaillées comprennent notamment une amélioration de la digitalisation pour les procédures d'autorisation et une incitation de l'UE à s'engager au niveau mondial pour harmoniser les méthodes de calcul des émissions des GES. Deux paragraphes détaillés sur la faisabilité et les coûts pour atteindre les objectifs à court terme à l'horizon 2030 et sur l'empreinte GES des importations d'hydrogène concluent que les principaux obstacles mentionnés ci-dessus doivent être levés pour atteindre les objectifs nationaux ambitieux en 2030, et que les importations devraient se concentrer sur l'hydrogène renouvelable ou l'hydrogène à faible teneur en carbone avec une analyse du cycle de vie certifiée.

Utilisation de la chaleur résiduelle

Cette section identifie les obstacles et fournit des recommandations pour faire progresser l'utilisation de la chaleur et du froid résiduels dans l'UE. L'étendue des sources de chaleur résiduelle et des applications considérées diffère de la définition de la REDII révisée et est détaillée dans le chapitre. En outre, quatre études de cas ont été réalisées pour analyser les obstacles ainsi que les meilleures pratiques et pour formuler des recommandations concernant des applications spécifiques de la chaleur et du froid résiduels.

L'UE dispose d'un important potentiel de chaleur et de froid résiduels (provenant de sources industrielles et non conventionnelles). Une meilleure utilisation de ce potentiel pourrait permettre de décarboniser une part importante des besoins actuels de l'UE en matière de chauffage et de refroidissement. Le potentiel total de chaleur résiduelle (tel que défini par la REDII) pourrait dépasser 3 000 TWh/an, l'industrie et la production d'électricité étant responsables d'une grande partie de ce potentiel (même en tenant compte d'une diminution significative de la production d'électricité thermique vers 2040), mais les sources non conventionnelles telles que les centres de données, les installations de traitement des eaux usées et les bâtiments tertiaires offrent également un potentiel important. De nouvelles sources de chaleur résiduelle apparaîtront également, notamment l'électrolyse et la méthanisation. En outre, alors que l'utilisation de la chaleur résiduelle est généralement axée sur les applications de chauffage urbain (y compris l'utilisation industrielle), des applications indirectes telles que la production d'électricité à partir de la chaleur résiduelle devraient également être envisagées.

L'utilisation de la chaleur résiduelle se heurte à d'importants obstacles techniques, économiques et financiers, législatifs et réglementaires, et sociétaux :

- **Les obstacles techniques** sont dus à l'inadéquation temporelle, géographique et de qualité entre les sources de chaleur et de froid résiduels disponibles et leur utilisation potentielle, qui existera toujours dans une certaine mesure. Ces inadéquations peuvent toutefois être gérées grâce aux solutions techniques existantes et aux politiques et mesures appropriées. En outre, la façon dont la chaleur résiduelle est représentée dans les modèles et les scénarios de systèmes énergétiques pourrait être améliorée ;
- **Les obstacles économiques et financiers** sont liés à des facteurs internes qui affectent les coûts des projets et réduisent leurs revenus (tels que l'intensité capitalistique des actifs pour la valorisation des déchets et les réseaux de chauffage et de refroidissement urbains, et la faible valorisation de la chaleur résiduelle), ainsi qu'à des facteurs externes qui faussent la concurrence avec d'autres options de chauffage (en particulier la non-internalisation de certaines externalités négatives des sources de chauffage conventionnelles). En outre, l'incertitude et la complexité des projets, ainsi que l'aversion au risque des acteurs, aggravent ces facteurs ;
- **Les obstacles législatifs et réglementaires** sont surtout liés à l'absence de cadres de gouvernance et de planification appropriés aux différents niveaux géographiques (de l'UE aux niveaux national et local) et de planification (avec le chauffage et le refroidissement, l'énergie et le climat au sens large, et l'aménagement du territoire). La reproductibilité limitée des solutions et les lacunes dans la comptabilisation des empreintes climatiques et environnementales de la chaleur résiduelle ont également un impact sur sa compétitivité ;

- **Les obstacles sociétaux** comprennent le manque de connaissances et/ou d'acceptation des différentes parties prenantes, notamment les autorités (européennes, nationales et locales), les fournisseurs potentiels de chaleur résiduelle, les opérateurs de réseaux de chaleur et les consommateurs. Cette catégorie d'obstacles comprend également le manque de compétences suffisantes pour planifier et mettre en œuvre des projets dans le domaine de la chaleur et du froid résiduels.

L'une des principales recommandations de ce chapitre est que les décideurs politiques accordent une plus grande priorité à la chaleur et au froid résiduels. Les politiques récemment adoptées, telles que la REDII révisée et la DEE, devraient déjà lever (totalement ou partiellement) un grand nombre d'obstacles. Dans une large mesure, ces nouvelles dispositions politiques sont en phase de mise en œuvre. Cependant, les parties prenantes peuvent bénéficier d'une plus grande clarté concernant les principes politiques pour la récupération et l'utilisation de la chaleur et du froid résiduels à long terme.

Les États membres devraient être à l'avant-garde des actions visant à faire progresser l'utilisation de la chaleur résiduelle. À cet égard, bon nombre des recommandations adressées à la Commission concernent la proposition d'une guidance et l'échange de bonnes pratiques afin que les États membres puissent mettre en œuvre des mesures pertinentes (un certain nombre d'initiatives sont déjà en cours). Il reste des actions plus concrètes à mener, telles que l'amélioration de la représentation de la chaleur résiduelle dans les modèles de systèmes énergétiques, l'inclusion de cette source spécifique dans les statistiques énergétiques, le financement des études de planification et de faisabilité, l'amélioration des initiatives liées aux compétences et l'extension de l'obligation aux fournisseurs de gaz et de chaleur de publier l'information relative aux sources d'énergie fournie. Au niveau national, les États membres devraient en général améliorer leur planification du système énergétique et leur soutien à la récupération et l'utilisation de la chaleur résiduelle, tout en supprimant les distorsions du marché.

Aspects transversaux de l'intégration des systèmes énergétiques

Une analyse supplémentaire se concentre sur les défis qui ne sont pas couverts en détail dans l'analyse des aspects spécifiques mais qui sont considérés comme des défis importants. Ces défis doivent être relevés pour faciliter et accélérer l'intégration des systèmes énergétiques dans l'UE. L'accent est mis sur les aspects suivants:

1. Planification et exploitation intégrées des infrastructures énergétiques ;
2. Stockage de l'énergie ;
3. Numérisation et innovation ;
4. Suivi et cadres régulatoires ;
5. D'autres aspects, en particulier les matières premières et les compétences essentielles.

Les résultats globaux montrent que pour accroitre l'intégration de l'infrastructure énergétique, des questions telles que l'utilisation actuellement insuffisante des capacités d'interconnexion et le manque d'interopérabilité des solutions technologiques de réseau doivent être abordées. D'une manière générale, un meilleur couplage des différents vecteurs énergétiques est nécessaire. Les recommandations soulignent également l'importance d'aborder la complexité croissante de l'équilibrage des systèmes de distribution, ce qui nécessite une meilleure coordination entre les GRD et les GRT. La nécessité d'accélérer l'expansion et le renforcement des réseaux électriques, et de faciliter des investissements dans la production décentralisée d'électricité renouvelable ainsi que dans les équipements du côté de la demande, est identifiée comme un facteur clé pour réduire les retards dans l'électrification et l'intégration des sources d'énergie renouvelables. Des avantages supplémentaires en matière d'intégration peuvent être récoltés par une collaboration plus étroite entre ENTSO-E et ENTSOG (et à l'avenir ENNOH), en mettant l'accent sur la révision de leurs modèles respectifs pour y inclure des objectifs et trajets à court et à long terme.

Pour faciliter les échanges transfrontaliers et créer des conditions équitables pour les acteurs du marché, il est nécessaire d'harmoniser les cadres réglementaires nationaux, notamment les règles relatives à l'accès au réseau, aux tarifs, aux échanges et à l'attribution des capacités, ainsi que les règles de conformité, d'autorisation et d'octroi de permis pour les projets transfrontaliers. La Commission devrait également soutenir les États membres dans la mise en œuvre de cadres réglementaires et d'investissements dans des infrastructures transfrontalières dédiées au transport de CO_2.

En ce qui concerne le stockage de l'énergie, les obstacles les plus importants sont la lenteur des procédures d'autorisation, l'absence de prise en compte du double rôle du stockage et l'inadéquation des mécanismes de capacité. Il est recommandé de mettre à jour les cadres réglementaires existants et de lever les obstacles économiques au stockage de l'énergie. En tant que moteur économique, la valeur du stockage pourrait être plus transparente si des évaluations adéquates des besoins de stockage étaient réalisées.

Bien que la numérisation du secteur de l'énergie soit déjà en cours et qu'une série d'actions aient été définies au niveau de l'UE, leur mise en œuvre peut bénéficier d'une harmonisation des actes législatifs, des normes et des réglementations au niveau de l'UE et des États membres. Cela permettra de créer une infrastructure sûre de partage des données au niveau européen pour soutenir un vaste système énergétique intégré.

De manière générale, l'accent devrait être mis sur la mise en œuvre adéquate et le suivi des politiques et mesures. Un cadre de suivi pour évaluer l'efficacité des mesures est recommandé, avec des indicateurs axés sur les réseaux électriques, le stockage de l'énergie et la numérisation. Des rapports périodiques pourraient être mis à disposition pour aider les parties prenantes à connaître les progrès réalisés et à identifier les actions nécessaires. Étant donné que bon nombre des recommandations spécifiques de cette étude, par exemple en ce qui concerne le déploiement des ressources énergétiques distribuées, auront des incidences socio-économiques - positives ou négatives - une attention accrue de la part de la Commission est nécessaire pour améliorer l'acceptation publique et accélérer le déploiement des technologies tout en réduisant au minimum les incidences négatives potentielles.

1. The role of system integration in the context of the REPowerEU plan

The objective of this study is to assess the progress of energy system integration in the EU by looking into existing barriers as well as identifying solutions and providing recommendations to address the barriers. The outputs of the analysis aim to support various Commission workstreams.

This chapter introduces the structure of the analysis, providing an overview and holistic analysis of the EU Energy System Integration Strategy linking the various insights developed in the analysis of the specific study topics.

The remaining chapters of this report are structured according to the main topics of analysis, as follows:

- ✓ Chapter 2 presents the analysis for **topic 1: electrification of end-uses and decentralised renewable energy integration;**
- ✓ Chapter 3 presents the analysis for **topic 2: uptake of hydrogen;**
- ✓ Chapter 4 presents the analysis for **topic 3: utilisation of waste heat;**
- ✓ Chapter 5 presents the **assessment of cross-cutting topics** which were not analysed in the previous chapters (notably energy storage, infrastructure, digitalisation, and innovation)**.**
- ✓ The **annex** presents:
    - o Overview of recommendations;
    - o Stakeholder survey;
    - o Stakeholders interviewed;
    - o Stakeholder workshop poll results;
    - o Status of actions in the EU Energy System Integration Strategy
    - o Uptake of hydrogen - Details on environmental impacts;
    - o Waste heat utilisation case studies; and
    - o Selected energy system integration studies considered.

1.1. Overview of the EU Energy System Integration Strategy and its links with the study

The EU Energy System Integration (ESI) Strategy3 was published by the European Commission in July 2020 and “proposes concrete policy and legislative measures at EU level to gradually shape a new integrated energy system”, aiming to support the Fit-for-55 package of legislative actions which was proposed in the following year.

The Strategy contains sections on its objectives, the definition and benefits of energy system integration, and on an action plan to advance energy system integration in the EU, organised in six pillars. As indicated by the Strategy, energy system integration is the ‘planning and operation of the energy system “as a whole”, across multiple energy carriers, infrastructures, and consumption sectors, by creating stronger links between them with the

[3] COM(2020) 299 Final. Powering a climate-neutral economy: An EU Strategy for Energy System Integration

objective of delivering low-carbon, reliable and resource-efficient energy services, at the least possible cost for society'.

The Strategy then introduces the hierarchy for cost-effective decarbonisation:

- **A 'circular' energy system with energy efficiency as the core principle** should be prioritised, with reduction of energy demand and use of unavoidable waste materials and energy when these cannot be reduced further;
- **Greater direct electrification of end-uses** leveraging the rapidly decreasing costs of renewable electricity sources and the high source-to-sink efficiencies from electricity generation to consumption;
- **The use of renewable and low-carbon fuels for hard-to-decarbonise applications** where direct electrification is not feasible due to low efficiency and/or high costs.

The process of switching from technologies or processes that use fossil fuels to those that use electricity, preferably from renewable or low-carbon sources, is referred to as electrification. Electrification is one of the most important and effective strategies for reducing CO_2 emissions from energy, and in general, it can result in improved efficiency and lower costs.

In addition to the three mentioned approaches to decarbonise the EU sector, the strategy indicates another characteristic of a highly integrated energy system:

- **Consumers play a greater role in energy supply within a 'multi-direction' energy system**, both vertically (decentralised generation and provision of flexibility by consumers) and horizontally (exchanges of energy between consumers across sectors).

In the main sections presenting an EU action plan for advancing energy system integration, the Strategy addresses the following six pillars:

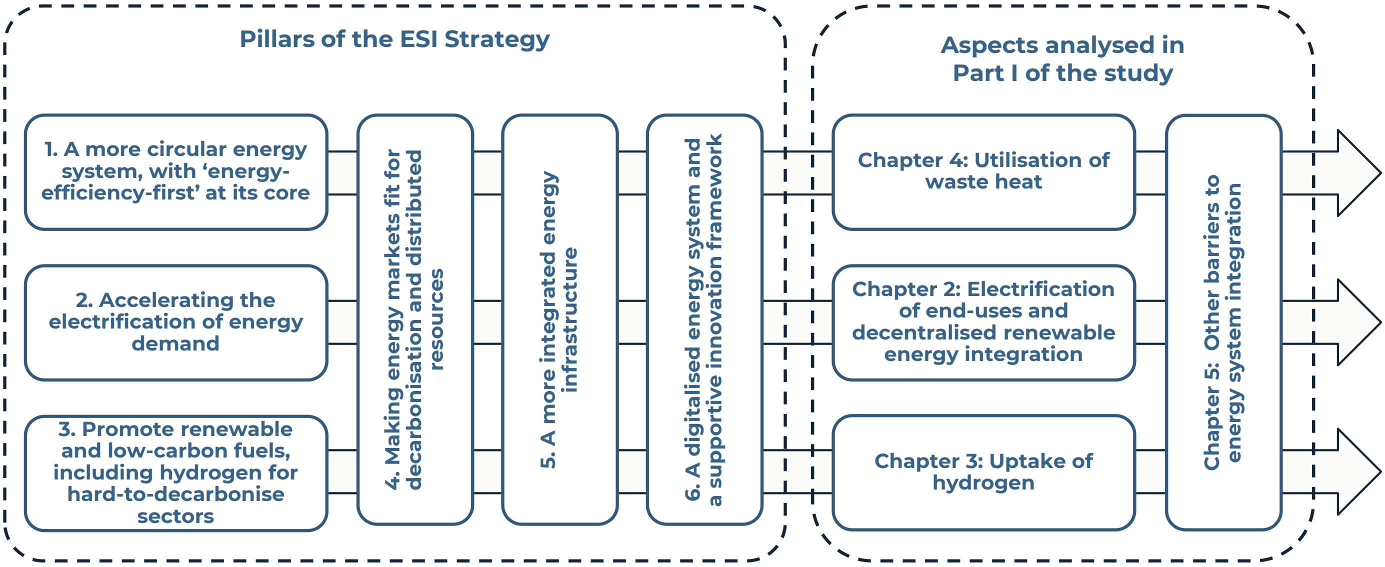
1. A more circular energy system, with 'energy-efficiency-first' at its core;
2. Accelerating the electrification of energy demand, building on a largely renewables-based power system;
3. Promote renewable and low-carbon fuels, including hydrogen, for hard-to-decarbonise sectors;
4. Making energy markets fit for decarbonisation and distributed resources;
5. A more integrated energy infrastructure;
6. A digitalised energy system and a supportive innovation framework.

The six pillars of the Strategy are directly related to the hierarchy for cost-effective decarbonisation of the energy system. Pillar 1 addresses the priority solution in the hierarchy, of increasing the circularity of the energy system and advancing the energy efficiency first principle. This is related not only to energy efficiency but also to the necessary and complementary concept of energy sufficiency. While not mentioned in the ESI Strategy, energy sufficiency has since been gaining traction with EU policymakers and stakeholders more broadly. There is not a single definition of energy sufficiency, but it can be defined as "a level of energy service consumption that is consistent with equity, well-being and environmental limits and as a strategy for reducing energy service consumption to achieve that goal".[4]

Pillar 2 addresses electrifying end-uses when energy demand cannot be reduced further, and pillar 3 addresses the last solution, leveraging renewable and low-carbon fuels when energy demand can neither be reduced nor electrified at a reasonable cost or performance. Pillars 4 to 6 in the ESI Strategy support the multidirectional aspects of energy system integration.

Thus, the three solutions in the hierarchy to decarbonise the energy system as stated in the EU Energy System Integration Strategy (circularity and energy efficiency, direct electrification, and use of renewable and low-carbon fuels) are related to the three main topics analysed in this report (waste heat utilisation, electrification of end-uses and decentralised renewables, and uptake of hydrogen, respectively). The remaining pillars of the strategy address all solutions. However, energy system integration as well as the specific topics analysed in this study are complex. There is therefore not a full one-to-one relationship between the ESI Strategy and the chapters of this study, as illustrated in Figure 1-1.

Figure 1-1 Relationship between the EU ESI Strategy and the chapters of this study



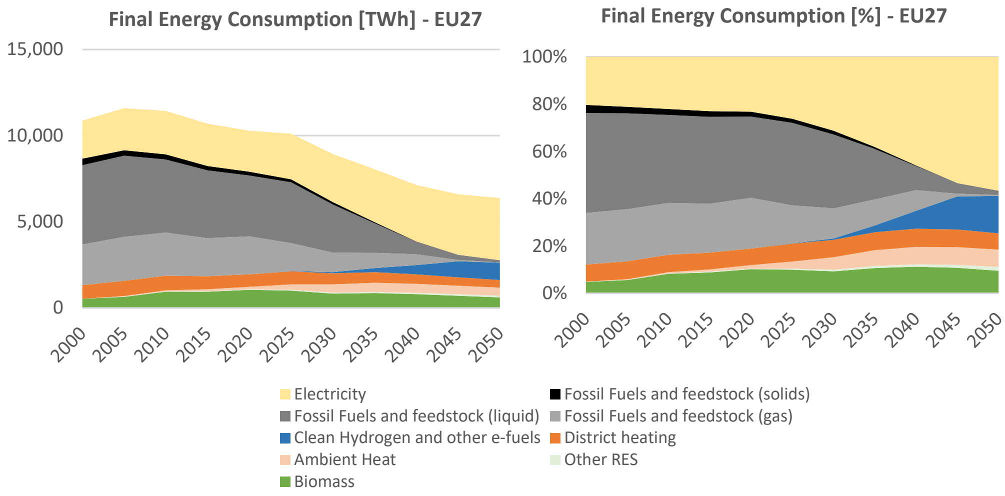
1.2. EU energy system trends

Figure 1-2 illustrates the anticipated- final energy consumption trajectory of EU energy system to 2050 broken down by the main energy carriers. This stylised trajectory is compatible with the latest 2040 climate target plan of the EU.[5] A substantial shift is evident in the overall energy landscape. It is crucial to recognise that these projections are subject to evolution over time due to technological advancements, evolving policies, and emerging challenges.

[4] Sorrell, quoted in Beltoldi (2022) Policies for energy conservation and sufficiency: Review of existing policies and recommendations for new and effective policies in OECD countries

[5] Impact assessment report "Europe's 2040 climate target and path to climate neutrality by 2050 building a sustainable, just and prosperous society" {SWD(2024) 64 final

Figure 1-2 Final energy consumption broken down in different energy carriers. Shown in (a) absolute values (TWh) and (b) relative shares (%)



Source: Stylised projections based on 2040 Climate target plan. SWD (2024) 63 final

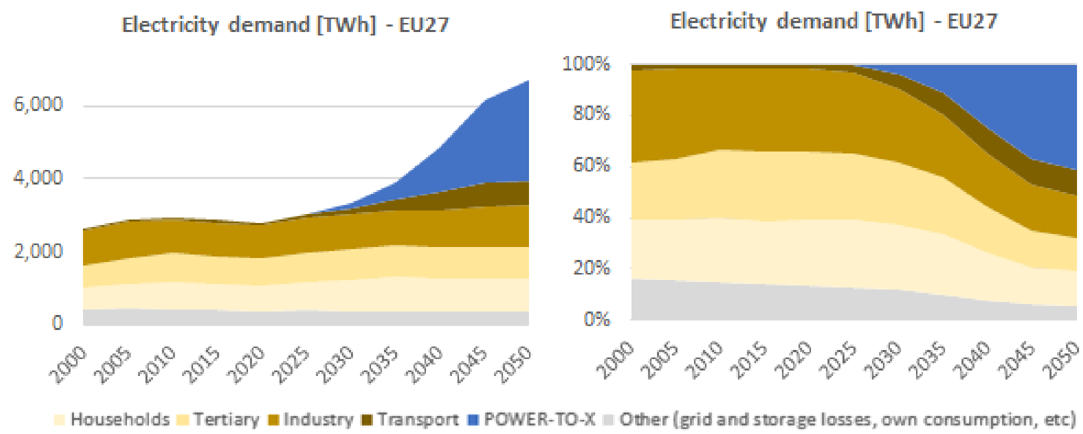
A prominent trend in future energy consumption is the focus on enhancing energy efficiency across various sectors, following the first pillar of the EU ESI Strategy. Projections indicate a nearly 50% reduction in total energy consumption by 2050 compared to current levels. The related "energy efficiency first" principle can be applied not only to energy consumption, but across the energy sector. It involves for example the adoption of advanced technologies, improved insulation in the built environment, and more efficient industrial processes, but also maximising the utilisation of energy infrastructure and flexibility assets across the energy value chain. This broader understanding of energy efficiency brings new challenges related to the application of the energy efficiency first principle to new stages of the value chain beyond consumption. On the other hand, energy efficiency, mitigates the vast changes and infrastructure needs that will happen due to mass electrification, as it effectively reduces the energy and subsequently the electricity needs to satisfy end-uses.[6]

Following the 2nd pillar of the Strategy, an EU-wide trend is noticeable in the gradual replacement of existing solid, gaseous, and liquid hydrocarbons with other sources, particularly through the electrification of end-uses across all sectors, which accelerates from around 2025 onwards. The share of electricity as a final energy carrier in the overall energy mix is expected to increase to more than 50% by 2050, complemented by contributions from other renewable and low-carbon carriers. In absolute terms electricity consumption in end-use sectors will increase by more than 50% till 2050. This trend will require an important transformation of the energy system, by scaling up established technologies but also deploying electrification to more challenging applications such as in industry and in sectors that currently the consumption of electricity is almost non-existent, such as the transport sector. Following the above projections, Figure 1-3 presents the expected evolution of electricity generation. Compared to today, electricity in households is expected to rise by approximately 30% (with also an important rise in the tertiary sector), and in the industry sector by 25%. Note that apart from the electricity needed for final energy consumption, the total

[6] The commission announced their revised carbon emission target in February 2024, namely to reach 90% reduction by 2040: https://ec.europa.eu/commission/presscorner/detail/en/ip_24_588
There will also be an important role for CCU/S to reach this target, as pointed out in the factsheet Industrial Carbon Management: https://ec.europa.eu/commission/presscorner/detail/en/fs_24_587

electricity needs will almost double as large amounts will be needed in order to produce hydrogen and other alternative fuels.

Figure 1-3 Electricity demand broken down by use shown in (a) absolute values (TWh) and (b) relative shares (%)



Source: Stylised projections based on 2040 Climate target plan. SWD (2024) 63 final

In line with the 3rd pillar of the strategy, clean fuels, including hydrogen, are gaining traction as viable clean energy carriers, especially in sectors where direct electrification poses challenges, such as heavy industry and long-haul transportation. The widespread adoption of these alternatives is anticipated to become more evident post-2030, thus following the electrification of end-uses which will have gained speed earlier. Other energy carriers such as heat and biofuels will also play an important role in the future, particularly ambient heat (in combination with electricity for the operation of heat pumps).

1.3. Current status of implementation of actions of the EU Energy System Integration Strategy

The ESI Strategy lists 42 key actions associated with the six pillars, but further actions have been undertaken since. Tracking indicates that the majority of the actions as of October 2023 were either implemented/partly implemented (28 actions out of the 42) or on track (4 actions), with 2 actions dropped,[7] and 8 being continuous actions, as detailed in the Annex section 6.5.

Many actions that the Commission and other EU bodies have initiated before and after the EU Energy System Integration Strategy publication already address barriers to energy system integration. We analyse in this study recent and planned policies and measures in the context of recent socio-economic and policy developments which fully or partly address the barriers identified in this study under the analysis for each topic, such as the:

- ✓ Amended Renewable Energy Directive (EU) 2018/2021;
- ✓ Alternative Fuels Infrastructure Regulation (AFIR);
- ✓ Carbon Border Adjustment Mechanisms (CBAM) Implementing Regulation;

[7] The dropped and delayed actions were the following: A) Establishing minimum mandatory green public procurement criteria and targets in relation to renewable electricity as part of the RED II revision, supported by capacity building under the LIFE programme; B) Organising a transversal public event dedicated to Energy System Integration.

- ✓ FuelEU Maritime Regulation;
- ✓ Revision of the Energy Efficiency Directive 2023/1791;
- ✓ Provisionally agreed revision of the Energy Performance of Buildings Directive;
- ✓ Provisionally agreed Gas and Hydrogen market decarbonisation package;
- ✓ Provisionally agreed reform of the EU electricity market design;
- ✓ EU regulation for the development of the market for CO_2 transport and storage under discussion;
- ✓ ReFuelEU Aviation Regulation;
- ✓ Revised EU Emissions Trading Scheme
- ✓ New EU Emissions Trading Scheme (ETS 2)
- ✓ Carbon Capture and Storage Directive
- ✓ Council Regulation 2022/2577 (Emergency Regulation);
- ✓ EU Taxonomy;
- ✓ Proposed revision of the Energy Taxation Directive;
- ✓ Proposed Net Zero Industry Act;
- ✓ Renovation Wave Strategy;
- ✓ EU Hydrogen Strategy
- ✓ EU Heating and Cooling Strategy
- ✓ EU Heat Pump Action Plan under preparation;
- ✓ EU Action Plan for Grids;
- ✓ REPowerEU Plan
- ✓ European Hydrogen Bank
- ✓ Clean Hydrogen Partnership
- ✓ European Hydrogen Academy
- ✓ Various other EU financing mechanisms for the energy sector

The reader is referred to the specific sections in chapters 2 to 4 for further details and other specific initiatives, where the provisions impacting the specific topics of this study are analysed. Furthermore, a (non-exhaustive) list of energy system integration-related studies considered in the analysis is presented in annex section 6.8.

Further pillars or challenges that are relevant for energy system integration in the EU are not included in the ESI Strategy but have led to increased attention more recently from policymakers. As such topics do not fall under the specific topics of this study (electrification and decentralised renewables, hydrogen and waste heat), they are discussed in the dedicated chapter 5. This includes the topics of resource efficiency, competitiveness and raw material dependency issues linked with certain key energy technologies, biogas and biomethane integration, and skilled workforce and employment. Again, these are of course areas that have gained increased attention from EU and national policymakers since the publication of the EU ESI Strategy in 2020.

The EU also supports energy system integration through various funding mechanisms, including the Framework Research Programmes for Research and Innovation. Examples of EU-funding research which has advanced knowledge on energy system integration-related aspects and identified best practices which can be replicated across Member States include the projects INTERRFACE, CoordiNet, COMPILE, MUSE GRIDS, TRINITY, and X-FLEX. These projects have addressed various aspects, particularly for addressing the challenges that arise from increasing electrification of end-uses and integration of decentralised renewables (covered under chapter 2).

1.4. Overview of energy system integration barriers and specific recommendations of this study

This study identifies technical, financial and economic, legislative and regulatory, and societal barriers for the three specific topics studied in-depth. Our analysis indicates that important barriers remain in all categories, as listed in Table 1-1 and detailed in the respective chapters: electrification of end-uses and decentralised RES (chapter 2), uptake of hydrogen (chapter 3), waste heat utilisation (4) and other aspects (chapter 5). They are specific to each topic, but also frequently exhibit interactions with the broader energy system, as discussed below. This illustrates an important challenge of the present study and of advancing system integration more broadly, where barriers (and associated solutions) are often specific while needing to consider many complex interactions.

Table 1-1 Key barriers identified for the three specific topics of this study

Barrier type	Barrier
Electrification of end-uses and decentralised renewables[8]	
Technical	1. Insufficient distribution network expansion and reinforcement
	2. Delays in the rollout of smart metering equipment
	3. Insufficient digitalisation at distribution level
	4. Delays in grid connection and permitting
Economic and financial	5. Upfront costs for equipment and installation
	6. Operational costs for equipment
Legislative and regulatory	7. Adjusting regulation at national level
Societal	8. Lack of professional experience and skills
	9. Lack of consumer awareness and/or knowledge
Uptake of hydrogen	
Economic and financial	1. Cost gap of renewable and low-carbon H_2 towards costs of fossil-based hydrogen
	2. Complex use of additional revenue streams, such as balancing market services
	3. Reaching bankability for hydrogen related projects
	4. Competition from non-EU sources of hydrogen
	5. Lack of H_2 transportation and storage infrastructure
Technical	6. Insufficient manufacturing capacities for electrolysers[9]
Legislative and regulatory	7. Missing international regulation and import policy
	8. Long, complex, unstandardised permitting processes for RES and H_2 projects
	9. Lack of a skilled workforce e.g. for H_2 project management and H_2 project permitting

[8] Additional sector-specific barriers are analysed in the chapter.
[9] Nameplate manufacturing capacities have in the meantime surpassed the demand from project developers (e.g. recent report by BNEF (https://www.hydrogeninsight.com/electrolysers/severe-overcapacity-the-global-supply-of-electrolysers-far-outstrips-demand-from-green-hydrogen-projects-bnef/2-1-1618327), thus making it unlikely to face insufficiencies in the medium term.

Barrier type	Barrier
Societal	10. Lacking acceptance of derivatives of hydrogen such as ammonia (high toxicity) or methanol and safety issues
Utilisation of waste heat	
Technical	1. Location/temporal/quality mismatch between heat supply and demand
	2. Technical performance of waste heat recovery and district heating/cooling systems
Economic and financial	3. Profitability/long payback period
	4. Inadequate pricing signals
	5. Project uncertainty, complexity, and risk aversion of DHC operators/split incentives
Legislative and regulatory	6. Limited replicability of solutions and lack of standardised contracts/tools
	7. Lack of governance and planning, including information on potentials and integration across carriers and with urban planning
	8. Accounting of climate and environmental footprint/benefits of waste heat utilisation
Societal	9. Knowledge/capacity of actors
	10. Acceptance and behavioural issues

Complete decarbonisation of the EU economy will require a significant transformation of the energy system. – System integration can help achieve it in a cost-efficient manner. The trends illustrated in Figure 1-2 are well known and acknowledged by a wide range of stakeholders as necessary to achieve the net decarbonisation of the EU economy. However, Figure 1-2 potentially the impression that net decarbonisation is a matter of simply increasing energy efficiency and sufficiency, electrifying end-uses as much as possible and deploying renewable and low-carbon fuels for the remaining applications. But while this is undoubtedly necessary (and most of the technical solutions for it already exist), decarbonisation will entail much more far-reaching integration between sectors (i.e. sector coupling), decentralisation of energy assets (upending the traditional linear value chain from supply to transmission, storage and finally consumption), greater involvement of consumers, higher utilisation of assets for flexibility and adequacy services as well as energy trade across all market timeframes, and a more innovative and responsive regulatory framework. All these trends are reflected in the six pillars of the EU Energy System Integration Strategy, which thus goes beyond the hierarchy for decarbonisation of the energy sector.

Figure 1-4 illustrates the complexity of an integrated energy system and highlights the main recommendations for each of the topics analysed in this report. It shows the main elements of the supply, energy transport, conversion, storage and consumption value chain along with important technologies for specific elements (such as battery and fuel cell electric vehicles for transport or co-located/behind-the-meter storage for renewable energy plants, industry and the built environment). Selected recommendations are also indicated for each of the main chapters of the study. The recommendations are selected based on their relevance to illustrate the complexities of energy system integration but are not necessarily the most important of each chapter, as many others are listed, as shown in Figure 1-4.

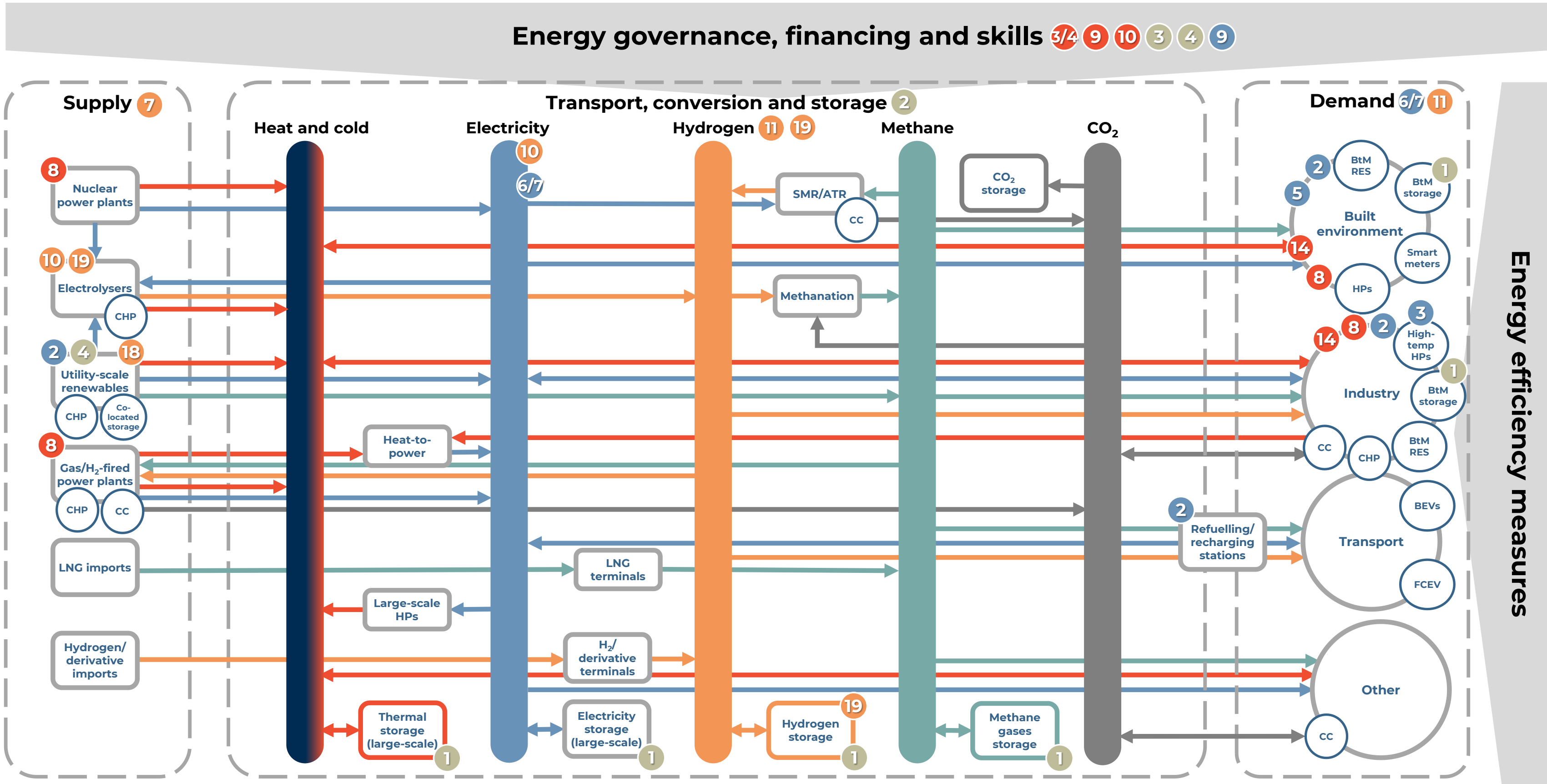
Figure 1-4 does not capture all the possible elements of an energy system, nor their interlinkages, as this would be intractable. For example, liquid (fossil) fuels are a major energy carrier in our current energy system but are not included – nor is coal. Electricity, methane gases and hydrogen networks could also be separated between transmission (including cross-border interconnection points and domestic lines) and distribution levels.

Nonetheless, the figure already conveys the complexity of our future energy system, where networks, large-scale and decentralised renewables and storage, conversion and other technologies interact.

System integration will require a transformation not only of our energy system, but also of the IT, market and governance frameworks. Figure 1-4 only shows the physical layer of the energy system. However, any energy system entails also communication and control (also named ICT), market (i.e. economic) and governance (i.e. policy) layers. As much as investing in and operating efficiently the right assets, energy system integration will also entail a transformation of the 'higher' layers.

Addressing the many barriers identified in this study is to a significant extent a matter of implementation, although many others will require additional measures. As almost all actions identified in the EU Energy System Integration Strategy have been completed and several other initiatives have taken place since, regulatory, market-based and cooperation-focused measures have been adopted. However, several still require further implementation at the EU and Member State-level, and the impacts on solving the various system integration barriers will still be seen. For these actions, focus should be on implementation and, once impacts can be evaluated, assessment and improvement.

Figure 1-4 Overview of the integrated energy system and selected recommendations



Selected Recommendations

Electrification and decentralised RES	Hydrogen uptake	Waste heat utilisation	Cross-cutting aspects
2 Grid connection principles review	7 Fossil fuel subsidy phase-out	3/4 Waste heat accounting/modelling	1 Promoting energy storage
3 High-temperature HP R&D	10 Electrolysis revenue and network tariffs	8 Heat emissions regulation/tax	2 Integrated infrastructure planning
5 Equipment and installation financing	11 Further H_2 quotas/targets	9 Waste heat utilisation principles	3 Digitalisation and innovation
6/7 Dynamic pricing and ToU tariffs	18 Expanding on PPAs	10 Support national/local authorities	4 Monitoring and reporting
9 Strategy on electrification	19 Accelerating permitting	14 Supply mix disclosure obligations	

2. Electrification of end-uses and decentralised renewable energy integration

2.1. Introduction

Direct electrification refers to using electricity as a direct replacement for fossil fuels in end-use applications such as electric cars and heating (notably using heat pumps). Indirect electrification, on the other hand, refers to using electricity as an input in industrial processes and converting it to an alternative energy carrier or feedstock, such as converting (renewable) electricity into hydrogen (more on this in chapter 3). Direct electrification is considered more efficient than indirect electrification due to fewer energy conversion processes, and their associated efficiency losses, but it is not applicable to all sectors, at least not with existing technologies. However, indirect electrification is more suitable for long-term storage and allows to manage renewable energy's intermittency. For some applications, renewable energy-based alternatives other than electrification can be used to substitute fossil fuels, e.g. solar heating. This section focuses on direct electrification, while indirect electrification is covered partially in the chapter on uptake of hydrogen (see chapter 3).

Transportation and industry are the focus of this section, while commercial and residential sectors are studied together under the heading of “buildings”. The buildings sector includes offices, malls, stores, schools, hospitals, hotels, warehouses, restaurants, houses and apartments, as well as industrial buildings. Potential uses of electricity in the transportation sector mainly refer to electric vehicles (EVs), but also rail transport (trains) and ships (electric ferries). Electric ships and aircraft may also emerge in the future. The industrial sector can electrify use processes that employ fossil fuels today, such as in low- and medium-temperature heat applications. Here key technologies are heat pumps for low-enthalpy heat, micro-waves, plasma technologies and others in direct heat applications, and, in the future, high-temperature heat pumps for steam production via mechanical vapor compression. In the industrial sector, this report did not look into the role of PPAs, which could have been a useful mechanism to overcome identified barriers.

For the buildings sector, the electrification process concerns the electrification of space heating and hot water (mainly through heat pumps), local production of RES, local storage, recharging of electric vehicles, smart appliances, monitoring and control systems and smart metering. The Smart Readiness Indicator is a tool that rates the smart readiness of buildings (or building units) in their capability to perform the following three key functionalities: optimise energy efficiency and overall in-use performance adapt their operation to the needs of the occupant, adapt to signals from the grid (for example energy flexibility). Heat production in district heating systems can also be converted from using fossil-fuels to electricity, through the deployment of large-scale heat pumps.

Decentralised renewable energy is usually referred to as generation on or close to the site where energy is used while centralised generation is delivered through the transmission or distribution grid to energy users. After self-consumption and eventual local storage, the surplus of decentralised generation installations is injected into the grid. The main purpose is production for self-use, including storage, by individual consumers or grouped users located in the proximity of generation. Often, small-scale smart grids are useful in the case of user groups. Decentralised power generation is efficient by reducing grid losses. Furthermore, it has the potential to increase the flexibility of grid operation, when combined with storage and demand response options, such as load shifting and shedding. The maximum volume of renewable power capacity that can be handled by a given grid infrastructure can be increased by developing decentralised renewable electricity generation.

Active participation of a prosumer in electricity markets is easier and more effective when consumers can purchase from the grid, consume self-production, eventually store electricity locally and sell their surplus electricity via the grid. Peak shaving may be possible through time shifting with charging and discharging batteries. Such active participation of a prosumer is favourable for the electricity grid, as combining load shifting, load shedding and local storage can increase flexibility. Besides easier connectivity to the grid, decentralised generation has potentially smaller environmental impacts, compared to large-scale RES installations (which require environmental permits), and can be licensed easier than centralised renewables generation. Finally, a major advantage of decentralised generation is societal, as the users (households and enterprises) directly and via aggregators get the eventual net profits from demand response while saving on electricity (and heat) bills. Provided that capital financing is available or is supported via state support to reduce loan costs, such an investment by final users pays off by improving energy affordability, which is of great importance for society.

Electrification combined with decentralised renewable generation and various local storage systems is a system integration approach that can bring higher benefits to the users, the grid, and overall decarbonisation efforts. Consumers having to accommodate large electricity bills due to high consumption volumes have great incentive to invest and act as prosumers seeking net profits from active market participation and electricity cost savings due to the lower cost of local renewable energy generation. Similarly, by joined efforts in energy-sharing or collective self-consumption schemes, it is possible to invest in larger-sized decentralised self-generation assets using renewables, as compared to investments by a single consumer. At the same time, the grid system requires expansion as the grid has to accommodate larger volumes of electricity. An additional reason is that the increased volume of electricity demand features high variability with in particular daily peak and off-peak demand cycles for mobility and seasonal patterns due to electricity use for heating.

Decentralised electricity generation from renewables in combination with storage and demand response, decreases the quantities exchanged with the grid, thus partly offsetting the need for reserve and balancing services of the grid and increasing the flexibility services that demand response and decentralised generation can offer to the grid. In other words, there is a clear synergy between electrification and decentralised renewables generation; when both increases, their synergy can mitigate grid congestion, reduce the need for scarce -centrally procured- power reserves, and increase the efficiency of new investment in the grids, reducing eventually the per unit investment needs. Additional benefits arise when decentralised renewable generation combines with electricity storage installed at the prosumer's premises. Moreover, additional benefits can arise by combining decentralised assets with heat storage and by applying bi-directional use of EV batteries in the future, or other advanced technologies (e.g. grid forming inverters). In such cases, electricity injected into the grid and taken from the grid can adjust to specific load profiles as needed by the grid to reduce variability, reserves, and costs. In this manner, decentralised renewables with storage and demand response can become a source of high-value flexibility services for the grid and the energy system in general. Markets can be designed that remunerate such high-value services, and in this way the infrastructure's high investment costs for grids with decentralised assets can eventually be paid off.

Electrification and decentralised renewable energy operating as an integrated system are among the major enablers to cost-efficiently decarbonise the energy system. However, considerable barriers currently exist, impeding the rapid development of decentralised assets together with electrification. This is the subject of the section below.

The remainder of this chapter is structured as follows:

- Section 2.2 analyses the barriers;
- Section 2.3 provides recommendations (focused on the EU-level).

2.2. Barriers to electrification and decentralised RES integration

For the purpose of structuring this chapter, the barriers are grouped into four overarching categories, depending on their nature:

- Technical barriers;
- Economic and financial barriers;
- Legislative and regulatory barriers;
- Societal barriers.

The barriers are also categorised with respect to the three sectors:

- Buildings;
- Industry;
- Transport.

We also note here that not all barrier categories apply to all of these sectors.

Although the barriers are grouped for reporting purposes, it is clear that barriers and challenges have technical, economic, and legal aspects that need to be jointly understood and evaluated. For example, network upgrades, from a technical point of view, require in general long project lead time periods, and the immediate improvements may be limited. Network upgrades also have an economic aspect, as massive grid investments are required, increasing network tariffs and affecting the financial capacity of the DSOs. Similarly, and regarding the recovery of the investments, there is a need for an assessment and potential redesign of the regulatory framework regarding the network tariffs' structures approved by the Regulators and how the Development Plans of the Networks are compiled. This electrification process entails higher charges for consumers, on top of their expenditures for new equipment. Similarly, in the buildings sector, the upgrade of the electrical installation (panels, wiring) might be technically challenging and quite expensive. Therefore, it is the combination of the two barriers, technical complexity and financial burden, which makes building owners reluctant to electrify their heating installation.[10]

Most key barriers apply to multiple sectors and only few apply to specific sectors and are thus reported separately. Based on stakeholders' feedback and the conducted literature review, the remaining overarching barriers and their root causes are outlined and briefly described in the following subsections: for all sectors (subsection 2.3.1), for the buildings sector (subsection 2.3.2), for the industrial sector (subsection 2.3.3) and for the transport sector (subsection 2.3.4).

2.2.1. All sectors

The barriers discussed in this section are applicable to all sectors and are summarised in the following table. The survey confirmed that most of the suggested barriers are either important or fundamental. Across the three sectors the economic and financial barriers were considered the most important.

[10] https://www.enelgreenpower.com/learning-hub/energy-transition/renewables-electrification/electrified-end-use-consumption

Table 2-1 Summary of barriers in all sectors

Barrier type	Barrier
Technical	1. Insufficient distribution network expansion and reinforcement
	2. Delays in the rollout of smart metering equipment
	3. Insufficient digitalisation at distribution level
	4. Delays in grid connection and permitting
Economic and financial	5. Upfront costs for equipment and installation
	6. Operational costs for equipment
Legislative and regulatory	7. Adjusting regulation at national level
Societal	8. Lack of professional experience and skills
	9. Lack of consumer awareness and/or knowledge

2.2.1.1. Technical barriers

Insufficient electricity network expansion and reinforcement

Issues related to network development and delayed investments are among the most cited and important challenges with respect to the integration of decentralised RES and the electrification of end uses in all three sectors.[11,12] Depending on the speed of electrification and decentralised RES integration, the power grid infrastructure should be ready to accommodate a significant increase in peak demand and supply.[13]

In many Member States, distribution systems, and often transmission systems, are not able to: [14,15]

a. Accommodate increased energy flows, in multiple directions, and balance effectively supply and demand which is becoming an increasingly complex task. It seems that existing modes of operation for the networks (especially the distribution systems) are still functional but not adequate to efficiently cope with the new challenges.
b. Serve the increasing number of requests for new connections, either of RES production, storage facilities and recharging points, or for the upgrade of existing connections to accommodate increased electricity consumption (e.g., electrifying heating).

The root causes for delays in increasing the capacity of the networks are: [16,17]

- **The pace of implementation of investment projects and the rate of uptake of new technologies, including smart equipment and digitalised control centres, is much lower than the rate of growth in electrification**. From a technical perspective, projects network upgrades, which include reinforcements and extensions, are relatively complex projects requiring both significant lead time for permitting, and design, as they should be combined with new technologies, as well as time for construction.

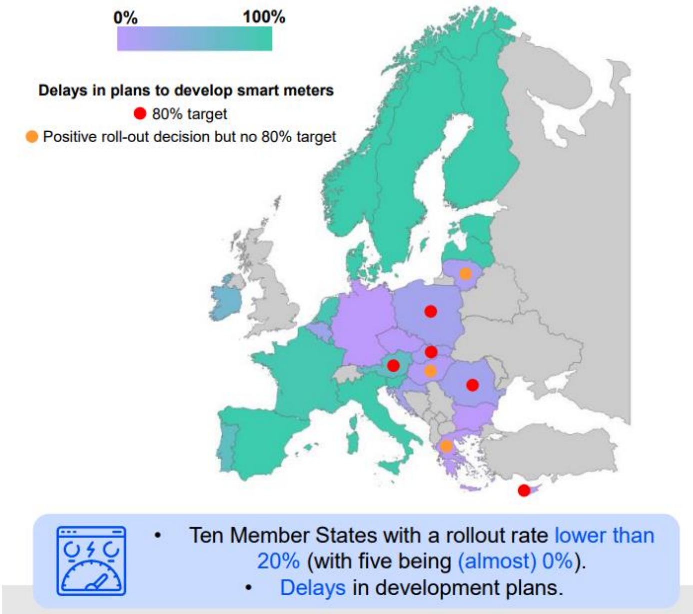
[11] IEA (2021) Distributed energy resources for net zero: An asset or a hassle to the electricity grid?
[12] IRENA (2023) Innovation Landscape for Smart Electrification
[13] Eurelectric (2021) Connecting the dots: Distribution grid investment to power the energy transition
[14] https://auroraer.com/media/grid-management-challenges-costing-spanish-energy-consumers/
[15] https://www.bmwk.de/Redaktion/EN/Dossier/grids-grid-expansion.html
[16] IEA (2023) Electricity Grids and Secure Energy Transitions
[17] Eurelectric (2023) Power System of the Future: Keys to delivering capacity on the distribution grid

- **The cost of new projects leads to increased network charges paid by consumers, putting political pressure on regulators, as people expect these projects to decrease prices**. In some cases, securing the financing may delay the projects, as DSOs face increasing financial challenges to fund investment projects in equipment (cables, transformers), digitalisation projects and smart equipment, IT projects and structural maintenance.

Delays in the rollout of smart electricity metering equipment

A more specific issue related to the system development and modernisation is the rollout of smart meters.[18] More than 50% of respondents to the survey consider that accelerating and completing the roll out of smart meters across Europe is an important or fundamental issue regarding the integration of decentralised RES and the electrification of end uses. Some Member States have already reached high penetration rates exceeding 80% for electricity[19] (Denmark, Estonia, Finland, France, Italy, Latvia, Luxembourg, Malta, the Netherlands, Slovenia, Spain, Sweden) or are in the range of 70% like Austria and Portugal (as shown in Figure 2-1); however, stakeholders cite that progress for several of the remaining Member States remains slow.[20]

Figure 2-1 Smart meters roll-out - 2022



Source: ACER 2023 Market Monitoring Report
Demand response and other distributed energy resources

Scaling up the deployment of smart meters and smart control equipment, which enable the real-time transmission of information and the monitoring/ control of energy flows, is a key prerequisite for active market participation by consumers and the development of demand-

[18] Vitiello et al. (2022) Smart Metering Roll-Out in Europe: Where Do We Stand? Cost Benefit Analyses in the Clean Energy Package and Research Trends in the Green Deal. https://doi.org/10.3390/en15072340
[19] ACER/CEER (2023) Energy Retail and Consumer Protection - 2023 Market Monitoring Report
[20] EU (2019) Benchmarking smart metering deployment in the EU-28

side flexibility.[21] It is also crucial for the efficient integration of DER, as it will significantly enhance the grid management and network development planning capabilities of operators.[22]

Stakeholders also cite that all functionalities and use cases for smart meters should be enabled across the EU by harmonising minimum/ default requirements imposed by Member States (e.g. provision of readings directly to consumer and/or any 3rd party, upgrading of readings at sufficient frequency to use energy saving schemes). It is noted that the European legislation already includes provisions to this respect applicable to new rollouts.[23]

Key issues related to the further rollout of smart meters include; the required high volume of work for the concerned DSOs, that need to ensure efficiency in such large-scale deployment projects, the need to develop adequate tools, mechanisms and platforms, to facilitate the optimal use of the data to be provided by the meters and to facilitate product exchanges, including energy, storage, flexibility etc., and transactions.

Insufficient digitalisation at distribution level

A key challenge to the electrification of end uses in all three sectors and the integration of DER is the digitalisation of the distribution grid.[24] This is a key prerequisite to interoperability and (near) real-time access of all concerned market parties to energy-related data in a non-discriminatory manner, including metering and consumption data, as well as data required for demand response and supplier switching.[25] This in turn is of critical importance in order to ensure a level playing field between market operators competing for the provision of various services to end-users or prosumers (e.g. suppliers, aggregators) in the context of the energy transition, that will enable consumers/prosumers to play a bigger and more active role in the electricity market (including by reducing peak time demand), benefit from variable or dynamic electricity market prices and flexible network tariffs, and reduce their bills.[26]

Delays in grid connection and permitting

Network connection and permitting delays pose another important challenge, especially with regard to the integration of renewable energy units and storage facilities both at the demand and the supply sides. According to stakeholders, it should be ensured that grid connection procedures, are transparent, and streamlined.[27]

2.2.1.2. Economic and financial barriers

Upfront costs for equipment and installation

The high upfront cost for purchasing and installing equipment for electrical heating/ cooling as well as renewable energy generation units and storage facilities is cited as one of the most significant barriers to electrification and the integration of decentralised RES.[28,29]

[21] https://www.enlit.world/digitalisation/think-smart-act-smart-win-smart/
[22] EC (2023) Smart grids and meters
[23] See Article 20 of Electricity Directive (EU) 2019/944 on the functionalities for smart metering systems and relevant implementing Regulation (EU) 2023/1162 on access to metering and consumption data that also accounts for smart metering data
[24] Eurelectric (2023) Action Plan on Grids
[25] COM(2022) 552 Final. Digitalising the energy system - EU action plan
[26] Digital Europe (2023) Roadmap for Europe's energy ecosystem digital transformation
[27] SolarPower Europe (2023) Grid planning and grid connection: recommendations for a future-proof implementation of the Clean Energy Package
[28] JRC (2021) EU challenges of reducing fossil fuel use in buildings
[29] IEA (2022) The Future of Heat Pumps

Stakeholders consider that the upfront cost of purchasing and installing heat pumps and decentralised RES systems is still generally perceived as high, mainly because of high initial capital investment costs and long payback period.

Similar considerations are mentioned regarding the higher price of electric vehicles, compared to conventional cars, reflecting the high cost of batteries and the fact that the electric car industry competes with well-established and mature conventional technologies.

The potential stranding of fossil-fuel-related assets and especially regulated assets such as natural gas transport and distribution networks that have not yet been fully depreciated presents an additional issue as the residual cost of existing infrastructure which will be scrapped and not reused or repurposed, is from a societal perspective increasing the cost of electrification.[30]

Operational cost of electrical equipment

Another important challenge is the operational cost of electrical equipment, especially the price ratio between electricity and fossil fuels.[31] Stakeholders point out that despite the high energy efficiency of electrical equipment, legacy charging structures for energy and non-energy costs, as additional costs, as levies, surcharges and taxes, added to the unit cost of electricity, act as a barrier to electrification.

Specifically, electricity tariffs in several Member States tend to include various charges (taxes, levies, etc.) which are not related to the cost of energy supply.[32] Thus, price signals are distorted, and consumers are burdened with overhead costs which limit the competitiveness of heat pumps and other electrical equipment, hindering their uptake. Stakeholders report that overall energy taxation currently favours gas and oil heating due to high taxes/ levies on electricity and the low taxation of fossil fuels and especially of natural gas used for small installations which are not included in the ETS.

Regarding DER, additional transactional and/ or operational costs may arise due to the need for prosumers to rely on professional support such as legal or consulting services for contracting with aggregators and other parties.

2.2.1.3. Legislative and regulatory barriers

Adjusting and implementing regulation at national level

Delays in the transposition of the EU's electricity market design and the implementation of appropriate secondary legislation in Member States poses a challenge to the electrification of end-uses in all three sectors and to the integration of DER.[33,34] Although a range of implementation options are available, these have not yet been thoroughly evaluated at the national level in some Member States, while in others, different approaches have been

[30] FSR (2021) Stranded gas assets: the dilemma of the energy transition costs
[31] IRENA (2023) Renewable solutions in end-uses: Heat pump costs and markets
[32] EHPA (2023) EU Heat Pump Accelerator: A joint plan for boosting heat pump deployment and meeting the REPowerEU targets
[33] A joint report by ENTSO-E and the European Associations representing DSOs (CEDEC,E.DSO, Eurelectric, GEODE), June 2021, Roadmap on the Evolution of the Regulatory Framework for Distributed Flexibility
[34] SmartEn (2022) The implementation of the Electricity Market Design to drive demand-side flexibility

applied. This is an important aspect discussed extensively in the literature and highlighted by stakeholders. Key elements are outlined below.

- **Design of <u>electricity supply pricing and network tariffs</u> in MS is not yet adequately aligned with the energy system integration objectives.**[35,36] Respondents to the survey consider that the development of dynamic electricity price signals in the retail segment will be instrumental in mobilising the significant potential of demand-side flexibility. Large-scale electrification of various sectors and applications, including heating/ cooling and EVs, entails significant investments in equipment and installations by the end user. At the same time, investments for network expansion and reinforcement as well as in generation capacity are required to accommodate the increasing load, particularly at peaks. A key challenge is to optimise the network and system usage level. This is done by providing adequate electricity pricing signals, which should be achieved through well-functioning markets, through market-based variables, or even dynamic supply prices. These provide incentives to consumers/prosumers to adjust their use of heating and cooling appliances, thus adding flexibility to the system and reducing the overall energy system costs.[37] The design and structure of distribution network tariffs poses a challenge for the economic feasibility of electrification applications, the integration of DER, and other equipment including storage and other equipment increasing consumption. A balance needs to be struck between grid reinforcement/expansion and the associated increase in network charges that may pose a disincentive to the uptake of end-use electrification. Consumers may hesitate to accept higher network charges if those charges are based on their supply capacity, as it would require them to increase their capacity to accommodate higher energy flows. This reluctance stems from the fact that consumers have already made significant investments in electrification applications and equipment, and they certainly do not want to be charged twice for actively participating in the operation of the network, e.g. charges for inflows and outflows. Stakeholders point out that distribution network tariffs should take into account the benefits provided by DER, storage and EVs, to the network through decreasing the local (peak) load and providing various balancing services (see "congestion management" below).
- **Stakeholders consider that there is a need for a clear definition and an estimation of the different types of flexibility products and services (frequency, volume, duration) required at each level (local, national and regional).**[38] At a more advanced (i.e. mature) stage, which will be associated with a significant increase in the number of grid connected electricity installations (DER, storage, charging stations) and market players as well as enhanced market-oriented conditions and dynamics, it is expected that an even more pressing need will arise to streamline and harmonise/ standardise different products (e.g. energy, capacity, ancillary services) and procedures through a combination of appropriate regulatory designs and possible state interventions/ schemes[39], e.g. minimum guaranteed offtake, prioritisation etc.

[35] Eurelectric (2021), Powering the Energy Transition Through Efficient Network Tariffs
[36] smartEn (2019) The smartEn Map: Network Tariffs and Taxes
[37] CEER (2020) Recommendations on Dynamic Price Implementation
[38] RAP (2022) The joy of flex: Embracing household demand-side flexibility as a power system resource for Europe
[39] Eurelectric, Power System of the Future, Keys to delivering capacity on the distribution grid, 2023

- **The transposition of EU legislation concerning Energy Communities is yet to be fully implemented in several Members States**.[40] Energy Communities are a key element of the clean energy transition, supporting private investments in renewable energy and storage facilities as well as ensuring citizen participation in suitable energy markets, on a level-playing field with the other market actors. Energy Communities can thus provide direct benefits to citizens through lower electricity bills and local job opportunities, also contributing to the public acceptance of energy transition projects and to increased consumer awareness.[41]

2.2.1.4. Societal barriers

Professional expertise and skills

A key element highlighted in the literature and by stakeholders is the scarcity of skilled professionals with appropriate expertise in the fields of heating electrification, DER and storage installation. Regarding heat pumps in particular, respondents to the survey consider that, to meet REPowerEU's roll-out targets, sufficient numbers of skilled workers are needed for every part of the heat pump value chain, from manufacturing to installation and maintenance. EU's Joint Research Centre (JRC) reports that the heat pumps industry in the EU today employs nearly 320,000 people,[42] while at least 500,000 skilled workers are needed to meet REPowerEU's heat pump roll-out targets by 2030 according to estimates by the European Heat Pump Association (EHPA).[43]

Electrification brings major value creation opportunities for industrial companies across the value chain but also requires timely actions and investments.[44]

Finally, the transition to electrified industrial processes may be challenging due to the need to adjust company organisation and roles. Stakeholders report that converting fuel-based to electrical equipment can trigger a variety of other changes in integrated industrial processes. This would entail the need for employees to acquire new skills and adapt to new processes and conditions.

Consumer awareness and/or knowledge

Many consumers may lack awareness and appropriate information both about the technologies and the associated benefits of electrification, as well as the efficient use of energy resources, and the decentralised renewable energy options.

Specifically:

- **The technical complexity of installing and operating DER systems, within an active market access approach, presents a behavioural barrier to their uptake**. Despite the wide deployment of residential PVs, storage and participation of households in energy communities in several Member States, sometimes under support schemes, like net metering, which do not reflect accurately the value for DERs, customer engagement can be further improved by enhancing consumers' awareness and skills.[45] Respondents to the survey cite that it is complex for residential end-users to interact

[40] smartEn (2022) Energy communities to increase local system efficiency
[41] EC (2023) Energy communities
[42] JRC (2023) The Heat Pump Wave: Opportunities and Challenges
[43] EHPA (2023) Wanted: half a million heat pump workers
[44] ETC (2021) Making Clean Electrification Possible
[45] https://onenet-project.eu/wp-content/uploads/2023/07/OneNet-Deliverable-D11.5_v1.0.pdf

with the electricity system. Active participation of household consumers in the energy market requires both informed consumers willing to invest in equipment (i.e. renewable energy units and storage facilities), as well as the development of associated technical skills and capabilities for their efficient utilisation and operation, either independently or through market parties (e.g. aggregators). Lack of awareness and insufficient information can also pose barriers with respect to consumers' participation in collaborative schemes which comprise the exchange/ pooling of products, capacity and data.

- **Residential and tertiary sector consumers can benefit from improved access to appropriate guidance and advice on the installation of relevant equipment (e.g. specification of heat pump type and size, technical feasibility of retrofits, potential need for energy efficiency upgrades).** Stakeholders cite that access to information and/or guidance is a real issue when it comes to mainstreaming these technologies in buildings and represents a major cause for the delay in their installation. In their view, consumers need to be able to make an informed choice and easily acquire information about whether their building is ready for a heat pump, up-front and operational costs, financing and installation options, and have access to users' experiences.[46]
- **Lack of sufficient information by consumers' may entail concerns about the impact of electrification on their overall energy bill, or misconceptions about the technical performance of equipment such as heat pumps.** In cases where existing heating equipment has not yet reached the end of its useful life, consumers may consider that the replacement of existing heating systems is not yet warranted, downplaying the positive effect of energy savings. Respondents to the survey cite risk aversion as a key reason for the low acceptance of electrification by consumers. Consumers may also be subject to a "not in my backyard" syndrome from their neighbours. Some respondents to the survey cite noise pollution concerns with respect to heat pumps.[47] Additionally, consumers may hold a false perception that electrical heating and electrical equipment (notably heat pumps) are more "challenging" and less effective in terms of usage, primarily due to a bias stemming from lack of appropriate information and their familiarity with the existing equipment that can be difficult to overcome.[48]

2.2.2. Buildings Sector

The barriers discussed in this section concern the electrification of end-uses in buildings and the integration of decentralised renewable energy. Electrification of end-uses is examined with respect to heating/ cooling.

Almost all respondents to the survey underlined that reducing fossil fuel use in buildings is the clear priority target for the buildings sector, through the combination of two approaches.

[46] BEUC (2023) From Boilers to Heat Pumps: What consumers need in the switch to renewable heating
[47] EHPA (2020) Heat Pumps & Sound
[48] ACEEE (2022) Ready to Upgrade: Barriers and Strategies for Residential Electrification

- **Firstly, by improving the energy performance of buildings**, which is achieved through (a) energy efficiency measures to improve insulation and (b) increased use of high-efficiency household appliances and heating equipment.
- **Secondly, by replacing fossil-fuel heating systems with low-carbon energy sources**.

A potential option to further increase the efficient use of electricity is by using DC electricity in buildings and microgrids. The expansion of digital technology allows DC electricity to match perfectly with embedded generation and storage equipment, EV charging and numerous other applications. The energy savings that are possible by eliminating the need of power converters is significant, but probably not enough to provide clear economic signals and trigger replacement. In the existing stock of buildings, which are not yet renovated and digitalised, and DER and storage equipment is not yet widely installed, the benefits from installing only DC networks probably are not enough to outweigh technical and cost challenges.

The challenges to deploying DC systems in buildings are consumers and industry professionals' unfamiliarity with the DC technologies and small markets for DC devices and components. On the other hand, the switch from AC to DC, is the way forward for smart buildings and DER systems to function efficiently. A major challenge would be to efficiently coordinate the introduction of all new equipment (embedded energy generation, storage and charging), with the renovation works in the building (panels, wiring, etc.).

Table 2-2 Summary of barriers in buildings

Barrier type	Barrier
Technical	1. Specific building stock constraints
Economic and financial	2. Split incentives between owners and tenants of buildings
Legislative and regulatory	3. Planning and permitting framework

2.2.2.1. Technical barriers

Building stock constraints

Specific building stock characteristics may hinder the retrofitting of heating electrification and decentralised RES equipment and/or increase installation costs.[49,50] For example, in multi-apartment and high-rise buildings, it may not be possible to ensure the availability of appropriate space for installing equipment such as storage facilities or outdoor units of heat pumps. Older buildings may also require the upgrade of electrical panels and internal wiring to support new equipment such as heat pumps, solar panels or storage facilities.[51]

Additionally, in buildings with existing oil or gas boilers, the flow temperature of the hydronic distribution systems is relatively high, often exceeding the flow temperature at which heat pumps operate efficiently. In order to attain optimally efficient operation of heat pumps, improvements are thus required in the thermal envelope of buildings and/ or in the surface area of the heat distribution system (e.g. underfloor heating or larger radiators) and/ or

[49] EC (2023) Integrating Heat Pumps in Existing Residential Buildings
[50] EHI (2021) Rolling out heat pumps: Barriers and how to overcome them
[51] ACEEE (2022) Ready to Upgrade: Barriers and Strategies for Residential Electrification

hydronic balancing of the heating system.[52] JRC estimates that some kind of energy efficiency improvement or adjustment to the heating distribution system are required for 60% of EU dwellings, to ensure high-efficiency operation of the heat pumps.[53]

On the other hand, the JRC notes that deep renovations may not be necessary; a partial renovation and/or adjustments to the distributional heating system of these buildings will also enhance their efficiency.[54] Additionally, some studies estimate that because heating systems in existing buildings are oversized, the share and depth of the required retrofits could be limited.[55,56] For example, a study on Danish houses estimates that approximately 80% of the heating systems are over-dimensioned relative to their current heat load and concludes that houses with currently over-dimensioned heating systems can be heated with supply temperatures below 60 °C for most of the year.[57] In this regard, the evidence regarding the distribution and depth of the changes required to existing buildings is not conclusive.

2.2.2.2. Economic and financial barriers

Split incentives between owners and tenants of buildings

Split incentives between the owners and the tenants of a building, referring to the fact that the electrification investment is borne by the owner but the benefits accrue to the tenant in the form of reduced utility costs, poses an important challenge.[58] The electrification investment can be recouped by the building owner through an increase in rent costs, however, it may be challenging for the owner and the tenant to reach an agreement regarding the "fair" increase in rent. Additionally, higher rent costs due to investments undertaken for electrification can put off potential tenants that may fail to acknowledge the associated energy cost savings, thus preferring less energy efficient buildings. As mentioned in Section 2.4.1, the revised EED requires Member States to remove regulatory and non-regulatory barriers in order to improve split incentives between owners and tenants.

2.2.2.3. Legislative and regulatory barriers

Planning and permitting framework

The planning and permitting framework for buildings in several Member States poses a challenge to the installation of heat pumps and the integration of DER by adding a layer of unnecessary complexity. However, the revised REDII now provides specific measures to accelerate permit granting process of renewables projects, including heat pumps, under specific conditions (see hereafter). This directive will have to be transposed by Member States by 21 May 2025. Respondents to the survey highlight that building regulations need to recognise the value of flexibility that storage can provide.

2.2.3. Industry

The barriers examined in this section concern specifically the electrification of industrial sector processes and are summarised in the following table.

Table 2-3 Summary of barriers in the industrial sector

[52] IRENA (2023) Renewable solutions in end-uses: Heat pump costs and markets
[53] JRC (2023) The Heat Pump Wave: Opportunities and Challenges
[54] Ibid.
[55] https://www.lsta.lt/files/events/ljunggren.pdf
[56] https://publications.deltares.nl/11205149a.pdf
[57] https://www.sciencedirect.com/science/article/pii/S037877881831702X
[58] JRC (2023) The Heat Pump Wave: Opportunities and Challenges

Barrier type	Barrier
Technical	1. Unavailable suitable electricity-based technologies for high-temperature heat processes
	2. Requirement for significant re-design of processes posing disincentive for investors
Economic and financial	3. Competitiveness and reliability of electricity against other resources (natural gas, oil)

2.2.3.1. Technical barriers

Unavailable suitable electricity-based technologies for high-temperature heat processes

A significant part of industrial activities (e.g. steel, cement, glass) require high-temperature heat processes reaching temperatures above 1000°C that cannot be served through electrical heat pumps which can currently operate efficiently at temperatures up to 150°C.[59] Other industrial activities (e.g. food, chemicals) require high-temperature heat pump technology that can deliver heat above 150°C which is not yet considered mature and has not been adequately commercialised to date.[60] The International Renewable Energy Agency (IRENA) reports that as of 2020, 89% of industrial heating processes still relied on fossil fuels.

Requirement for significant re-design of processes posing disincentive for investors

The electrification of industrial activities will be implemented mostly through customised solutions, posing a challenge to the development of standardised methods/ approaches, and thus to the attainment of potential economic/ financial efficiencies. Requirements to develop and design in some cases industry-specific systems and manufacturing lines would be a challenge especially for medium and smaller sized companies.[61]

Stakeholders report that many industrial processes, are not designed to use electricity and that suitable electrified alternatives would need significant redesign that will change significantly the way that energy intensive industry currently operates.

2.2.3.2. Economic and financial barriers

Competitiveness and reliability of energy sourcing

An important economic/ financial barrier arises from the strong competitiveness of conventional fuels (e.g. natural gas) both in terms of the respective price ratio (e.g. electricity/ gas ratio) as well as in terms of their (usually) optimal, mature and long-serving sourcing and reliable delivery. Industrial processes require that energy sourcing has very specific characteristics (e.g. **price predictability, specific diurnal profile**), which may be particularly challenging to meet through decentralised renewable energy generation solutions, as resource variability can limit their reliability, mainly from an economic perspective.

[59] IRENA (2023) Innovation Landscape for Smart Electrification
[60] Such higher temperatures can be reached by renewable sources of heating (geothermal, biomass and solar thermal) as well as district heating.
[61] Lawrence Berkeley National Laboratory (2018) Electrification of buildings and industry in the United States

Energy purchases from the grid, including the relevant shaping, profiling and balancing costs, increase uncertainty, affecting negatively the price predictability required.

Furthermore, industries rely on supply chain robustness to avoid production disruptions or failures. According to stakeholders, even a momentary interruption in electricity supply can result in costly production losses or even destruction of production assets, such as for float glass production. Until now, on-site fossil fuel storage has ensured operational availability and reliability, and operators are seeking guarantees for the same level of service from electricity.[62]

Stakeholders also cite that until 2021 (before the energy supply crisis), relatively cheap natural gas presented tough competition for industrial electrification. Additionally, it may be challenging to convert industrial equipment powered by direct fuel combustion (e.g. CHP systems) to electricity, since fuel combustion generates significant amounts of heat as a by-product, which is used to power various other processes without substantial additional cost.[63]

2.2.4. Transport

The electrification of road transport, powered by renewable and low-carbon electricity, is a cost-efficient approach for meeting the EU goals of decarbonisation and energy security in this sector. Electric vehicles can also provide storage and flexibility services to the grid, facilitating the further integration of renewable sources.[64] The uptake of electric vehicles (EVs) has a two-fold impact on the power sector.

Electrification of road transport increases total electricity demand and is likely to also increase peak demand, which require grid reinforcements. Firstly, the increase in local (peak) demand, both in dense residential areas with high EV use as well as in areas with fast charging stations, stresses the local distribution grid. Secondly, the increase in system (peak) demand and residential load centres puts pressure on the transmission grid. Overall, however, an efficient operation of (existing and future) generation, transmission and distribution assets is crucial for consumers to benefit from the cost savings of using renewable sources. Matching electricity production profiles to consumption remains however as a key challenge.

The advanced use of smart charging, namely optimising charging schedules of EVs when costs for the user are lowest and supply is not scarce and further promoting bi-directional technologies which use the EV batteries as a local flexibility source, can reduce potential grid constraints and make more efficient the investments into grid capacity. Simulations of the power system show that smart charging systems can offset the adverse effects on peak load and are thus increasingly considered an enabler to the mass uptake of EVs, contributing to decarbonisation and to a more efficient use of resources including power generation assets and grid infrastructure.[65]

However, both the uptake of EVs and the implementation of smart charging systems at a large-scale are subject to some barriers that are discussed in this section and are summarised in the following table.

Table 2-4 Summary of barriers in the transport sector

[62] IISD (2022) Industrial Electrification
[63] Lawrence Berkeley National Laboratory (2018) Electrification of buildings and industry in the United States
[64] EEA (2022) Decarbonising road transport — the role of vehicles, fuels and transport demand
[65] https://doi.org/10.1016/j.enpol.2021.112751

Barrier type	Barrier
Technical	1. Delays in the development of charging infrastructure network
Economic and Financial	2. Cost of EV vehicles
Legislative and regulatory	3. Incomplete framework for communication protocols and interoperability standards
Societal	4. Range & charger-availability anxiety

2.2.4.1. Technical barriers

Delays in the development of electric charging infrastructure network

One of the most important technical challenges regarding the uptake of EVs relates to the timely and efficient development of a network of public and private recharging stations, including bi-directional charging capabilities.[66,67] Respondents to the survey point out that the availability and accessibility of charging stations is currently limited, posing a significant barrier to the uptake of EVs.

According to the OECD's 2022 Environmental Policies and Individual Behaviour Change Survey, insufficient charging infrastructure is a barrier to greater electric car uptake. Overall, 33% of respondents report that there are no charging stations for electric cars within three kilometres of their home, ranging from 22% in the Netherlands to 43% in France.[68] Moreover, the growing number of electric vehicles already today poses a challenge for DSOs to connect the necessary recharging infrastructure. On the other hand, certain stakeholders such BDWE, an association of utility companies in Germany, point to an oversupply of charging options, reporting an average occupancy of 11.6% at the country's public recharging points in 2023.[69] At the same time, Europe's recharging infrastructure is growing at a fast pace while the public Alternative Fuels Infrastructure Regulation (AFIR) that came into force in October 2023 set mandatory targets for public recharging points on the main roads (see section 2.3.1 below). Specifically, in 2022, slow recharging points in Europe amounted to 460,000, a 50% increase from the previous year, while the overall stock of fast recharging points numbered over 70,000, an increase of around 55% compared to 2021.[70] However, other stakeholders such as VDA, Germany's car industry association, assert that a lack of adequate charging infrastructure remains one of the biggest hurdles for the rollout of EVs in the country.[71]

The literature points to the fact that EV recharging infrastructure shows certain public good characteristics common to public infrastructure, that merit the full attention of policy makers.[72]

However, the development of recharging infrastructure, like other decentralised infrastructure (small scale generation, storage) depends critically on grid connection capabilities and the relevant network reinforcement, which should be synchronised with the increase in EV stock. This requires appropriate planning-based or demand-driven roll-out programmes to support the implementation of anticipatory yet economically efficient investments, especially in recharging infrastructure with bi-directional capabilities, in order to facilitate the accelerated

[66] EC (2021) Sustainable & Smart Mobility Strategy
[67] IEA (2022) Policy brief on public charging infrastructure
[68] https://www.oecd.org/env/how-green-is-household-behaviour-2bbbb663-en.htm
[69] https://www.cleanenergywire.org/news/germany-passes-100000-public-electric-car-charging-points-eve-industry-show-iaa
[70] https://www.iea.org/reports/global-ev-outlook-2023/trends-in-charging-infrastructure
[71] https://www.boersen-zeitung.de/english/challenges-persist-in-the-charging-infrastructure-for-electric-cars
[72] https://doi.org/10.1016/j.rser.2021.111733

uptake of EVs and unlock their potential benefits.[73,74] Indicatively, the share of electric cars in total fleet sales in Europe reached 21% in 2022, up from 18% in 2021, 10% in 2020 and under 3% prior to 2019.[75]

2.2.4.2. Legislative and regulatory barriers

Inadequate framework for standardisation and market access

The development of a clear enabling regulatory framework for inter-operability standards and market access through bidirectional capabilities presents a critical challenge to the efficient development of charging infrastructure and the timely uptake of EVs.[76]

The development and enforcement of the communication standard, EN ISO 15118-20 standard in convergence with ongoing industry practice such as the Open Charge Point Protocol, is a critical aspect in order to ensure interoperability/ compatibility of software platforms and hardware devices as well as bidirectional communication between equipment and actors at multiple levels (e.g. grid operator, charger, vehicle, charging point operator, energy supplier, aggregator).[77] Manifold protocols developed by industry operators should converge and become international standards by standardisation development organisations (SDOs) in order to simplify the landscape and provide a more certain, stable and robust development where views by all relevant stakeholders are duly discussed.

Regarding bidirectional recharging capabilities in particular, stakeholders point to the differences in regulatory treatment across technologies, segments, markets and Member States.[78] Due to the early stage of standards and market access, the number of vehicles and chargers supporting this functionality remains limited.

Additionally, rapid European electricity legislation implementation at national level is needed to allow demand-side flexibility access to the electricity markets.[79] In this direction, the preparation of a new network code on demand response, in line with the existing Electricity Market Design and expected to be submitted end of 2024, is an important step to unlock the potential of electric vehicles.

2.2.4.3. Societal Barriers

Range & charger-availability anxiety is an important barrier to the uptake of EVs. Stakeholders report that potential users may still be put off by the perception that an EV is likely to run out of battery power before the intended destination is reached, thus leaving EV users stranded. Specifically, respondents to the survey consider that the range of electric vehicles, in terms of the distance they can cover on a single charge, remains a challenge compared to conventional fuel-powered vehicles. A similar perception, concerning uncertainty about the availability of recharging points, also poses an important barrier to the uptake of EVs by potential users.[80]

[73] ETC (2021) Making Clean Electrification Possible
[74] IEA (2022) Policy brief on public charging infrastructure
[75] IEA (2023) Global EV Outlook
[76] DG Energy (2021) Best practices and assessment of regulatory measures for cost-efficient integration of EVs into the electricity grid
[77] IEA (2022) Policy Brief on Public Charging Infrastructure
[7878] RAP (2023) Enabling two-way communication: Principles for bidirectional charging of electric vehicles
[79] Ibid.
[80] IRENA (2023) Innovation Landscape for Smart Electrification

2.3. Recommendations on electrification and decentralised RES integration

Addressing the barriers as reported on in section 2.3. requires a combination of technological innovation, policy support, and public engagement. A key factor is to ensure efficient coordination and synchronisation of the different agents' effort and plans towards electrification, avoiding conflicts between their goals and delays in the deployment and integration of the required equipment and tools for electrification. This section provides an overview of recent or planned policies and measures as well as recommendations to accelerate electrification and decentralised RES integration. Recommendations are generally addressed towards the European Commission, if other stakeholders are needed or addressed, they are explicitly mentioned.

Several new provisions to advance electrification and decentralised renewable energy integration in the EU have been introduced in revised REDII, EPBD, ETD, EED and AFIR.

These new provisions already address some of the recommendations from stakeholders put forward in the survey as well as in various studies and policy papers and are expected to partially or fully address some of the barriers identified.

2.3.1. Recent or planned policies and measures

This section provides an overview of the recent or planned policies and measures at the EU level addressing the topic of electrification and decentralised RES integration.

This allows to identify which barriers will in principle be addressed by these existing or planned policies and measures, and thus which barriers would remain. The main relevant EU policies and measures for electrification and decentralised RES integration:

- ✓ The 2021 proposal for a recast of the Energy Performance of Buildings Directive includes provisions aimed at addressing barriers to electrification and decentralised RES integration:
    - Member States are required to take measures (technical assistance, one-stop-shops, financing schemes, removing unanimity requirements in co-ownership structures) to overcome barriers regarding renovation and attain minimum energy performance standards (MEPS) in all buildings (art. 9). New buildings must be 'zero-emission buildings' as of 2030 and new public buildings must be zero-emission as of 2027.
    - Member States are required (art. 12) to: (a) equip buildings with minimum numbers of private recharging points and ducting infrastructure (new provisions and lower applicability thresholds compared to EPBD in its current form) and (b) take measures to overcome barriers to the installation of recharging points in residential buildings, in particular the need to obtain consent from the landlord or co-owners for a private recharging point for own use (c) ensure that the recharging points are capable of smart charging and, where appropriate, bidirectional charging, and that they are operated based on non-proprietary and non-discriminatory communication protocols and standards, in an interoperable manner.

- ✓ The 2023 proposal for a Regulation to reform the Union's Electricity Market Design (EMD) on which the Council and the Parliament have reached a provisional agreement:
  - Amending Regulation (EU) 2019/943:
    - Requires that every two years, the regulatory authority, or another authority or entity designated by a Member State, shall adopt a report on the estimated needs for flexibility for a period of at least the next 5 to 10 years at national level, in view of the need to cost effectively achieve security and reliability of supply and decarbonise the electricity system, taking into account the integration of variable renewable electricity sources and the different sectors (art. 19c).
    - Requires Member States to define an indicative national objective for non-fossil flexibility, including the respective specific contributions of both demand response and energy storage to that objective. (art. 19d).
    - Member States may apply non-fossil flexibility support schemes consisting of payments for the available capacity of non-fossil flexibility (art. 19e).
    - Specifies design principles for non-fossil flexibility support schemes such as demand response and storage (art. 19f).
    - Requires DSOs and TSOs to cooperate with each other in publishing information on the capacity available for new connections in their respective areas of operation in a consistent manner and giving sufficient granular visibility to developers of new energy projects and other potential network users (art. 57).
  - Amending Directive (EU) 2019/944:
    - Specifies that all households, small and medium sized enterprises and public bodies and, where Member States have decided so, other categories of final customers, shall have the right to participate in energy sharing as active customers (art. 15a).
    - Requires DSOs to provide system users with the information they need for efficient access to, including use of, the system. In particular, the DSO shall publish in a clear and transparent manner information on the capacity available for new connections in its area of operation, including in congested areas if flexible energy storage connections can be accommodated, and update that information regularly, at least quarterly (art. 31, par. 3).
- ✓ The 2023 revision of the Energy Efficiency Directive 2023/1791 requires Member States to take the necessary measures to remove regulatory and non-regulatory barriers to energy efficiency as regards split incentives between owners and tenants, or among owners of a building or building unit (art. 22).
- ✓ The Council Regulation 2022/2577 (Emergency Regulation) laying down a framework to accelerate the deployment of renewable energy, sets temporary

requirements for a period of 18 months, regarding the permitting process for solar energy and storage equipment as well as heat pumps:

  - The maximum deadline for the permit-granting process for the installation of solar energy equipment and its related co-located storage and grid connections is set at 3 months (provided that the installations' primary aim is not energy production).
  - Regarding the installation of heat pumps below 50 MW, the permit-granting process shall not exceed 1 month, while in the case of ground source heat pumps it shall not exceed 3 months.

- ✓ The Directive [(EU) 2023/2413] that entered into force on 20 November 2023 (to be transposed by Member States by 21 May 2025), amending the REDII:
  - Sets requirements, similar to those of [Council Regulation 2022/2577] (Emergency Regulation), regarding the permitting process for solar energy and storage equipment as well as heat pumps:
    - The maximum deadline for the permit-granting process for the installation of solar energy equipment and co-located storage is set at 3 months (provided that the installations' primary aim is not energy production).
    - The maximum deadline for the permit-granting process for the installation of solar energy equipment with a capacity of 100 kW or less, and co-located storage is set at 1 month.
    - Regarding the installation of heat pumps below 50 MW, the permit-granting process shall not exceed 1 month, while in the case of ground source heat pumps it shall not exceed 3 months.
    - In general, Member States shall ensure that connections to the grid shall be permitted within two weeks of the notification to the relevant entity: (a) for heat pumps of up to 12 kW electrical capacity; and (b) for heat pumps of up to 50 kW electrical capacity installed by renewables self-consumers, provided that the electrical capacity of a renewables self-consumer's renewable electricity generation installation amounts to at least 60 % of the electrical capacity of the heat pump.
  - Requires Member States (art. 18, par. 3) to: (a) ensure the sufficiency of trained and qualified installers of renewable heating and cooling systems through appropriate training programmes leading to qualification/ certification and (b) put in place measures to promote participation in such programmes, in particular by small and medium-sized enterprises and the self-employed.
- ✓ The [Alternative Fuels Infrastructure Regulation (AFIR)] that came into force in October 2023:
  - Sets mandatory deployment targets for public electric recharging infrastructure:

        - For each light-duty battery-electric car in a Member State, a power output of 1.3 kW must be provided by publicly accessible recharging infrastructure (art. 3, par. 1).
        - Every 60 km along the trans-European transport (TEN-T) network, fast recharging points of at least 150 kW need to be installed from 2025 onwards (art. 3, par. 4).
        - Regarding heavy-duty vehicles, by 2030 dedicated recharging points with a minimum output of 350 kW need to be deployed every 60 km along the TEN-T core network, and every 100 km on the larger TEN-T comprehensive network (art. 4, par. 1.)
    - Mandates the installation of publicly accessible: (a) fast recharging infrastructure in urban nodes and (b) overnight recharging infrastructure along the main transport network.
    - Specifies that operators of publicly accessible recharging points shall provide end users with the possibility to recharge their electric vehicle on an ad hoc basis (art. 5).
    - Sets requirements regarding the technical specifications of public power recharging points and specifies a clear legislative process to adopt standards in relation to e-mobility, including relevant aspects of interaction with the grid (art. 24 and Annex II).
- ✓ The proposed revision of the Energy Taxation Directive aims to introduce a new structure for minimum tax rates based on the real energy content and environmental performance of fuels and electricity, which will ensure that the most polluting fuels are taxed the highest.
- ✓ The 2023 Commission Implementing Regulation (EU) 2023/1162 on interoperability requirements and non-discriminatory and transparent procedures for access to metering and consumption data (as provided for by the Electricity Directive, art. 24).
- ✓ Preparation of Commission Implementing Acts on interoperability requirements and non-discriminatory and transparent procedures for access to data required for demand response and customer switching (as provided for by the Electricity Directive, art. 24).
- ✓ Preparation of a new network code on demand response, expected to be submitted end of 2024, to unlock the potential of electric vehicles, heat pumps and other electricity consumption to contribute to the flexibility of the energy system in line with the existing Electricity Market Design (both Electricity directive and Regulation and the revised EMD).
- ✓ The Code of conduct for energy-smart appliances under preparation by DG ENER and JRC to enable interoperability and boost the participation of energy-smart appliances in demand response schemes.
- ✓ The 2020 Renovation Wave Strategy presents a strategy to trigger renovation, in line with the Energy Efficiency First principle outlined in the EU strategy on Energy System Integration, which aims to address long-standing barriers which are still relevant today (insufficient understanding of energy use and savings, split

incentives between owners and tenants, disagreements between owners of the same building, lack of or limited financing).

- ✓ The EU Heat Pump Action Plan under preparation which seeks to set out measures aimed to address the main barriers for a faster rollout of heat pumps (high upfront costs of heat pumps, technical (un)preparedness of buildings for lower-temperature heating, information gaps, low customer and installer awareness and acceptance, split incentives, financing constraints, permitting procedures, national building regulations, skills gaps).
- ✓ The EU Action Plan for Grids outlines specific actions at EU level, aimed at alleviating barriers for network expansion and reinforcement, by improving implementation of the agreed legal framework. Key actions include:
    - o Supporting DSO grid planning and identifying conditions under which anticipatory investments in grid projects should be granted (actions 3 & 4).
    - o Promoting uptake of smart grid, network efficiency and innovative technologies inter alia through tariff design (actions 7 & 8).
    - o Increasing visibility on opportunities from EU funding programmes for smart grids and modernisation of distribution grids (action 10).
    - o Providing guidance and technical support on how to implement existing legislative tools to implement permit acceleration measures (action 11).
- ✓ European Commission initiatives on standardisation of recharging infrastructure specifications:
    - o European Standardisation Organisations are currently in the process of adopting key smart charging standards at European level.[81]

2.3.2. Recommendations to address the technical barriers

Recommendation 1: Provide guidelines to maximise benefits of smart meter networks
Addressee: European Commission
Related policies & measures: JRC Guidelines for cost-benefit analysis of smart metering deployment, Commission Recommendation for the roll-out of smart metering systems, Electricity Directive, Regulation (EU) 2023/1162
Expected impacts: 2030
Relevant sectors: Building and transport sectors

Provide guidelines on how to enable different value propositions for the utilisation of smart meter networks and maximise benefits for consumers and energy systems, making more efficient use of lessons learned from the implementation of rollout programmes to date.

The progress of rolling out smart meters varies between the Member States, as many countries have already progressed significantly while others are delayed, especially with regard to tendering for equipment and effective installation plans. However, further reflection on how to maximise the benefits of the smart meter network for grid users is necessary, particularly analysing information from countries with mature rollout projects and

[81] https://ecostandard.org/wp-content/uploads/2022/12/ECOS-RAP-Standards-for-EV-smart-charging.pdf

implementation experience. Member States should be able to utilise such information/ guidelines in order to ensure that their smart meter networks will truly enable active market participation, as envisaged.

ACER reports that based on NRAs estimates, the smart metering devices installed across Member States enable mostly standard value propositions, allowing consumers to better understand and control their energy consumption (e.g. energy consumption in real-time, overview of historical consumption).[82] However, to maximise the direct benefits of smart meters for final customers, more advanced value propositions are required, based on advanced data analytics and full access to flexibility markets, allowing consumers to better manage and reduce their electricity bill (e.g. ability to valorise the provision of explicit demand response to the power markets, functionalities facilitating smart charging of EVs at home).

The topics on which best relevant practices can be collected and promoted may include the following:

- How has the smart metering equipment (including distributed measurement and sub-metering devices) and data facilitated the DSOs' network operation and maintenance?
- How has the smart metering equipment and data facilitated participation of end-users in short-term wholesale and ancillary services markets?
- How has the smart metering equipment and data facilitated retail market functioning, improved billing and facilitated supplier switching?
- How has the smart metering equipment and data facilitated the development of flexibility services, demand response, decentralised renewable generation and storage?
- How has the data gathered from smart meters been used for estimating and analysing the energy patterns and savings of consumers, to develop targeted efficiency programmes?

Recommendation 2: Review electricity grid connection principles
Addressee: European Commission
Related policies & measures: JRC Guidelines for cost-benefit analysis of smart metering deployment, Commission Recommendation for the roll-out of smart metering systems, Electricity Directive, Regulation (EU) 2023/1162
Expected impacts: 2030
Relevant sectors: Building, industry and transport sectors

a. **Review current principles of the process for handling connection requests**, referring to:
    - The 'first come first serve' principle, especially in areas where connection capacity is scarce.
    - The legal obligation for TSOs and DSOs to connect new network users in all cases with limited options to refuse, no matter the cost or the impact specific connections may bring to the system.
b. **Review firmness on connection terms** and further develop structured regulatory schemes and incentives promoting flexible connections, both for RES generators

[82] ACER (2023) Demand response and other distributed energy resources: what barriers are holding them back?

(injections) and end-users (off-take) without however undermining investment in RES generation and storage.[83]

Indicatively, different forms of alternative connection agreements, some of which are already implemented in Member States such as France, Netherlands and Belgium, include: temporary firm connection agreements, fully flexible connection agreements, time-limited firm connection agreements, combination of fully flexible and time-limited firm connection agreements, shared connection agreements, ‘dynamic operating envelopes’, and Use-it-or-lose-it (UIOLI) or use-it-or-sell-it (UIOSI) connection agreements.[84]

To address the evolving trends in Europe's energy and transport sectors, particularly the growing presence of decentralised electricity generation, storage facilities, electric heat pumps, and EV charging points, the Commission is actively working to adapt the interconnected power system. This involves preparing amendments to two delegated acts, namely the Network Code on Requirements for Generators (2016/631) and Demand Connection (2016/1388). These policy developments are crucial in the decarbonisation efforts of Europe and ensuring the smooth integration of emerging technologies. Additionally, the draft Network Code on demand response that is currently under development, includes provisions on non-firm connection agreements. The aim is to specify the process for national terms and conditions to align (at least nationally) the use of such agreements.

Recommendation 3: Further promote R&D to improve efficiency of heat pumps at (very) high temperatures for electrification of industrial processes
Addressee: European Commission
Related policies & measures: Energy Efficiency Directive, Renewable Energy Directive
Expected impacts: 2030
Relevant sectors: Building and industry sectors

Promote Research & Development (R&D) with the aim to improve the efficiency of heat pump systems at high (i.e. above 160°C) temperatures in order to accelerate the technical development and commercialisation of heat pumps in the industrial sector and increase their competitiveness compared to conventional fuels-based technologies (e.g. natural gas).[85]

Additionally, early deployment of electrified industrial processes, including heat pumps and other electro-heating technologies (e.g. induction, resistance, infrared, electric-arc, radiofrequency, microwave) and translating policy targets into electrification plans and pilots can prove out technologies and support scaled-up investment.[86]

[83] CEER (2023) CEER Paper on Alternative Connection Agreements
[84] Ibid.
[85] Lawrence Berkeley National Laboratory (2018) Electrification of buildings and industry in the United States
[86] IISD (2022) Industrial Electrification

Recommendation 4: Promote pilot projects and develop works protocol/ manual for replacing AC to DC
Addressee: European Commission
Related policies & measures: Energy Efficiency Directive, Electricity Directive
Expected impacts: 2040
Relevant sectors: Building sectors

Promoting further pilot projects as well as developing work protocols and manuals is necessary for training purposes and for preparing the workforce to be in place at a later stage, when further efficiency gains using DC current will gain momentum along with increasing embedded electricity generation and storage projects, to maximise efficiency gains.

The efficient coordination between the digitalisation process, the employment of smart technologies and further actions, like shifting from AC to DC in buildings, with an objective to maximise efficiency gains, requires a prioritisation of actions. Promoting the replacement of AC with DC electricity, without having in place applications like embedded generation and storage, and other digital equipment, reduces the potential to maximise the benefits of such measures.

2.3.3. Recommendations to address the economic and financial barriers

The economic and financial barriers to further electrification mainly relate to:

- **High upfront costs of purchasing equipment and installation**, to which the residual value of the undepreciated equipment being replaced is added.
- **No clear energy price signals**, including tariff structures and difficulties to maximise benefits from further electrification.
- **Strong competition for electrification investment** and deployment from conventional fossil fuel-based technologies and established processes.

Funding levels and the way these funds are allocated to the different steps in the electrification process is a key factor to overcome financial barriers. As an example of asymmetries in funding allocation, the tremendous expansion of RES generation, backed by subsidy schemes, tax credits, and a falling levelised cost of energy (LCOE) due to scaling–up and competition, should be contrasted to the development of the transmission and distribution network capacity as well their modernisation pace that are falling behind.

Recommendation 5: Support emerging business models for financing of upfront equipment and installation costs
Addressee: European Commission, Member States
Related policies & measures: Renewable Energy Directive, Energy Efficiency Directive
Expected impacts: 2030/2040
Relevant sectors: Building and transport sectors

Regarding heating/ cooling electrification, emerging business models such as “heat as a service” and “pay-as-you-save schemes” can help alleviate the burden of high upfront costs. In the “heat as a service” model, the investment, its maintenance and output (heat/cool) are provided by specialised energy service companies (ESCOs) on a long-term basis as a bundled service, while in “pay-as-you-save schemes”, the customer pays a fixed rental fee for the heating/cooling equipment based on energy savings. These business models may be facilitated through appropriate definitions of concepts, as well as regulations and guidance regarding pre-contractual transparency as well as contractual terms and conditions. Such solutions could be particularly suitable for consumers that do not have easy access to capital and could hance to some extent also address energy poverty issues.

Recommendation 6: Implement dynamic electricity commodity pricing to enhance competition at the supply side
Addressee: European Commission, Member States
Related policies & measures: Electricity Regulation and Directive
Expected impacts: 2030/2040
Relevant sectors: Building and transport sectors

One option for promoting the efficient use of distributed energy resources, including storage, EVs and bidirectional charging, smart meters, and demand response, would be to improve price signals by applying variable or dynamic supply tariffs which can allow end users and prosumers to take benefit of the market dynamics. Dynamic price formulas are specially designed for supply contracts, using smart meters or timers to allow end-users or prosumers to adjust their injection or offtake based on price signals and/or time zones. [87]

A prerequisite for advancing organised electricity and ancillary services’ markets (including for grid congestion management), based on automated structures and exchanges, is smart equipment and an adequate level of digitalisation of the system operators for procuring all these market-type services. However, a well-functioning flexibility and ancillary services market may take a long time to mature, and easy-to-apply solutions such as dynamic electricity commodity pricing may apply, without however contradicting the right consumers to fixed-price electricity contracts.

Recommendation 7: Implement cost-reflective Time of Use (ToU) grid tariffs to provide adequate price signals for demand response
Addressee: European Commission, Member States
Related policies & measures: Electricity Regulation and Directive
Expected impacts: 2030/2040
Relevant sectors: Building and transport sectors

To facilitate the effective integration of distributed energy resources, including storage, electric vehicles (EVs), bidirectional charging, smart meters, and demand response, there is a need to develop a robust flexibility and ancillary services market. In the absence of such a market, promoting the efficient utilisation of these resources can be achieved through user-friendly solutions like Time of Use (ToU) grid tariffs. These tariffs would reflect the costs associated with services provided by the distribution system operator (DSO) or transmission system operator (TSO) and enable end users and prosumers to take advantage of market dynamics while maximising their benefits.[88]

In parallel, the procurement of ancillary services at the local level (DSO’s level) also needs to be developed. Integration of DER into the network and electrification of end uses requires the

[87] ACER (2023) Demand response and other distributed energy resources: what barriers are holding them back?
[88] Ibid.

establishment of detailed and transparent frameworks regarding DSO congestion management and access to flexibility services through a combination of regulation, connection agreements, network tariffs and procurement of services through tenders.[89]

Harmonisation of actions for managing flexibility and congestion at the system and local levels provides better possibilities for end-users and prosumers to optimally use their equipment, with a clear view of the options and opportunities. These designs and approaches should not be competitive but complementary, ensuring exchanges of products and services between the local and system levels optimising the use of resources. This will be facilitated by unifying the marketplaces and platforms to exchange products and services, ensuring equal and open access to participants, either directly or through specialised entities, like aggregators, energy community operators, etc.

In this regard, a Network Code on demand response is under development, to be published before mid-2024, which aims to unlock the potential of EVs, heat pumps and other electricity consumption to contribute to the flexibility of the energy system, addressing remaining regulatory barriers for the development of demand side and other flexibility sources in the electricity market. It includes in particular rules on aggregation, energy storage and demand curtailment.

Recommendation 8: Promote flexible and partial industrial electrification
Addressee: European Commission, Member States
Related policies & measures: Electricity Regulation and Directive
Expected impacts: 2030/2040
Relevant sectors: Industry sectors

For many industrial activities currently using fossil fuels, gradual approaches to electrification should be examined, whereby energy needs will be partially covered with electricity, allowing at the same time the possibility to switch in a flexible manner between electricity and fossil fuels. Industries facing international competition must safeguard their competitiveness while transitioning to electrification, to avoid any negative impact. This hybrid approach may provide more time for technology improvements towards full electrification and may also relax the concerns of industrial users regarding a rapid and complete switch from existing and mature fossil-fuel uses to electrified alternatives.

Through this hybrid setup, industry users have the option to mitigate the volatility in energy prices arising from the intermittency of renewable resources. Utilising both existing fossil fuel equipment and new investments towards a moderately paced electrification path, can protect industrial customers from undesirable price volatility and mitigate concerns regarding their competitiveness.

Current technologies already allow industrial consumers to replace a significant share of their fossil-fuel intake with electricity, and electricity prices are low enough in certain regions that companies could lower their energy costs by switching from fossil fuels to electric power. Opportunities to adopt electric technology should only continue to expand as electricity prices fall and electric technologies improve.

[89] CEER (2020) CEER Paper on DSO Procedures of Procurement of Flexibility

2.3.4. Recommendations to address legislative and regulatory barriers

Recommendation 9: Formulate an actionable strategy for Electrification
Addressee: European Commission
Related policies & measures: Electricity Directive
Expected impacts: 2030
Relevant sectors: Building, Industry and transport sectors

Stakeholders highlight the need for a dedicated electrification action plan to accelerate the uptake of direct, smart electrification in Europe. Indicatively, the Electrification Alliance[90] advocates that the Electrification action plan should set a target of 35% electrification of final energy use across the EU by 2030 and should ensure that electrification becomes an integral element of Member States' National Energy and Climate Plans (NECPs). Concrete actions according to stakeholders, would include a reform of grid planning both for transmission and distribution networks to improve coordination and political oversight, programmes to attract skilled workers, the prioritisation of direct and smart electrification in the EU's funding and financing programmes and the empowerment of end-users to utilise the full potential of demand side management.[91] The strategy can also propose specific regulatory and price-based incentives and mechanisms to further increase the rate of electrification.

Recommendation 10: Monitoring report concerning the access of DERs in markets, and progress on business models (ESCOs, Aggregators)
Addressee: European Commission/ ACER
Related policies & measures: Electricity Directive
Expected impacts: 2030
Relevant sectors: Building, Industry and transport sectors

A regular monitoring report by a competent EU authority such as ACER, concerning the market access of DERs in markets, and progress on business models (ESCOs, Aggregators) would enhance transparency and provide important information to policy-makers and stakeholders alike on barriers and latest developments. The monitoring report could indicatively include a review of roles and responsibilities of new actors, eligibility provisions (e.g. to participate in day-ahead and intraday markets, provide balancing and congestion management services), legal frameworks on aggregation models, availability of incentives and price signals, latest updates on business models, key national measures, barriers, and recommendations. Member States would be required to regularly collect and provide relevant information and data to the competent authority in a structured manner.

[90] Electrification Alliance is an alliance of associations including Avere (electro-mobility), Eurelectric, the European Climate Foundation, the European Copper Institute, the European Heat Pump Association, EuropeOn (electrical contractors), smartEn, SolarPower Europe and WindEurope.
[91] Electrification Alliance (2023) Electrification Manifesto

Recommendation 11: Support national and local authorities in coordinating assessment and planning efforts
Addressee: European Commission, Member States
Related policies & measures: Renewable Energy Directive, Energy Efficiency Directive
Expected impacts: 2030/2040
Relevant sectors: Building, Industry and transport sectors

EU authorities can support national and local authorities in the planning process for national network development plans, both at transmission and distribution levels, through appropriate guidelines and supervision. As noted in EU's Energy System Integration Strategy, future network planning will require a more integrated and cross-sectoral approach, notably of the electricity and gas sectors. It will also require full consistency with climate and energy targets, including alignment with National Energy and Climate Plans, an adequate consideration of all relevant actors, and should be informed by local conditions.

Recommendation 12: Adopt and implement common European standards to ensure interoperability, including for smart and bidirectional charging
Addressee: European Commission, Member States and manufacturers
Related policies & measures: AFIR Regulation
Expected impacts: 2030
Relevant sectors: Transport sector

The development and enforcement of the communication standard, EN ISO 15118-20 in convergence with ongoing industry practice such as the Open Charge Point Protocol, is a critical aspect in order to ensure interoperability/ compatibility of software platforms and hardware devices. This includes bidirectional communication between equipment and actors at multiple levels (e.g. grid operator, charger, vehicle, charging point operator, energy supplier, aggregator).[92]

Manifold protocols developed by industry operator should converge and become international standards by standardisation development organisations (SDOs) in order to simplify the landscape and provide a more certain, stable and robust development where views by all relevant stakeholders are duly discussed.

2.3.5. Recommendations to address societal barriers

Addressing the skills and knowledge gaps for further electrification and DER as well as increasing awareness of consumers is critical for achieving the energy and climate objectives. Re-skilling and training is necessary to prepare the workforce for the massive effort into the development and deployment of low-carbon technologies.

[92] IEA (2022) Policy Brief on Public Charging Infrastructure

Recommendation 13: Develop training programmes for sector professionals on electrical equipment and EVs
Addressee: European Commission
Related policies & measures: Net-Zero Industry Act, Heat Pump Action Plan, funding opportunities addressing skills such as LIFE calls
Expected impacts: 2030
Relevant sectors: Building, Industry and transport sectors

The development of training programmes for the certification of sector professionals by Member States and the development of systematic processes for the installation/ retrofitting of electrical equipment would streamline the quality and cost efficiency of associated works. These measures should include the provision of coordinated social and professional reskilling/ upskilling assistance in declining sectors and regions.[93] Additionally, regarding industrial electrification and the increasing uptake of EVs, training and reskilling/ upskilling of personnel will be required to support the introduction of new roles.

[93] JRC (2020) Employment in the Energy Sector

3. Uptake of renewable and low-carbon hydrogen (and other low-carbon gases)

3.1. Introduction

It is generally agreed that hydrogen plays an important role in integrating the energy system. Findings of a recent study[94] indicate that a fully decarbonised Europe can only be reached (at reasonable cost) through sufficient uptake of hydrogen. The uptake of renewable and low-carbon hydrogen is, however, still in its early stages. The flexibility services of hydrogen-based generation to balance an increasingly intermittent renewable energy supply may be especially valuable but is dependent on a supportive regulatory framework at national and local levels and certainly the so-called “hard-to-abate” sectors will rely on hydrogen to reach decarbonisation goals.

Despite active development by the European Commission through various policy measures (e.g. the REDII or the FuelEU Maritime/Aviation) the sector still faces various barriers.

This chapter provides an overview of barriers based on literature and stakeholders input and provides recommendations on how the European Commission can help to overcome them. Additionally, the report specifically addresses in two separate chapters the issues of feasibility and costs of meeting the EU ambition to produce 10 million tonnes of renewable hydrogen in 2030 and the climate and environmental impacts of (long-distance) hydrogen imports. Two detailed paragraphs on the feasibility and costs for reaching the targets in the short term by 2030 and on the GHG footprint of hydrogen imports,[95] conclude that the above-mentioned barriers need to be addressed to reach the ambitious national targets by 2030, and that the imports should focus on renewable hydrogen or low-carbon hydrogen with certified lifecycle analysis. The cross-border adjustment mechanism (CBAM)[96] will to some extent also prevent/avoid unfair competition from fossil energy-based hydrogen (or hydrogen based) imports.

3.2. Barriers to the uptake of hydrogen

This section gives an overview of barriers to the uptake of hydrogen in the EU on the basis of literature review and stakeholder consultation - survey, interviews and workshops. The barriers mentioned in this chapter generally concern the uptake of all of the following types of hydrogen: renewable hydrogen from renewable energy sources and low-carbon hydrogen which is defined as hydrogen with at least 70% less CO_2 emissions than fossil fuels (hydrogen made using nuclear power or hydrogen made using fossil fuels in combination with carbon capture and storage (CCS)). Those barriers that effect only certain types of hydrogen are indicated accordingly in the sub-sections. Due to the growing availability of renewable energies across the EU, renewable hydrogen will be the most prominent hydrogen type contributing to decarbonisation of end-uses and system integration. Therefore, the focus of the barrier analysis lies on renewable hydrogen. Still, barriers particularly relevant for other types of hydrogen are also addressed and highlighted. The barriers are further grouped into the overarching categories “economic and financial barriers”, “technical barriers”, “legislative and regulatory barriers” and “societal barriers”. Each barrier and its effects are briefly described.

[94] Fraunhofer ISI (2023) The impact of industry transition on a CO2-neutral European energy system
[95] https://www.transportenvironment.org/discover/hydrogen-hype-why-the-eu-should-be-cautious-about-uncertain-imports-from-far-flung-places/
[96] Carbon Border Adjustment Mechanism - European Commission (europa.eu)

Table 3-1 Summary of main barriers for the uptake of hydrogen

Barrier type	Barrier
Technical	1. Insufficient manufacturing capacities for electrolysers[97]
Economic and financial barriers	2. Cost gap of renewable and low-carbon H_2 towards costs of fossil-based hydrogen
	3. Complex use of additional revenue streams, such as balancing market services
	4. Reaching bankability for hydrogen related projects
	5. Competition from non-EU sources of hydrogen
	6. Lack of H_2 transportation and storage infrastructure
Legislative and regulatory barriers	7. Missing international regulation and import policy
	8. Long, complex, unstandardised permitting processes for RES and H_2 projects
	9. Lack of a skilled workforce e.g. for H_2 project management and H_2 project permitting
Societal	10. Lack of acceptance and concerns of about derivatives of hydrogen such as ammonia (high toxicity) or methanol and safety issues

3.2.1. Technical barriers

3.2.1.1. Technological development (of hydrogen production)

Achieving sufficient reliability and safety is of high importance, although further technology improvement is also needed.

Both hydrogen via electrolysis (from renewables or nuclear) and hydrogen via natural gas and CCS are technically proven technologies. Therefore, while there are still technical improvements to be made in hydrogen production, especially the limitations concerning the deployment of functioning hydrogen infrastructure remain open. This includes lack of standards on leakage testing. In terms of hydrogen production from electrolysis, alkaline electrolysers are currently the most mature and market-ready technology. However, other electrolysis technologies like PEM (Proton exchange membrane - more compact design, higher flexibility), SOEC (Solid Oxide Electrolyser Cell - integration of industrial waste heat, improved electrical efficiency, reversible operation), and AEM (Anion Exchange Membrane - higher flexibility, no use of noble materials) exist and would have strong benefits for the integration of hydrogen, but have not yet been brought to an equal technology readiness level.[98]

Electrolysis in larger scale may face water scarcity in some arid regions.

With electrolysis projects continuing to significantly increase in size, the desalinated water scarcity becomes an increasingly important technical barrier to hydrogen project

[97] Nameplate manufacturing capacities have in the meantime surpassed the demand from project developers (e.g. recent report by BNEF (https://www.hydrogeninsight.com/electrolysers/severe-overcapacity-the-global-supply-of-electrolysers-far-outstrips-demand-from-green-hydrogen-projects-bnef/2-1-1618327), thus making it unlikely to face insufficiencies in the medium term.
[98] IRENA (2023) Innovation Landscape for Smart Electrification

implementation. Especially in areas with large amounts of solar energy, like southern Europe, local availability of water will be a growing issue.[99]

Carbon capture and storage technology lacks experience in Europe.

For fossil-based low-carbon hydrogen production, the SMR components are widely available and commercialised, however, applications of CCS are still expensive due to Europe's lack of experience and scale.

The use of waste heat from electrolysers requires technical adaptations downstream (see also chapter 4 on waste heat utilisation).

With regard to the use of waste heat from electrolysers, e.g. in district heating, some stakeholders mention that while technical feasibility seems realistic, still more research is needed on understanding "manageable configurations". Especially with regards to the operational profile of electrolysers and thus availability of waste heat, which means all downstream systems "need to be capable to cope with these fluctuations" through for example the use of thermal energy storages.

3.2.1.2. Hydrogen infrastructure & storage

Infrastructure build-out is planned but needs accelerated implementation and comprehensive integrated planning.

The integration of hydrogen will need a transportation network to carry hydrogen across the EU to the demand locations. While this in principle may also be possible through strong expansion of the electricity grid, the amounts that can be transported via pipeline usually exceed those of high voltage lines leading to many cases where transport via pipeline is more economical (e.g. Aquaventus project in the German North Sea[100]). Furthermore, the development of electricity transmission has a long lead time leading to risks for decarbonising sectors requiring hydrogen supply already towards 2030 and even 2035.

It is essential to plan the infrastructure in an integrated manner, which has also been pointed out by several stakeholders. For example, TEN-E only obliged ENTSO-E to develop the offshore electricity network development plans but should – with the next revision or ideally beforehand – also include gas stakeholders. Three stakeholders in the survey pointed out that the top-down planning approach of the EU is problematic. They believe that instead of assessing the potential supply and demand and optimal energy carriers across the different sectors via high-level modelling, a bottom-up approach should be considered that is able to incorporate local specificities.

Pipeline infrastructure for hydrogen is currently insufficient

However, literature review and survey results shows that the current transport capacities of a total of 2,000 km[101] of dedicated hydrogen pipelines across Europe are not sufficient in both length and transport capacities. Retrofitting existing pipelines is suggested to be the least expensive option but will take time and experience and needs to be closely coordinated with a slow phase-out of natural gas over the next decades. Moreover, recently the European Clean Hydrogen Alliance highlighted that even if all hydrogen pipelines are retrofitted or built

[99] Hu et al. (2020) A Review of Technical Advances, Barriers, and Solutions in the Power to Hydrogen Roadmap
[100] https://aquaventus.org/wp-content/uploads/2022/05/AquaDuctusShortStudy_OffshoreHydrogenProduction_v120_EN.pdf
[101] BCG (2021) The Green Tech Opportunity in Hydrogen

as currently envisioned in the European Hydrogen Backbone by 2030, several large European regions would still remain without pipeline access.[102]

Hydrogen storage infrastructure needs targets and accelerated build-out.

Hydrogen storage infrastructure would bring flexibility and resilience to the European energy system by allowing large-scale and long-term storage of renewable and low-carbon energy. However, (long-term) hydrogen storage systems have not yet been rolled out. Among the first projects is Green Octopus Mitteldeutschland project[103] that will involve hydrogen storage in salt caverns and is scheduled for completion in 2026. This has been in part because the technical differences between natural gas and hydrogen storage have not been fully overcome. Stakeholders suggest implementing hydrogen storage capacity targets, combined with increasing demand targets for hydrogen.

3.2.1.3. Hydrogen imports infrastructure

Technical challenges remain for all maritime import routes.

Hydrogen transport via sea is still physically non-existent with worldwide only one single hydrogen tanker demonstration vessel being in test operation, between Australia and Japan. Currently, all different routes for shipping hydrogen or its derivatives still have process steps that are not yet at a commercial level[104]:

- Liquid Hydrogen (LH_2): maritime transport, scale-up of liquification;
- Synthetic LNG: CO_2 transportation, CO_2 sourcing;
- Ammonia (NH_3): NH_3 cracking; safety issues;
- Liquid Organic Hydrogen Carriers (LOHC): hydration and dehydration steps.

All of the derivatives lead to large energy efficiency losses, especially in combination with further re-conversion to hydrogen. For some derivatives, additional safety aspects need to be studied and standardised, due to issues of very high toxicity (ammonia).

European governments (including Germany, intending to import renewable hydrogen from Canada; and the UK, already funding pilot plants for ammonia cracking)[105] have announced support for repurposing existing LNG terminals for LH_2 or ammonia but have not yet communicated a clear preference for either of the technologies. So far, no terminal has been converted, making cost estimates uncertain. However, a switch of an existing LNG terminal to LH_2 is expected by initial studies to be more expensive than a switch to an ammonia terminal, due to the significantly lower temperatures required. Furthermore, the uptake of new terminals is limited by the uncertainty regarding the scale of future imports of hydrogen and its derivatives.[106] All in all, the EU should considerer carefully which countries to target for importing renewable H_2.[107]

[102] Hydrogen Europe (2023) Jorgo Chatzimarkakis at EUSEW2023. Bringing hydrogen to industry: the right infrastructure to unlock decarbonisation
[103] https://www.ontras.com/de/go
[104] DVGW (2023) Kurzstudie zu Transportoptionen von Wasserstoff
[105] Energy Monitor (2023) LNG terminals
[106] IEA (2022) Global Hydrogen Review
[107] https://www.transportenvironment.org/wp-content/uploads/2024/02/202402_H2_imports_TE_briefing.pdf

3.2.2. Economic and financial barriers

3.2.2.1. Cost gap

The cost gap between unabated fossil-based hydrogen and renewable as well as low-carbon hydrogen remains significant and is considered a fundamental barrier by a large majority of stakeholders.

One of the most cited and important barriers to a rapid uptake of hydrogen is the current cost premium for renewable and low-carbon hydrogen technologies compared to conventional fossil-fuel based hydrogen.[108] Price of electricity (energy) to power renewable hydrogen is one of the key determining factors to produce cost competitive renewable hydrogen, along with improvements of economies of scale in the manufacturing of electrolysers. The US Clean Hydrogen Strategy and Roadmap (June 2023[109]) estimates that electricity prices of USD 30/MWH are necessary for H_2 to be priced at about 2 USD / H_2 kg and about USD 20 MWh for 1 USD/H_2 kg. As already analysed above in the survey responses (see also annex 6.1), especially renewable hydrogen faces high costs due to the need for expanded renewable energy production, as well as high investment costs for the electrolysers. One reason for the high investment costs for electrolysers is that these have not yet reached the economies of scale.

Yet, also low-carbon hydrogen that needs CCS technology faces higher production costs. A reduction in production costs and an improved price competitiveness will be a key factor for large-scale deployment of clean hydrogen.[110] Competing products, such as fossil-based hydrogen produced via SMR in northwest Europe had a levelised cost of hydrogen production (LCOH) in 2021 of EUR 1.4–2.0/kgH_2, while the LCOH of solar PV-powered electrolysis was around EUR 6.8-9.4/kgH_2 according to the IEA.[111] IRENA estimates a lower LCOH for Europe's renewable hydrogen production at EUR 3.8-5.1/kgH_2, which is still higher than the conventional alternative.[112]

Subsidies remain focused on CAPEX.

Not much emphasis has been put on OPEX subsidies in the EU (compared to the U.S. with its Inflation Reduction Act providing tax reductions of up to USD 3/kgH_2, or EUR 2.6 /kgH2). EU focus so far has been on CAPEX subsidies and obligations, even though many stakeholders argue OPEX subsidies would facilitate a faster transition to renewable fuels.[113] The European Hydrogen Bank is an important tool to address the above mentioned barriers. The first EU-wide auction was launched in November 2023 with Germany contributing 350 Mio € in addition to the 800 Mio € foreseen for European projects from the EU Innovation Fund[114]. Applicants are informed on their application for the first pilot round as early as April 2024 and the Commission intends to launch a second round of auctions in 2024[115]. The Commission will use the results from the pilot scheme to inform future auctions.

Another challenge is the potential volatility of hydrogen production costs for projects without 'fixed price' PPAs, due to its higher dependency on the costs of electricity to power the

[108] Agora (2020) Making renewable hydrogen cost-competitive
[109] U.S. National Clean Hydrogen Strategy and Roadmap (energy.gov)
[110] Renewable or low-carbon hydrogen encompassing all production technologies and sources such as nuclear, or fossil fuels combined with CCU/S
[111] IEA (2022) Northwest European Hydrogen Monitor
[112] IRENA (2023) Innovation Landscape for Smart Electrification
[113] According to an interview with Richard Yu, held on June 30, 2023
[114] European Commission (2023) Commission launches first European Hydrogen Bank auction with €800 million of subsidies for renewable hydrogen production
[115] European Commission (2023) Commission launches first European Hydrogen Bank auction with €800 million of subsidies for renewable hydrogen production

electrolysers. The production costs of renewable hydrogen depend to a large extent on renewable energy prices, whereas the cost of low-carbon hydrogen depends on e.g. natural gas prices (plus the non-volatile cost of CCS), or nuclear electricity prices.[116] Currently, premiums are being paid due to scarcity of renewable hydrogen. Renewable hydrogen production may mitigate the exposure towards renewable energy price volatility via both, physical measures such as dedicated renewable power plants connected via direct line, or through participation on long-term energy markets, such as (preferably 'fixed price') PPAs.

Literature[117] has put forward the issue that PPAs, as considered under the REDII and DAs, may not be possible through intermediate contracts with electricity traders, as a direct contract between the electricity producer and hydrogen producer is needed according to the current Commission guidance on implementation of the hydrogen delegated acts.[118] This limits the possibilities to optimise the debt-to-equity ratios for smaller project developers not being able to use a more credit-worthy intermediary and in countries (incl. e.g. Canada) with state-mandated power purchasers, it may not be possible for hydrogen projects to directly contract with power generators.

Uneven taxation/levies/carbon pricing among energy sectors is referred to by many stakeholders in the survey as critical in order to reach a level-playing field among all energy sectors.

This is relevant for all types of hydrogen. Germany, for example, proposed an electricity price cap of 0.06 €/kWh for its energy-intensive industries (such as chemicals, steel, and glass manufacturing), which will likely be implemented through tax reductions on the energy purchases for all industrial off-takers. The impacts of a subsidisation of electricity for industry on the competitiveness of renewable and low-carbon hydrogen have not been studied in the literature in sufficient detail, yet arguments put forward include the dilemma of on the one hand keeping electricity-intensive production in Europe and preventing a shift of CO_2 emissions abroad, and on the other hand the problems of an uneven playing field and of a lack of long-term investment incentives to transform the energy supply to industry, thus leading to lock-in into currently used technologies.

A further detailed discussion of hydrogen costs and their impact on reaching the EU ambition of 10 million tonnes for domestic renewable hydrogen production is provided in section 3.5.1.

3.2.2.2. Revenue streams from flexibility services

The electricity balancing market remains highly complex, while revenue streams remain volatile and therefore insufficient to build business cases on.

The balancing market as currently designed includes products electrolysers can technically deliver[119] (FCR, aFRR and mFRR). Additionally, the introduction of a peak shaving product is under discussion[120] (not as a pan-European product, but in MSs respectively), which could also provide additional revenue streams. Many stakeholders, however, consider flexibility

[116] Gordon et al. (2023) Socio-technical barriers to domestic hydrogen futures
[117] https://www.kslaw.com/news-and-insights/eu-regulatory-challenges-complicating-the-development-of-international-green-hydrogen-projects
[118] FAQ on implementation of Delegated Acts July 2023
[119] https://itm-power.com/markets/grid-balancing
[120] European Commission (2023) Commission welcomes deal on electricity market reform

markets to be very complex with highly volatile revenue streams[121], which makes it especially difficult for small scale electrolyser projects to participate and build a business case on.

Electrolyser manufacturers do not provide long-term warranties for electrolysers being operated under fluctuating load.

Different technologies are available on the market, including Alkaline, Proton Exchange Membrane electrolysers (PEM), Anion exchange Membrane (AEM) electrolysers, and Solid Oxide (SOEC) electrolysers. Despite some electrolyser projects (especially for AEL and PEM technologies) having reached prequalification for the balancing market[122], and thus technical maturity in principle, manufacturers are hesitant to provide long-term warranties on stack reliability and require impractical process steps such as nitrogen flushing, hindering short response times. However, the servicing of the membranes in case of the PEM technology is a normal commercial process, and they need to be replaced when reaching their normal lifetime even without fluctuating loads.

3.2.2.3. Financing and funding

Reaching bankable projects remains a major challenge, especially due to lack of guaranteed offtake and predictability of demand.

As explained above, clean (renewable and low-carbon) hydrogen production from all sources is currently not yet at the financial breakeven point, and therefore continues to have the two problems: Firstly, it is still difficult to prove the bankability of all projects for all hydrogen types to investors (several stakeholders in the survey emphasise that bankability is closely tied to guaranteed offtake and thus long-term perspectives to business cases). Secondly, governmental support is needed to bridge the gap between the high production costs and the lower prices that off-takers are willing to pay, which again negatively affects renewable hydrogen, but also affects low-carbon hydrogen.

In addition, components of the hydrogen supply chain are improving in maturity and in the ramp-up of commercial implementation. In the future technical advances and efficiency gains bear the risk for investors[123] to lose competitiveness over time ('First-Mover penalty'). For example, electrolyser efficiency may improve significantly with next generation products, thus enabling hydrogen production at lower levelised costs compared to projects using the "older equipment".

Finally, there is a lack of scalability and standardisation of the technology beyond current project sizes and towards future projects that are significantly larger, which reduce the profitability and bankability.

Projects are still facing regulatory uncertainty (acknowledging that much of the uncertainty will be lifted, when the European regulatory framework is completed in 2024), this however also includes a lack of harmonisation in terms of regulation, due to competition between different national jurisdictions, such as on preferred specifications of produced and transported hydrogen.

121 https://www.regelleistung.net/Portals/1/downloads/modalit%C3%A4ten_rahmenvertraege/marktbeschreibung/Description%20of%20the%20balancing%20process%20and%20the%20balancing%20markets.pdf?ver=jxP7kkJgWsQjOyQ98AwSsA%3D%3D;
122 https://h2me.eu/wp-content/uploads/2021/10/H2ME2-D4.11-Public-FV-Report-assessing-the-current-%E2%80%A6.pdf
123 Renewable and Low-Carbon Fuels Value Chain Industrial (RCLF) alliance at EUSEW2023. Gearing up for the rollout of renewable and low-carbon fuels!

Off-takers remain cautious to adopt renewable or low-carbon alternatives making it difficult to sign contracts to prove bankability.

Although many hydrogen production facilities are planned (within the EU and projects located outside the EU, looking to export to the EU), many producers have not yet been able to find off-takers, due to the high cost of renewable and low-carbon hydrogen "scaring off" off-takers from switching to hydrogen.

3.2.2.4. Availability of hydrogen

Availability is perceived by some stakeholders as challenging, others see increasing momentum.

A further barrier to the uptake of hydrogen frequently put forward is the lack of available renewable and low-carbon hydrogen. This is supported by studies and organisations such as the European Clean Hydrogen Alliance which have come to the conclusion that an exponential supply increase is needed and that this will be a daunting task.[124,125] However, some studies do not see that the quantity of available renewable and low-carbon hydrogen is the most pressing issue, as potential imports and production capacities in Europe are sufficient.[126,127] Please note our detailed discussion of this issue in section 3.5.1.

3.2.3. Legislative and regulatory barriers

3.2.3.1. Regulation

Despite a very well-advanced regulatory environment, the remaining incompleteness still creates insecurities.

Many stakeholders are fairly positive that with the Hydrogen and Decarbonised Gas Market package put in place and the pending rules for a low-carbon hydrogen GHG methodology spelled out, the overall regulatory framework is satisfyingly complete. However, as long as there are remaining discussions and no final decisions on the GHG methodology DAs, insecurities remain on details.

Harmonisation among Members States is lacking on both speed and ambition.

Some stakeholders stated that harmonisation among Members States is lacking due to the different legislative velocities and ambition. Also, the complexity of the various legislative measures addressing the uptake of hydrogen is mentioned and the rules defined in the Delegated Acts are mentioned by about a fifth of the respondents to be "too restrictive".

While local specificities need to be taken into account, national regulations should be harmonised to enable the development of effective clean hydrogen trade in Europe.[128] Within the EU this is soon implemented by the Hydrogen and Decarbonised Gas Market Package.

Additionally, an official, clear, and coherent payment framework for hydrogen transmission between regions is missing, which would need to cover entry and exit fees and charges, or payments for supplied/ injected hydrogen. This limits business cases and delays projects from passing beyond the demonstration phase.[129] Stakeholders, such as gas traders, emphasise

[124] IEA (2022) Northwest European Hydrogen Monitor
[125] European Clean Hydrogen Alliance (2021) Alliance Roundtables on Barriers and Mitigation Measures
[126] Renewable and Low-Carbon Fuels Value Chain Industrial (RCLF) alliance at EUSEW2023. Gearing up for the rollout of renewable and low carbon fuels!
[127] IEA (2022) Global Hydrogen Review
[128] IEA (2022) Global Hydrogen Review
[129] Gordon et al. (2023) Socio-technical barriers to domestic hydrogen futures

the need for transmission fees to be adapted such that projects can reach viable business cases.

3.2.3.2. International regulation and imports policy

The international (global) regulatory environment is not sufficiently harmonised especially regarding carbon pricing and CCS.

Furthermore, the regulatory environment with the above-mentioned principles needs to be increasingly harmonised globally and across the EU. In literature, several areas are specifically mentioned, in which there is a lack of harmonisation:

- An internationally (globally) agreed framework for pricing carbon emissions is not yet in place. Despite CBAM incentivising third countries to implement pricing schemes. This hinders the development of a clean hydrogen market, hinders the international trade of hydrogen, and is a reason for hydrogen remaining economically unattractive in several use cases.[130]
- There is still no harmonised regulatory framework for international transport of hydrogen (via ship or pipelines), which is a barrier to international hydrogen trade.[131]
- For natural gas-based low-carbon hydrogen projects to reach the Final Investment Decision (FID), the creation of a well-defined legal and regulatory regime for CCS is a precondition. See also discussion paragraphs on certification.

The definition of renewable hydrogen in the EU requires significant interpretation to be applied in potential exporting countries.

Hydrogen Guarantees of Origin (GO)[132] are a reliable way of ensuring customers that the hydrogen they buy is actually produced from renewable energies. Additionally, together with the appropriate certification processes they can provide a regulatory base for the trade of clean hydrogen between EU Member States and third countries.[133] Several exporter and importer countries such as Germany, France, the Netherlands, the EU as a whole, Australia and the UK have included certification schemes in their hydrogen strategies.[134]

Some stakeholders indicate there is a lack of clarity for non-EU countries on the exact application of certification criteria both in and outside the EU, e.g. countries such as Canada, Egypt, or the US that are looking to export to the EU, as some of the requirements are closely linked to the European energy system and regulations.[135] Especially the applicability of requirements such as on bidding zones is not necessarily straight forward on energy markets without similar concepts.

[130] Gordon et al. (2023) Socio-technical barriers to domestic hydrogen futures
[131] Gordon et al. (2023) Socio-technical barriers to domestic hydrogen futures
[132] GOs have the purpose of informing final consumers, while certification has the purpose of demonstrating legal compliance for target achievement and financial support under with the Renewable Energy Directive recast.
[133] European Clean Hydrogen Alliance (2021) Alliance Roundtables on Barriers and Mitigation Measures
[134] European Commission (2023) Commission sets out rules for renewable hydrogen
[135] King & Spalding (2023) Europe's Definition of Green Hydrogen (RFNBO) Adopted into EU Law

3.2.3.3. Definition and certification of renewable and low-carbon hydrogen

While certification criteria are becoming increasingly well-defined, many stakeholders consider the requirements as complex and the additionality criterion in the DAs is considered detrimental to fast system integration.

The European Commission finalised the legislative process for two highly anticipated Delegated Acts, which have now become EU law, by publishing the EU's definition of renewable hydrogen on June 20, 2023. The first act establishes the criteria under which hydrogen, hydrogen-based fuels, or other energy carriers can be classified as renewable fuels of non-biological origin (RFNBOs). The second act outlines a methodology for calculating the life-cycle greenhouse gas emissions and reductions associated with RFNBOs.[136] In addition, guidance[137] has been provided to the operators of the recognised voluntary schemes[138] that can certify the production and consumption of hydrogen from renewable sources. While these acts provide clear guidelines for how RFNBOs need to be produced, some stakeholders still see them as complex, impractical and with strict production requirements. Especially the requirements concerning additionality have been mentioned (e.g. in Hydrogen Europe's position paper[139]) as legislative barriers that will increase the cost of hydrogen in Europe. Further, some stakeholders emphasise that additionality requirements are per-se a detrimental requirement to energy system integration (additional renewable energy capacities per production unit of hydrogen do not allow the hydrogen production site to interact strongly with the existing grid), preferring other criteria, such as "grid-serving". However, all stakeholders accept that the DAs are adopted and wish to provide input to be considered in future discussions.

The regulation on low-carbon hydrogen definition is pending.

Several stakeholders emphasise the need for regulatory clarity with regards to low-carbon hydrogen from all sources: fossil + CCS, nuclear, RCF. A fast deployment of a uniform GHG calculation method that should also apply to non-EU sources is mentioned several times. The upcoming methodologies, to be expected in 2024 or early 2025 (latest 12 month after entry into force of the Gas and Hydrogen Package[140]), will apply the same principles regarding imported hydrogen as defined for renewable hydrogen in the RED.

3.2.3.4. Permitting

Permitting remains complex and challenging, often due to lack of digitalisation, personnel and technical knowledge.

For new hydrogen projects of any kind, obtaining permits and other approvals is often a long and challenging process, which causes significant delays and cost increases, and discourages future projects.[141] There are several reasons for this. Parts of the regulatory framework for hydrogen have not been developed sufficiently or are outdated, this is particularly true for low-carbon hydrogen using CCS technology. Accordingly, the framework for authorisation of hydrogen projects is non-existent or lacks clarity in terms of relevant authorities, timelines, applicable processes and more.[142] The permitting processes involve complex legal and

[136] Directorate-General for Energy (2023) Renewable hydrogen production: new rules formally adopted
[137] https://energy.ec.europa.eu/system/files/2023-07/2023_07_26_Document_Certification_questions.pdf
[138] https://energy.ec.europa.eu/topics/renewable-energy/bioenergy/voluntary-schemes_en
[139] Hydrogen Europe (2022) https://hydrogeneurope.eu/wp-content/uploads/2022/05/2022.05.16_HE_PositionPaper_REPowerEU.pdf
[140] https://ec.europa.eu/commission/presscorner/detail/en/ip_23_6085
[141] IRENA (2023) Innovation Landscape for Smart Electrification
[142] European Clean Hydrogen Alliance (2021) Alliance Roundtables on Barriers and Mitigation Measures

administrative procedures between authorities, and the applicants receive scarce amounts of information and assistance.[143]

Across the EU, the permitting process has not been harmonised and remains complex and unclear. Due to the perceived safety risks, electrolysers or hydrogen infrastructure projects typically need safety insurance, which requires additional permitting.[144] Finally, the staff at the authorities often lack the technical knowledge for the authorisation as well as the final certification, even if they have prior experience with renewable energy permitting. These departments are also becoming increasingly understaffed as the frequency of applications for hydrogen projects increases.[145] This latter point is also emphasised by several stakeholders from the survey as the major concern regarding slow permitting processes. This is further supported by the fact that only 5 Members States[146] reported to have NRAs (National Regulatory Authorities) with competence for hydrogen infrastructure. Permitting issues are addressed in a provisional agreement on a framework covering necessary permitting authorisations for hydrogen from all sources in article 7 in the directive for "common rules the internal market in renewable and natural gases and in hydrogen" [147][148].

3.2.4. Societal barriers

3.2.4.1. Societal acceptance

Lack of public knowledge on hydrogen and derivatives creates risks for hydrogen application in larger scale.

There is currently still a lack of public knowledge surrounding renewable hydrogen and its benefits for the energy transition. Furthermore, the adoption of hydrogen technologies – despite being currently one of the more widely accepted solutions to decarbonisation – may in the future with increasing use and reports of e.g. accidents create fears and insecurities in people. Hydrogen and derivatives' safety is another aspect that is important for hydrogen acceptance. Safety needs to be proven; however, the required hydrogen leakage detection technology is not yet at a sufficient technological reliability level (TRL).[149]

Low-carbon hydrogen from fossil + CCS needs safe CCS technologies, but the public opinion remains sceptical.

While there is an increasing alignment that CO_2 can be stored safely, public perception of the technology remains sceptical. This hinders the implementation of projects in the European Union.[150]

3.2.4.2. Skilled Workforce

Both authorities and project developers lack qualified specialists.

Currently, there is a lack of qualified specialists to implement and oversee hydrogen projects. This shortage could further grow with a sharp increase in the number of hydrogen projects. As

[143] Gordon et al. (2023) Socio-technical barriers to domestic hydrogen futures
[144] IRENA (2023) Innovation Landscape for Smart Electrification
[145] European Clean Hydrogen Alliance (2021) Alliance Roundtables on Barriers and Mitigation Measures
[146] ACER (2023). Report on Investment Evaluation, Risk Assessment and Regulatory Incentives for Energy Network Projects
[147] https://ec.europa.eu/commission/presscorner/detail/en/ip_23_6085
[148] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021PC0803
[149] IRENA (2023) Innovation Landscape for Smart Electrification
[150] https://www.mdpi.com/1996-1073/15/15/5716

previously stated, the expert shortages apply both to the private and the public side of activities related to project development and permitting.[151,152]

3.3. Recommendations on the update of hydrogen

The following section provides an overview of recent or planned policies and measures as well as recommendations to accelerate the uptake of hydrogen. Stakeholder feedback obtained from a survey, interviews and workshops is used to highlight, prioritise, and focus on certain aspects. The recommendations are structured along the major barrier categories (economic, technical, legislative and societal), in order to differentiate renewable or low-carbon related recommendations, they are highlighted respectively: renewable, low-carbon and overarching. Recommendations are generally addressing the European Commission, if other stakeholders are needed or addressed, they are explicitly mentioned.

3.3.1. Recent or planned policies and measures

This section provides an overview of the recent or planned policies and measures at EU level on the uptake of hydrogen. It becomes clear that the overall EU regulatory framework is almost completed. However, decisive packages are still under discussion and their impact on the uptake of hydrogen remains to be seen.

- ✓ Under the **Renewable Energy Directive** (EU) 2018/2001, two delegated acts ((EU) 2023/1184 and (EU) 2023/1185) have been adopted on 13 February 2023. These delegated acts provide a definition for renewable fuels of non-biological origin (RFNBOs), i.e. hydrogen produced from renewable electricity and the methodology on how to calculate the respective GHG emission savings.
- ✓ The amended **Renewable Energy Directive** extends the scope to other industry sectors as well as raises the already existing binding targets of the Directive (EU) 2018/2001. The following targets for the use of hydrogen have been agreed upon:
  - Industry: 42% of the hydrogen should come from RFNBOs by 2030. This proportion shall be increased to 60% by 2035;
  - Transport: The 2030 target is more ambitious than before. It requires each Member State to mandate fuel suppliers to ensure that renewable fuels and renewable electricity supplied to the transport sector result in either:
    - A renewable energy share of at least 29% in the final energy consumption, or
    - A greenhouse gas intensity reduction of at least 14.5%,
    - This also includes using RFNBOs as intermediate products for conventional fuel production.

  Additionally, each Member State must ensure that the combined share of advanced biofuels, biogas and RFNBOs in the energy supplied to the transport sector is at least 1% by 2025 and 5.5% by 2030, with a minimum share of 1% from RFNBO in 2030.

- ✓ The **FuelEU Maritime** Regulation aims at reducing emissions from maritime transport by accelerating the uptake of sustainable alternative fuels. Mandatory

[151] Gordon et al. (2023) Socio-technical barriers to domestic hydrogen futures
[152] European Clean Hydrogen Alliance (2021) Alliance Roundtables on Barriers and Mitigation Measures

GHG reduction targets shall boost demand from ship operators to uptake alternative fuels. The approach is technology-neutral, though RFNBOs can be used to meet the targets. Where RFNBO are taken into account, the GHG emission intensity and the sustainability criteria of REDII have to be met and certified as such.

- ✓ The **ReFuelEU Aviation** regulation on ensuring a level playing field for sustainable air transport introduces an obligation on fuel suppliers to integrate sustainable aviation fuels (SAF) to airlines at all EU airports. Renewable hydrogen for aviation and low-carbon aviation fuels as synthetic aviation fuels play a role in decarbonising aviation and are therefore included within the scope of the ReFuelEU Aviation. In fact, the regulation sets out a mandate on the uptake of synthetic aviation fuels:
  - minimum 2% SAF from 1 Jan 2025;
  - minimum 6% SAF from 1 Jan 2030, of which a minimum of 0.7% of synthetic aviation fuels;
  - minimum 70% SAF from 1 Jan 2050, of which a minimum of 35% of synthetic aviation fuels
- ✓ By assigning a cost to carbon emissions, the **EU ETS** incentivises the uptake of low-carbon and renewable hydrogen. The revised EU ETS widens the scope of hydrogen production, now including all production methods as well as reducing the threshold for production capacity to 5 tonnes per day (which will benefit smaller installations). Further, investments in the generation and use of electricity from renewable sources, including renewable hydrogen are being supported through the money gained through the emissions trading.
- ✓ The **Carbon Border Adjustment Mechanisms (CBAM)** aims to address the risk of carbon leakage. In order to ensure a level-playing field with global production, the CBAM covers emission-intensive industries, applying the scope also on hydrogen and derivatives such as ammonia imported into the EU. At the moment, imports of hydrogen are relatively low. As this situation is expected to change, the EU wants to promote the uptake of renewable hydrogen. Through including hydrogen in the CBAM, the EU not only wants to create a level-playing field with competition from non-EU countries, but also foster the decarbonisation of hydrogen.
- ✓ As the **EU Taxonomy** covers the manufacture of hydrogen and hydrogen-based synthetic fuels, it drives investments towards renewable hydrogen. To fulfil the criteria of a green activity and benefit from investments, hydrogen has to fulfil the following criteria:
  - Lifecycle GHG emissions savings of 73.4% for hydrogen and 70% for hydrogen-based synthetic fuels relative to a fossil fuel comparator of 94 gCO_2eq/MJ.
- ✓ The **Alternative Fuels Infrastructure Regulation** sets out a number of mandatory national targets for the deployment of alternative fuel infrastructure in the EU. These targets also include the establishment of a hydrogen refuelling infrastructure. Member States shall ensure that:

- A minimum number of publicly accessible hydrogen refuelling stations are deployed;
- Publicly accessible hydrogen refuelling stations designed for a minimum cumulative capacity of 1 tonne per day and equipped with at least a 700-bar dispenser are deployed with a maximum distance of 200 km between them along the TEN-T core network;
- At least one publicly accessible hydrogen refuelling station is deployed at each urban node.

- ✓ The purpose of the **Gas and Hydrogen market decarbonisation package**[153] is to design the transition of the gas sector towards renewable and low-carbon gases. It consists of a proposal for a regulation and for a directive, which set common internal market rules for renewable and natural gases and hydrogen. The directive aims at creating a regulatory and certification framework and provides a definition for low-carbon hydrogen. The regulation will define the necessary framework for the future gas infrastructure to integrate a higher share of hydrogen and renewable gases.
- ✓ The **Net Zero Industry Act** provides a framework of measures to boost the manufacturing capacity of clean energy technologies. To scale up production, technologies falling under the scope of the regulation shall be subject to faster permit-granting processes as well as other benefits, such as state aid. Under the current proposal electrolysers and fuel cells are included. The Net Zero Industry Act can thus lead to increased implementation in projects related to renewable hydrogen.
- ✓ The EU Commission implemented the **European Hydrogen Bank** (EHB) as an instrument to foster and support investments in hydrogen. The purpose of the EHB is to bridge the investment gap in addressing the financial challenges the hydrogen market is currently under. Through financing and funding, this initiative shall accelerate investments and production projects.
- ✓ In promoting technology development and deployment of a safe and sustainable hydrogen value chain, the **Clean Hydrogen Partnership** contributes to the EU Green Deal and Hydrogen Strategy. The Partnership is a public-private partnership, which supports research and innovation in the field of hydrogen technologies. The Undertaking is funded through the EU Horizon Europe programme and private members.
- ✓ The **European Hydrogen Academy** contributes to the hydrogen market through building a skilled workforce along the hydrogen value chain. It established an alliance of universities and institutions, which can help in building a skilled workforce with training and necessary education materials.
- ✓ The Council adopted and renewed[154] the **emergency regulation laying down a framework to speed up the permit-granting process for renewable energy projects**. The regulation shall contribute to a secure and less volatile EU energy

[153] https://ec.europa.eu/commission/presscorner/detail/en/ip_23_6085
[154] https://energy.ec.europa.eu/news/commission-prolongs-energy-emergency-measures-12-months-2023-11-28_en

market. Furthermore, it is a measure for a rapid increase in renewable energy production.

- ✓ There is an EU regulation for the development of the market for CO_2 transport and storage under discussion[155].
- ✓ The **CCS Directive** sets out requirements for the selection of CO_2 storage sites and requires operators to prove long-term storage.
- ✓ Further Financing and Funding programmes, including IPCEI, Horizon Europe, InvestEU, LIFE programme and European Regional Development Fund.

3.3.2. Recommendations to address the technical barriers

3.3.2.1. Technological development

Recommendation 1: Further R&D on technical challenges
Addressee: European Commission and Member States
Related policies & measures: Clean Hydrogen Partnership, Horizon Europe, other R&D programs
Expected impacts: 2040

In order to profit from the respective benefits of the different technologies (SOEC - integrating industrial waste heat, improved electrical efficiency, reversable operation; and AEM - higher flexibility, no use of noble materials), research and development activities and product development activities need to be further supported to enable large demonstration projects at commercial scale.[156] Also the more market ready PEM and alkaline electrolysers can still profit from additional research and development to accompany their commercialisation.

Maritime transportation of hydrogen should be established in parallel with production facilities. For the different maritime supply chains for hydrogen or its derivatives, the TRL needs to be increased for those process steps that are not yet at a commercial level:[157]

- Liquid Hydrogen (LH_2): maritime transport, scale-up of liquification
- Synthetic LNG: CO_2 transportation, CO_2 sourcing
- Ammonia (NH_3): NH_3 cracking; safety issues
- Liquid Organic Hydrogen Carriers (LOHC): hydration and dehydration steps.

Recommendation 2: Consider water scarcity issues
Addressee: European Commission and Member States
Related policies & measures: Industrial Emissions Directive, Clean Hydrogen Partnership, Horizon Europe
Expected impacts: 2030

155 https://op.europa.eu/en/publication-detail/-/publication/bb3264da-f2ce-11ed-a05c-01aa75ed71a1/language-en?WT_mc_id=Searchresult&WT_ria_c=37085&WT_ria_f=3608&WT_ria_ev=search&WT_URL=https%3A//energy.ec.europa.eu/
156 https://www.clean-hydrogen.europa.eu/system/files/2022-02/Clean%20Hydrogen%20JU%20SRIA%20-%20approved%20by%20GB%20-%20clean%20for%20publication%20%28ID%2013246486%29.pdf
157 DVGW (2023) Kurzstudie zu Transportoptionen von Wasserstoff

To mitigate increasing water scarcity in hydrogen production areas, it is proposed in literature to pay more attention to this issue in the future by investigating the impacts of hydrogen production on water use and local availability of water.[158] Water scarcity for industrial applications is to be addressed in the Industrial Emissions Directive (IED),[159] this requires a differentiate approach in comparison to hydrogen production.

Recommendation 3: Address upstream methane emissions.
Addressee: European Commission and Member States
Related policies & measures: CCS Directive, Methane Emissions regulation, Horizon Europe
Expected impacts: 2030/2040

To reach a level-playing field between differently sourced CH_4 and to address public opposition upstream CH_4 emissions need to be addressed through strict requirements on life-cycle emissions in the GHG methodology, for both domestically sourced methane and especially for imported methane, if used for hydrogen production. See also a detailed discussion in section 3.5.2 and Annex 6.5. In fact, the council and parliament have very recently proposed rules to tackle the issue.[160]

On the long run also hydrogen upstream emissions could become an issue and research should be funded to further investigate the issue.[161]

3.3.2.2. Hydrogen Infrastructure and storage

Recommendation 4: Share risks for infrastructure build-out through regulated markets and appropriate financing and funding schemes also considering energy system integration aspects
Addressee: European Commission and Member States
Related policies & measures: Hydrogen and Gas Market Decarbonisation Package, Electricity Market Design
Expected impacts: 2030

Hydrogen infrastructure build-out has been mentioned as key across all stakeholder consultation. Hydrogen, methane gases and electricity systems should be planned in co-operation of the respective system operators already at an early stage.[162] The coordinating role is now foreseen for ENNOH in the Gas and Hydrogen Package.[163]

Stakeholders suggest applying smaller bidding zones (e.g. regional capacity zones) and locational pricing for renewable hydrogen production, in order to create market incentives for correct positioning of the electrolysers and to create the required revenue from the provision of flexibility services. At the very least however TSOs should provide transparency on where electrolysers could be located ideally to have a maximum grid-serving functionality.

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[158] Hu et al. (2020) A Review of Technical Advances, Barriers, and Solutions in the Power to Hydrogen Roadmap
[159] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022PC0156R%2802%29&qid=1651130627889
[160] https://www.consilium.europa.eu/en/press/press-releases/2023/11/15/climate-action-council-and-parliament-reach-deal-on-new-rules-to-cut-methane-emissions-in-the-energy-sector/
[161] https://acp.copernicus.org/articles/22/9349/2022/
[162] IRENA (2023) Innovation Landscape for Smart Electrification
[163] https://observcommon rules the internal market in renewable and natural gases and hydrogentory.clean-hydrogen.europa.eu/media/news/hydrogen-and-decarbonised-gas-package-agreement-marks-milestone-european-energy-policy

The bigger issue of optimal location of electrolysers remains a topic of high controversy and depends on many parameters.[164] In the case of energy system integration and the provision of flexibility services, electrolysers should be located at nodal points of the energy grid[165], also directly affecting the ability to create additional revenue through the balancing and other flexibility markets (potentially affecting system costs and thus end-consumer prices for both electricity and hydrogen). However, several stakeholders also emphasise the need for co-locating electrolysers near the demand centres, to avoid costly transport of hydrogen and e.g. enable the use of waste heat from the electrolysers. And in areas with weaker electricity grids or very high potentials for renewable energy production in Europe co-locating at the renewable energy production site may significantly reduce costs for grid expansion. To find the overall optimised location integrated planning is of highest importance and should consider all three aspects.

A hydrogen pipeline system is often mentioned as a solution to link supply with demand centres. Both new and repurposed hydrogen pipelines will be needed. Repurposing existing natural gas pipelines can cut investment costs by 50-80% and result in shorter lead times compared to new pipelines[166] and is a solution that is often mentioned in literature. These cost savings could lead to lower transmission tariffs and improve the competitiveness of clean hydrogen. Based on the ambitious targets set by European countries, the hydrogen network development needs to be accelerated.[167] While some stakeholders suggest requiring production projects to be planned together with the required infrastructure this may lead to further increasing costs, thus risk-sharing is best expanded to authorities via appropriate financing and funding schemes as recently announced for Germany[168] and also implemented in Belgium or the Netherlands. Only sufficiently backed political will and regulated tariffs allow to build-out infrastructure and share the risks adequately across all involved stakeholders.

Recommendation 5: Support Hydrogen storage development through geological surveys, additional revenue streams and adjusted transmission fees to storage operators.
Addressee: European Commission and Member States
Related policies & measures: Clean Hydrogen Partnership, Hydrogen and Gas Market Decarbonisation Package, Electricity Market Design
Expected impacts: 2030/2040

The further development of hydrogen storage in salt caverns depends on additional geological, engineering and techno-economic evaluations.[169] Some of the needed research includes: conducting geological surveys while implementing cavern leaching methods, conducting periodic surveys to monitor changes within the caverns during their operation, and performing a comprehensive characterisation of the site storage with the assistance of digital modelling development.[170] Several hydrogen storage projects are being developed, such as the Delta Green project and the HyPSTER project in France, and the Green Hydrogen Hub Project in Denmark that expects to have a hydrogen storage capacity of 400 GWh by 2030.[171] Further

[164] https://netztransparenz.tennet.eu/fileadmin/user_upload/The_Electricity_Market/German_Market/Grid_customers/Kundenforum_2021/2_Kundenforum_30_11_21_Vortrag_Quo-vadis-Elektrolyse.pdf
[165] https://green-planet-energy.de/presse/artikel/neue-studie-zeigt-vorteile-dezentraler-elektrolyseure
[166] IEA (2022) Northwest European Hydrogen Monitor
[167] IEA (2022) Northwest European Hydrogen Monitor
[168] https://www.offshore-energy.biz/germany-aims-to-set-up-hydrogen-core-network-by-2032/
[169] Williams et al. (2022) Does the United Kingdom have sufficient geological storage capacity to support a hydrogen economy? Estimating the salt cavern storage potential of bedded halite formations
[170] Tarkowski (2019) Underground hydrogen storage: Characteristics and prospects
Author links open overlay panel
[171] Green Hydrogen Hub (2023) Accelerate the integration of renewables

large-scale demonstration projects for hydrogen storage need to be supported in order to gain further geologic and techno-economic experience with geological hydrogen storage.[172]

Additionally, some stakeholders emphasise the need for transmission tariff design considering the transmission activity in a future hydrogen grid to make viable business models (e.g. no double charging) and to consider creating additional revenue streams on non-regulated markets.

Recommendation 6: Better understand the implications of CCU/S through scientific evaluations, and if needed, consider a CO_2 infrastructure build-out.
Addressee: European Commission and Member States
Related policies & measures: CCS Directive, Methane Emissions Directive, Hydrogen and Gas Market Decarbonisation Package, Net-Zero Industry Act, Clean Hydrogen Partnership
Expected impacts: 2040

When asked for recommendations for the uptake of hydrogen, many stakeholders mentioned the co-development of a sufficient CO_2 infrastructure and CC(U)S regulatory framework. Regarding opportunities for CCS the NZIA proposal includes CO_2 injection capacities in Chapter III. This is in large parts driven by the understanding that low-carbon hydrogen from fossil fuels with CCS should also be enabled to play a role in reaching the EU ambition to reach 10 million tonnes domestically produced hydrogen. In face of some sectors relying on circularity of carbon (e.g. chemical sector), more use cases of feasible CCU/S applications are needed. It is advisable to evaluate the consequences of CCU/S on the basis of scientific evaluations. Therefore, the European Commission should consider funding appropriate research projects, in order to enable a science-based decision making process in this controversially discussed topic.

3.3.3. Recommendations to address the economic and financial barriers

3.3.3.1. Cost gap

Recommendation 7: Remove fossil fuel subsidies
Addressee: European Commission and Member States
Related policies & measures: European Trading System, Energy Taxation Directive, Competition Policy
Expected impacts: 2030

In order to decrease and remove the cost gap, literature sources mention a variety of measures and levers. One of these measures is increasing the price of fossil fuel alternatives by the removal of existing fossil fuel subsidies. Beyond removing subsidies, carbon pricing can also strongly influence the uptake of both renewable and low-carbon hydrogen. For example the IEA predicts that under the so-called Announced Pledges Scenario (APS), an increase of the carbon price to USD 135/t_{CO2} (not too far from today's ~80€/t_{CO2}) could lead to hydrogen from renewables (USD 2.5-3.5/kg_{H2}) and hydrogen from natural gas with CCS (USD 2.3-2.7/kg_{H2}) both being cheaper by 2030 than hydrogen from natural gas without CCS (estimated at around USD 3/kg_{H2}).[173] It is thus advisable to also include discussions around

[172] IRENA (2023) Innovation Landscape for Smart Electrification
[173] IEA (2022) Northwest European Hydrogen Monitor

carbon pricing, upon further development of energy system integration and specifically the uptake of hydrogen therein.

Recommendation 8: Further develop existing subsidy concepts and sufficiently fund the respective financial pots to achieve the 2030 hydrogen targets
Addressee: European Commission and Member States
Related policies & measures: EU Taxonomy, European Hydrogen Bank, Innovation Fund, Connecting Europe Facility, IPCEIs and (other funding schemes)
Expected impacts: 2030

Base assumption on subsidy design should be a level-playing field across all actors from renewable energies.[174] However, eligibility and numbers are of the highest importance. E.g. the USA, through the Inflation Reduction Act of 2022 offers subsidies of up to USD 3/kgH_2, which could bring the LCOH of renewable hydrogen production below 2 USD/kg$_{H2}$ and thus make it competitive.[175] In response, the European Commission launched the European Hydrogen Bank that is designed to subsidise both EU production as well as the imports of renewable hydrogen and in the provisionally agreed electricity market design reform two-way contracts for difference are foreseen[176]. The German government, in turn, has launched the H_2Global double-sided auction programme as a contracts-for-difference (CfD) scheme (explained in further detail in the section entitled “financing and funding” below). Further hydrogen-focused subsidy programs could further decrease or eliminate the cost gap in the EU.

The EU and Member States could consider improvements to the current/planned support to hydrogen production by:

a) Use of carbon contracts-for-difference set against a benchmark fuel price per industry: Funds from the CCfDs are paid to RNFBO producers and when combined with the electrolyser rebates (next paragraph) the CCfD funds would be sized to correctly fund the more expensive hydrogen from renewable sources with prices above those of fossil fuel costs + ETS allowance price, as it also would take into account the targeted electrolyser capex cost (electrolyser cost post-rebate). The total support to the RNFBO producer should be capped on a per kg basis to prevent double subsidy. The combined effect would achieve a targeted hydrogen cost per kg against a benchmark fossil fuel price, simultaneously incentivise electrolyser manufacturing capacity and send a strong signal to industries that need to invest in their own infrastructure to be technology ready for RFNBO.
b) Electrolyser rebates (CAPEX support) could be used to drive down costs and could be most effective by directly subsidising project owners in hard-to-abate carbon intensive industries. The electrolyser rebates could enable more electrolyser demand and bring forward manufacturing capacity. The rebate amount should be sized to reach a target electrolyser cost and therefore a targeted levelised cost of hydrogen. The rebates could

[174] BEE (2020) Sector integration statement
[175] IRENA (2023) Innovation Landscape for Smart Electrification
[176] https://www.consilium.europa.eu/en/press/press-releases/2023/12/14/reform-of-electricity-market-design-council-and-parliament-reach-deal/?utm_source=dsms-auto&utm_medium=email&utm_campaign=Reform+of+electricity+market+design:+Council+and+Parliame

be reduced each year as the production capacity is scaled and the electrolyser costs decrease.

Stakeholders further emphasise that currently, some major subsidies e.g. EEAG and Innovation fund (limited by 60% funding rate of IF) are not foreseen to be cumulative.[177] Especially large-scale projects such as IPCEIs should be able to collect further support.

Recommendation 9: Consider expanding funding opportunities to low-carbon H_2 and provide clarity on conditions.
Addressee: European Commission
Related policies & measures: European Hydrogen Bank, EU Taxonomy
Expected impacts: 2030

Low-carbon hydrogen is currently excluded from funding opportunities such as the European Hydrogen Bank, due to the EHB's intrinsic requirement to be REDII-conform for funding. It should be considered whether low-carbon hydrogen should also receive funding, especially with regards to carbon negative technologies, which will be needed on the long-term. This is a controversial topic in literature and among stakeholders. Further research and political debate are needed to resolve this controversy.

Recommendation 10: Enable additional revenue streams for electrolysers and consider electricity network tariff exemptions.
Addressee: European Commission and Member States
Related policies & measures: Electricity Market Design, Network Codes
Expected impacts: 2030

By implementing more demonstration projects and enacting supportive regulations, electrolysers have the potential to reduce production costs in the future. They can achieve this by leveraging additional revenue streams, such as offering grid-balancing services (e.g., restoration reserves or peak shaving) and other flexibility services (e.g., capacity firming or mitigating grid congestion). The ongoing Demo4Grid project in Austria is showcasing the effectiveness of these approaches.[178]

In order to provide flexibility, new, simplified market designs might be required that allow electrolysers to participate in the system services market or that allow financial rewards for hydrogen producers for providing grid balancing services.[179] Market design in general has been addressed in the electricity market reform.[180] Further guidance has been prepared on a future Network Code on demand response,[181] defining flexibility contributions and rules on aggregation, energy storage and demand curtailment and should potentially directly involve hydrogen stakeholders (i.e. electrolysis operators).

Selling both by-product oxygen and low-temperature excess heat for district heating like in the HySynergy project[182] would provide further revenue streams to close the cost gap. Especially

[177] https://climate.ec.europa.eu/system/files/2020-09/innovation_fund_cumulation_public_en.pdf
[178] Sunfire (2021) Demo4Grid Project Partners Successfully Install a 3.2 MW Pressurized Alkaline Electrolyzer
[179] IRENA (2021) Green Hydrogen Supply: A Guide to Policy Making
[180] https://www.consilium.europa.eu/en/press/press-releases/2023/12/14/reform-of-electricity-market-design-council-and-parliament-reach-deal/?utm_source=dsms-auto&utm_medium=email&utm_campaign=Reform+of+electricity+market+design:+Council+and+Parliame
[181] https://consultations.entsoe.eu/markets/public-consultation-networkcode-demand-response/supporting_documents/Network%20Code%20Demand%20Response%20v1%20draft%20proposal.pdf
[182] FuelCellsWorks (2022) HySynergy announced as Lighthouse Project

regarding excess heat the third-party access to district heating is of high importance (see discussions in chapter 4).

A large lever for change would be to reduce or eliminate the tariffs that apply to electricity (largest contributor to OPEX of hydrogen production) that is consumed for hydrogen production, if the electrolyser is positioned or operated in a way not further congesting the grid. This could in principle be implemented through e.g. nodal pricing.[183]

Further levers that also affect the cost gap are mentioned in literature, such as R&D into electrolyser technology,[184] an increased electrolyser production capacity[185] or further governmental subsidy programmes will be discussed in the sections below related to other categories of barriers.

3.3.3.2. Financing and funding

Several key mitigants are discussed in literature to overcome current bankability issues. Grants and loans can be given out to level the playing field with fossil alternatives. Many of these subsidy types were mentioned in the previous recommendation section on closing the cost gap.

Recommendation 11: Consider defining binding targets for low-carbon hydrogen and specific to industry sectors.
Addressee: European Commission
Related policies & measures: EU Taxonomy, Amended Renewable Energy Directive, ReFuelEU Aviation, FuelEU Maritime
Expected impacts: 2030

Besides subsidies, mandatory stipulations such as quotas (e.g. ReFuelEU Aviation, FuelEU Maritime, REDII amendments quotas for hydrogen use in e.g. industry and transport) are also effective at integrating low-carbon and renewable hydrogen or exclusively renewable hydrogen and guaranteeing a sufficient market size. In order to scale-up the production and integration of renewable and low-carbon hydrogen, an effective framework of support mechanisms, including subsidy schemes and quotas, is needed.[186]

Despite the wish for differentiation and specific targets where possible, for the long-term perspective also high-level targets are considered helpful. Similar to the 2030 targets, it is suggested to set the target for 2040 ambitious enough. With publication of this report the Commission has recommended to achieve 90% greenhouse gas emissions reduction by 2040, and in the corresponding impact assessment hydrogen's role as key technology is emphasised[187].

While RFNBOs have set quotas, in e.g. the maritime, road transport or air transport sector, low-carbon hydrogen (fossil+ CCS and nuclear-based) remains unmentioned. The Commission could also consider setting demand targets for low-carbon hydrogen, which could help to develop these types of projects and reach bankability but would need evaluation against the overall strategy of the EU Commission to prioritise renewable H_2. Hence further detailed analyses will be needed here.

[183] Vp, Scjeodt et al (2022) Electricity Tariff Engineering for Integrated Energy Systems
[184] CMS (2021) Hydrogen law, regulations & strategy
[185] IRENA (2023) Innovation Landscape for Smart Electrification
[186] IEA (2022) Northwest European Hydrogen Monitor
[187] https://climate.ec.europa.eu/document/download/768bc81f-5f48-48e3-b4d4-e02ba09faca1_en

This would also echo action 20 of the ESI Strategy that sets out to “consider additional measures to support renewable and low-carbon fuels, possibly through minimum shares or quotas in specific end-use sectors through the revision of the Renewable Energy Directive and building on its sectoral targets […]".

3.3.3.3. Availability of hydrogen towards 2030

To address the potential shortage of hydrogen, several recommendations have been put forward, including the expansion of infrastructure (detailed description provided below), enhancing hydrogen trade policies (as outlined in the regulatory recommendations) and implementing additional measures such as scaling up electrolyser manufacturing. Furthermore, there is a need to accelerate the ambitious development of wind and solar capacity to significantly increase the European supply of hydrogen. These actions will contribute to mitigating the potential hydrogen scarcity and ensuring a robust and sustainable hydrogen ecosystem.[188] Which is also addressed by the Electrolyser Partnership (goal of 25 GW per year in 2025) and in the Net-Zero Industry Act, which defines that electrolysers and fuel cells are strategic technologies for Europe’s technological sovereignty and for these technologies, a benchmark of 40% of European manufacturing (for the deployment needs in 2030) is set. See also detailed discussion in chapter 3.4.1.

3.3.4. Recommendations to address the legislative and regulatory barriers

3.3.4.1. Regulatory

Recommendation 12: Further improve gas market through transparency and protection of consumer interests.
Addressee: European Commission and Member States
Related policies & measures: Hydrogen and Gas Market Decarbonisation Package
Expected impacts: 2040

A well-defined organisational framework for a regulatory body to oversee market operations is to be maintained. Increased transparency should be provided to enhance the efficiency of network investments (some survey stakeholders suggest providing transparency through reporting requirements for “integration levels [of hydrogen] in fuels at members state level”). Finally, unbundling measures could be implemented within the hydrogen value chain (as market players grow) to prevent a single market participant from exerting excessive control over significant segments of the supply chain and attaining a dominant position.[189] (as for example in the district heating market). Major steps towards these goals are indeed foreseen in the Gas and Hydrogen package[190]. Transparency and consumer protection should however also remain the guiding principles of any further policies impacting the uptake of hydrogen, e.g. CO_2 related markets.

[188] European Clean Hydrogen Alliance (2021) Alliance Roundtables on Barriers and Mitigation Measures
[189] ACER (2021) When and How to Regulate Hydrogen Networks
[190] https://observcommon rules the internal market in renewable and natural gases and hydrogentory.clean-hydrogen.europa.eu/media/news/hydrogen-and-decarbonised-gas-package-agreement-marks-milestone-european-energy-policy

Recommendation 13: Adopt rapidly DAs on GHG methodology for low-carbon hydrogen.
Addressee: European Commission
Related policies & measures: Hydrogen and Gas Market Decarbonisation Package
Expected impacts: 2030

To attain the Final Investment Decision (FID) for low-carbon hydrogen projects, a well-defined legal and regulatory framework for Carbon Capture and geological Storage (CCS) needs to be developed quickly.

Since low-carbon hydrogen is especially discussed to be of higher relevance towards the 2030s targets, it is of highest importance to reach fast clarity on the GHG methodology for low-carbon hydrogen. This will help fostering domestic low-carbon hydrogen production.

Recommendation 14: Strive for harmonisation where possible
Addressee: European Commission and Member States
Related policies & measures: n.a.
Expected impacts: 2040

Moreover, the global and EU regulatory landscape needs to be further harmonised, while acknowledging the need for accounting for local specificities, it is crucial to harmonise national regulations to facilitate the development of clean hydrogen trade in Europe.[191] Also, to enhance harmonisation, many stakeholders suggest prioritising the fast and consistent *implementation* of the EU regulatory framework (instead of focusing on *additional* policies).

A unified regulatory framework governing the international transmission of hydrogen through maritime routes and pipelines should be developed. This harmonisation would increase international hydrogen trade.[192] It can be expected that issues around intra-EU coordination on cross-border trading will be addressed by the newly created ENNOH as defined in the provisionally agreed Hydrogen and Decarbonised Gas Market package.

Efforts should be made toward a globally accepted framework for carbon emission pricing, which has yet to be established. This framework would facilitate the development of a hydrogen market, improve international hydrogen trade, and contribute to the economic viability of hydrogen in several applications.[193]

Recommendation 15: Develop EU-level regulatory sandboxes for hydrogen.
Addressee: European Commission and Member States
Related policies & measures: Net-Zero Industry Act, Hydrogen and Gas Market Decarbonisation Package, Amended Renewable Energy Directive
Expected impacts: 2030

Regulatory sandboxes, as also foreseen in the NZIA,[194] are critical for a new sector like renewable hydrogen. They allow innovation to be tested in real projects and under regulatory oversight, allowing assessments of potential regulatory frameworks and the resulting effects on business models and operations. Some stakeholders emphasise the need for these sandboxes in the context of infrastructure build-out; they should cover technical and

[191] IEA (2022) Global Hydrogen Review
[192] Gordon et al. (2023) Socio-technical barriers to domestic hydrogen futures
[193] Gordon et al. (2023) Socio-technical barriers to domestic hydrogen futures
[194] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52023PC0161

coordination aspects to enable "learning by doing". Member States have so far mainly focused on regulatory sandboxes on electricity,[195] and legislation and guidance at the EU level can help address this issue. Some concrete hydrogen related examples are mentioned in the SWD(2023) 277/2 of 29 August 2023.[196]

3.3.4.2. Definition and Certification of Hydrogen

Recommendation 16: Consider (further) differentiation of low-carbon hydrogen into at least fossil + CCS and electrolytic low-carbon hydrogen.
Addressee: European Commission
Related policies & measures: Hydrogen and Gas Market Decarbonisation Package, EU Taxonomy
Expected impacts: 2040

The current and forthcoming regulatory framework primarily defines low-carbon hydrogen based on the CO_2 reduction threshold and the energy content derived from non-renewable sources. However, when considering energy system integration, it is important to acknowledge that the impact on the electricity grid can vary between the two types of low-carbon hydrogen: electrolytic low-carbon hydrogen and fossil fuel-derived hydrogen coupled with carbon capture and storage (CCS). Further understanding the different implications on system integration could therefore help to better define the strategic targets in an advancing energy system integration strategy.

Recommendation 17: Address global competition and hold further Q&A sessions on applicability of EU requirements in non-EU countries.
Addressee: European Commission
Related policies & measures: Amended Renewable Energy Directive, Carbon Border Adjustment Mechanism
Expected impacts: 2030

There is an increasing global demand and resulting competition for renewable hydrogen imports, particularly with Asian countries, where different regulatory standards apply, and substantial subsidies are offered. Stakeholders, from diverse backgrounds (especially hydrogen producers and distributors), emphasise the need for a level-playing field for hydrogen sourced from domestic producers and imported hydrogen, for example requiring the consideration of transportation emissions in life-cycle assessments. In the case of renewable hydrogen, for example, application of some of the DA's requirements require a level of interpretation that may still lead to unbalance between EU and non-EU hydrogen producers. Further, CBAM and RED apply different methodologies for determination of the respective GHG emissions.

Remaining unclarities should best be addressed through further Q&A sessions as recently conducted.[197]

Recommendation 18: Expand on the concept of PPAs (long-term) to enable long-term procurement of electricity and reduce associated planning risks of hydrogen projects.
Addressee: European Commission

[195] Trinomics and Fraunhofer ISI (2023) Study on Regulatory Sandboxes in the Energy Sector
[196] swd_2023_277_f1.pdf (europa.eu)
[197] https://energy.ec.europa.eu/system/files/2023-07/2023_07_26_Document_Certification_questions.pdf

Related policies & measures: Electricity Market Design, Hydrogen and Gas Market Decarbonisation Package
Expected impacts: 2030

To ensure that electrolysers produce hydrogen in a sustainable manner, renewable power purchase agreements (PPAs) can be used. The utilisation of renewable PPAs with close temporal matching presents a motivation to increase renewable power supply and produce hydrogen exclusively during periods of high renewable generation. This approach reduces emissions without influencing electricity prices.[198] This means on a more general level that hydrogen production needs to reflect the availability of renewable electricity. Due to the complex interactions of PPAs also with competition law the Commission should support research to explore legal barriers further and lead the market towards reliable PPAs.[199] How to handle PPAs is streamlined in the recent Parliament and Council agreement[200] on the Electricity Market Reform, leaving large freedom with the MSs.

3.3.4.3. Permitting

Recommendation 19: Further accelerate permitting processes especially through increasing hydrogen competence in NRAs and digitalisation.
Addressee: European Commission and Member States
Related policies & measures: Emergency Regulation on Permit-Granting, European Hydrogen Academy, Net Zero Industry Act
Expected impacts: 2030

The objective put forward by the stakeholders is to keep simplifying the permitting processes, allowing stakeholders to construct electrolysers (being already addressed in the upcoming NZIA) and hydrogen infrastructure more efficiently and cost-effectively. Simultaneously, these measures will minimise project uncertainties and facilitate project management. Specific regulatory hydrogen frameworks should be implemented into national law across all Member States in order to provide the basis for an appropriate, standardised permitting framework. To clarify the appropriate permitting processes, national hydrogen permitting manuals could be adopted as for example the case for Portugal[201]. Furthermore, Member States should ensure that the right kinds of skills and resources are provided to the permitting authorities to deal with all requests.[202] This could for example be supported at EU level by the European Hydrogen Academy suggested below, this should be further backed by IT tools/digitalisation.

Additionally, fast-track permitting procedures[203] and "one-stop permitting shops" are strongly recommended.[204] These one-stop shops have already been implemented in Portugal (and e.g. South Korea), where they are used for offshore wind parks, and by

[198] Parkes (2022) Hourly electricity matching is the only reliable way to reduce emissions from green hydrogen: study
[199] IRENA (2023) Innovation Landscape for Smart Electrification
[200] https://www.consilium.europa.eu/en/press/press-releases/2023/12/14/reform-of-electricity-market-design-council-and-parliament-reach-deal/
[201] IAPMEI (2021). Guia do Promotor "Legislação e Regulação para a Economia do Hidrogénio
[202] European Clean Hydrogen Alliance (2021) Alliance Roundtables on Barriers and Mitigation Measures
[203] European Clean Hydrogen Alliance (2021) Alliance Roundtables on Barriers and Mitigation Measures
[204] IRENA (2023) Innovation Landscape for Smart Electrification

the regional Chinese authorities in Shanghai, Shanxi and Inner Mongolia in order to open a “green channel” for the approval of hydrogen energy projects.[205,206]

3.3.5. Recommendations to address the societal barriers

3.3.5.1. Skilled workforce

Recommendation 20: Expand on concepts such as the European Hydrogen Academy.
Addressee: European Commission
Related policies & measures: European Hydrogen Academy
Expected impacts: 2030

Skilled workforce is given more emphasis (by at least six of the stakeholders) over the acceptance issue (mentioned by only two stakeholders). Several roundtables have put emphasis on tackling the challenge of upskilling and reskilling the workforce in line with hydrogen developments to avoid shortages of occupational profiles, which could quickly become a bottleneck. Member states are therefore encouraged to provide the right kinds of trainings. This could be supported via different national or EU support schemes, such as the upcoming EU hydrogen Academy[207], in order to avoid the lack of availability of a skilled workforce being a barrier to the adoption and integration of hydrogen.[208] Also the NZIA explicitly addresses the issue of capacity building in Chapter V[209].

3.3.5.2. Societal acceptance

Recommendation 21: Transparent testing of safety of hydrogen and derivatives and CO_2-related infrastructure.
Addressee: European Commission and Member States
Related policies & measures: Horizon Europe, Union certification framework for carbon removals
Expected impacts: 2030/2040

For low-carbon hydrogen (from CCS), the safe capture and geological storage of carbon dioxide should be demonstrated to reduce public opposition and project delays.[210] Important steps towards reaching a publicly acceptable level of confidence have been proposed as part of the Regulation of the European Parliament and the Council establishing a Union certification framework for carbon removals[211]. This proposal aims at establishing an independent certification for carbon removals.

In order to raise user confidence in the safety of hydrogen, new generations of hydrogen leakage detectors should be developed. Possible solutions would be to base the technologies on acoustic, laser scanning, optical fibre sensors, infrared, odorised molecules or strain gauge-based technologies. Also, existing detection technologies should be improved

[205] IRENA (2023) Innovation Landscape for Smart Electrification
[206] Shanghai Municipal Development & Reform Commission (2022) Notice on Printing and Distributing the Medium and Long-Term Plan for the Development of Hydrogen Energy Industry in Shanghai (2022-2035)
[207] European Commission (2023) European Hydrogen Academy
[208] European Clean Hydrogen Alliance (2021) Alliance Roundtables on Barriers and Mitigation Measures
[209] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52023PC0161
[210] Petrounias et al. (2022) Current CO2 Capture and Storage Trends in Europe in a View of Social Knowledge and Acceptance. A short review
[211] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022PC0672

regarding measuring range, tolerance, temperature and pressure ranges and response times.[212] Further, derivatives need to be carefully assessed with regards to their toxic nature.

Recommendation 22: Keep emphasising the opportunities for a just transition by hydrogen technologies.
Addressee: European Commission and Member States
Related policies & measures: Just Transition Fund, Recovery and resilience Facility, European Regional Development fund
Expected impacts: 2030

To counter people's fear of not benefiting from a switch to hydrogen, there needs to be an ongoing discussion about what a "just transition" could look like. This transition would involve an analysis of the societal implications of the energy transition with a focus on the competitiveness of the economy, geographies, and jobs.[213] Here the impacts of energy imports to, for example, further fund existing industries, and possibly new opportunities in locations of "old" industries, need to be better understood. On any real wealth risks already identified, the EU offers several opportunities to connect hydrogen-related projects with e.g. the Just Transition fund, Recovery and resilience facility and generally the European Regional Development fund. So, hydrogen in general is particularly well suited in its potential to keep value creation in Europe.

3.4. Additional aspects analysed concerning the uptake of hydrogen and other low-carbon gases

3.4.1. Feasibility and costs of meeting EU ambition in hydrogen production capacity exclusively based on renewable sources

The REPowerEU plan targets production of 10 million tonnes of renewable hydrogen per year.

Issued in 2022, the REPowerEU plan targets an acceleration of the clean energy transition and a more resilient energy system in the EU.[214] It builds on the previously issued Fit for 55 package of proposals and addresses the four areas of saving energy, rapidly substituting fossil fuels, diversifying energy sources, and smartly combining investments and reforms. One key aspect is the shift away from (Russian) natural gas, coal, and oil, towards fossil-free hydrogen.[215]

The REPowerEU plan clearly focuses on "renewable hydrogen", with the explicit goal to achieve 10 million tonnes (Mtons) of annual domestic renewable hydrogen production by 2030, accompanied by another 10 million tonnes annually of renewable hydrogen imports into the EU.

Reaching the REPowerEU goal with renewable hydrogen faces multiple challenges.

[212] IRENA (2023) Innovation Landscape for Smart Electrification
[213] Renewable and Low-Carbon Fuels Value Chain Industrial (RCLF) alliance at EUSEW2023. Gearing up for the rollout of renewable and low carbon fuels!
[214] European Commission (2022) COM/2022/230 final
[215] European Commission (2022) Commission staff working document. Implementing the Repower EU action plan: Investment needs, hydrogen accelerator and achieving the bio-methane targets

This section aims at investigating the feasibility and costs of achieving a domestic production of 10 Mtons of hydrogen purely from renewable electricity. The section provides information on the required renewable electricity, electrolysis project development, electrolyser capacity, and systems integration aspects. Besides, it sheds light on the expected costs. Finally, it discusses the potential advantages and disadvantages of tapping into "low-carbon hydrogen", such as electrolytic hydrogen from nuclear power, hydrogen from fossil sources with carbon capture and storage, and recycled carbon fuel hydrogen, in order to reach the goal.

The main challenge is the scale up of renewable electricity generation.

Firstly, scaling up the domestic production of hydrogen to 10 Mtons annually requires further additional renewable electricity production of approximately 500-600 TWh per year.[216] The total investment costs are estimated to be 335-471 billion Euros, with 200-300 billion Euros required for additional renewable electricity generation.[217] Assuming that a large share of this electricity will be traded in the form of PPAs, the recent Reform of the Electricity Market Design foresees that an additional 220 TWh – 500 TWh per year of renewable PPAs are needed by 2030.[218]

In the course of the REPowerEU planning, additional demand was modelled to see how demand will play into the overall net installed power capacity in 2030. The resulting total installed capacity is 592 GW for solar and 510 GW for wind.[219] In this scenario, hydrogen will make up a considerable share of total renewable electricity demand in the EU. The technical potential in the EU for renewable electricity, at over 10,000 TWh/year, exceeds the sum of future demand from other sectors and this additional demand for renewable hydrogen.[220] This holds true not only on EU level, but also at a regional level.

The vast majority of regions in the EU and UK (81%) exhibit more than enough renewable electricity generation potential to cover the total future local electricity demand plus the electricity demand for producing hydrogen to substitute all currently used grey hydrogen in that location.[221] All remaining regions could achieve this with some renewable electricity imports from neighbouring regions.[222] However, political action, including action at EU level, is needed to turn this potential into reality, as multiple stakeholders note in the survey. Nine out of 37 stakeholders explicitly refer to the issue of availability of sufficient renewable electricity. For example, one survey participant noted the feasibility of the REPowerEU goal: "This target will be very difficult to achieve due to the need to increase massively the renewable power production in Europe [...]". Consequently, stakeholders have called for an increase in the renewable electricity target to 45% or more by 2030.[223] Furthermore, streamlining the permitting process of renewable energy projects, as requested by multiple stakeholders, is already planned by the European Commission.[224] The need for new installations could be somewhat reduced by considering existing renewable electricity plants outside of any support schemes (such as fixed feed-in tariffs) as additional.[225] Moreover, the Delegated Acts under

[216] Compare e.g. A. Battaglini and A. Ceglarz (2023) The role of hydrogen in a future, lowcarbon, and secure European energy system - Discussion Paper
[217] European Commission (2022) Commission staff working document. Implementing the Repower EU action plan: Investment needs, hydrogen accelerator and achieving the bio-methane targets
[218] European Commission (2023) Reform of Electricity Market Design (Commission staff working document)
[219] International Energy Agency (2022) Is the European Union on track to meet its REPowerEU goals?
[220] G. Kakoulaki, et al. (2021) Green hydrogen in Europe – A regional assessment: Substituting existing production with electrolysis powered by renewables
[221] G. Kakoulaki, et al. (2021) Green hydrogen in Europe – A regional assessment: Substituting existing production with electrolysis powered by renewables
[222] G. Kakoulaki, et al. (2021) Green hydrogen in Europe – A regional assessment: Substituting existing production with electrolysis powered by renewables
[223] See also Hydrogen Europe (2022) Delivering REPowerEU through a strong European hydrogen industry.
[224] European Commission (2022) Commission staff working document. Implementing the Repower EU action plan: Investment needs, hydrogen accelerator and achieving the bio-methane targets
[225] Hydrogen Europe (2022) Delivering REPowerEU through a strong European hydrogen industry

the Renewable Energy Directive provide for a ”grandfathering clause” on additionality for projects commissioned before 2028 in order to avoid that early movers need to consider two very different periods of PPA contracts in their projects.

The second challenge is the scale up of renewable hydrogen project development.

Secondly, for the goal of 10 Mt of annual H_2 production, approximately 90-100 GW of electrolyser capacity are required in the EU. For comparison, at the end of 2022 there were close to 700 MW of electrolyser capacity installed globally.[226] Looking at official electrolysis project announcements in the European Union, made by project developers, over 4 GW are announced for 2024 already. Globally, for 2030, a total of almost 420 GW in projects had been announced already at the end of 2023. However, it must be noted that 46% of those announced projects are in an early stage and 48% are in the stage of feasibility study. Only 6% of announced projects are operating or have taken final investment decision.[227] Developers in the EU have announced projects with about 125 GW of capacity for 2030. Most of these projects are in an early stage or feasibility stage.

As publications and survey responses show, a crucial lever for the achievement will be improved project permitting. As one respondent notes: “Securing rapid development […] and permitting is essential […]”. Currently, obtaining permits for new hydrogen projects is complex and lengthy. The complexity is further increased for projects that include co-location of renewable energy plants. For example, one survey respondent states: “Such a huge development of renewables in Europe must be accompanied by the relevant administrative workforce to guarantee an efficient permitting process.” In total, when asked "What needs to be done to ensure it [i.e. the 2030 goal] can be achieved?”, six respondents out of 29 refer to permitting issues. This is mirrored by literature which implies that lengthy permitting processes can lead to higher costs and hamper investments in hydrogen projects.[228] [229] First countries are planning to improve the permitting process. For example, the German federal government has announced to introduce a “Hydrogen Acceleration Law” to adequately adjust and simplify the regulatory and legal framework for hydrogen project permitting.[230]

Academic research based on probabilistic technology diffusion models has shown that if the scaling up of electrolyser capacity happens at a similar speed as historical PV and wind production upscaling, this will most likely (99.8%) not suffice to reach 100 GW in 2030. Instead, with a probability of over 95%, the electrolyser capacity will be less than 70 GW in 2030. Furthermore, there is a high probability (over 75%) that less than 1% of final energy in the EU is covered by domestically produced renewable hydrogen in 2030. In order to reach a higher diffusion speed, emergency-like special political coordination, regulation and financial support are needed, similar to wartime industry programs. Under the assumption of such “unconventional growth”, the probability of reaching the 100 GW goal increases to 49%.[231]

The third challenge is the scale up of electrolyser manufacturing capacity.

Thirdly, the market upscaling of electrolyser manufacturing capacity is one of the critical bottlenecks for the mass production of renewable hydrogen.[232] In March 2022, the Commission supported the industry commitment to a tenfold increase of its electrolyser

[226] IEA (2023), Global Hydrogen Review 2023, IEA, Paris https://www.iea.org/reports/global-hydrogen-review-2023, License: CC BY 4.0
[227] IEA (2023), Global Hydrogen Review 2023, IEA, Paris https://www.iea.org/reports/global-hydrogen-review-2023, License: CC BY 4.0

[228] S. Benz (2023) Genehmigungsrecht für Elektrolyseure – Änderungen der planungsrechtlichen Grundlagen.
[229] IRENA (2023) Innovation landscape for smart electrification
[230] German National Ministry for Economy and Climate Action (2023), Update of the National Hydrogen Strategy (German).
[231] A. Odenweller et al. (2022) Probabilistic feasibility space of scaling up green hydrogen supply
[232] A. Odenweller et al. (2022) Probabilistic feasibility space of scaling up green hydrogen supply.

manufacturing capacity from 1.5 GW/year at the time[233] [234] to 17.5 GW/year in 2025.[235] As of May 2023, Europe's operational electrolyser manufacturing capacity stood at 3.11 GW/year, with additional 2.64 GW/year planned by the end of 2023. Looking ahead to 2025, ongoing projects were expected to raise the manufacturing capacity to 7.65 GW/year.[236] Significant amounts of manufacturing capacity will therefore be needed in addition to these ongoing projects. Very recent reports[237] show that globally and in the EU the nameplate manufacturing capacities now seem to exceed the current market demands, indeed sending positive signals regarding a potential insufficiency. A sign that the above discussed "unconventional growth" might be feasible[238] with regard to this industry goal, the European Commission has announced to set an "enabling regulatory framework", create financing options.[239,240] The surveyed stakeholders mention this aspect much less frequently than the availability of renewable electricity and the project development/ permitting issues. The two respondents who mention this aspect, do not seem to regard it as unfeasible ("If scale up of electrolysers is possible which should be managed by the manufactures now, it is possible."; "I think it would be more dependant [sic] on the manufacturing capacity of the equipment (electrolysis)". Comparing these few replies to the larger number of replies in the survey about the renewables' build-out it becomes evident that both survey and literature review imply that electrolyser manufacturing capacity is a much less critical bottleneck for the 2030 goals than the build-out of renewable electricity capacity. This is further supported by the fact that the European Commission addresses manufacturing capacities via the NZIA, including e.g. the implementation of one-stop-shops to accelerate permitting processes for net-zero technologies including electrolyser manufacturing.

The fourth challenge is the temporal and spatial integration of renewable hydrogen plants into the overall energy system.

Fourthly, the targeted renewable hydrogen production in the EU has interactions with the energy system. Here, the rules for renewable hydrogen foster feasibility, especially until Jan. 1st, 2030, as they rather promote a rapid uptake of renewable hydrogen by relaxing the required temporal correlation to monthly granularity, the spatial correlation to bidding zones, and provide some exceptions for the additionality rules.

Regarding the temporal integration with the energy system (often covered under the term "flexibility") the most important effect is that, if hydrogen must be produced from renewable sources, the electrolysers have to adapt to the volatility of the renewable energy source, i.e. absorb this volatility. This decreases volatility in the overall energy system, can reduce curtailment in renewable generation (depending on the location of the electrolyser – see geographic correlation) and increases the value of renewable electricity.[241,242,243,244] Moreover, this also fosters the use of hydrogen as long-term storage, because electrolysers have an incentive to be operated in times of availability of cheap renewable electricity. This effect

[233] Measured in terms of hydrogen output; 2.5 GW if measured in terms of electricity input and assuming an electrolyser efficiency of 70%
[234] European Clean Hydrogen Alliance (2022) European Electrolyser Summit Brussels, 5 May 2022 Joint Declaration
[235] European Commission (2022) Hydrogen: Commission supports industry commitment to boost by tenfold electrolyser manufacturing capacities in the EU
[236] Clean Hydrogen Observatory (2023) The European hydrogen market landscape
[237] https://www.hydrogeninsight.com/electrolysers/severe-overcapacity-the-global-supply-of-electrolysers-far-outstrips-demand-from-green-hydrogen-projects-bnef/2-1-1618327
[238] Hydrogen Europe (2022) Delivering REPowerEU through a strong European hydrogen industry
[239] European Commission (2022) Commission staff working document. Implementing the Repower EU action plan: Investment needs, hydrogen accelerator and achieving the bio-methane targets
[240] Hydrogen Europe (2023) Critical Raw Materials Act – Hydrogen Europe's views
[241] F. vom Scheidt et al. (2022) Integrating hydrogen in single-price electricity systems: The effects of spatial economic signals
[242] IRENA (2023) Innovation landscape for smart electrification
[243] Oliver Ruhnau (2022) How flexible electricity demand stabilizes wind and solar market values: The case of hydrogen electrolyzers
[244] European Commission (2019) COM/2023/148 final

becomes larger as the share of fluctuating renewable electricity in the system grows above 74% of total installed capacity and flexibility needs increase significantly.[245]

Regarding the spatial integration with the energy system, the currently coarse requirements (i.e. bidding zone level) make it easier to develop hydrogen projects, but also forego efficiency gains from locating the electrolysers at nodes with low actual electricity costs which would decrease curtailment of renewable energy and associated curtailment and redispatch costs.[246] Besides, cross-border systems integration has a decisive effect. For instance, a former METIS study[247] – based on the former goal of 5 Mtons per year of domestic hydrogen production in the EU – finds that with optimal cross-border hydrogen pipeline capacity the need for electrolyser capacity decreases to 42 GW, compared to 53 GW under a business-as-usual scenario.

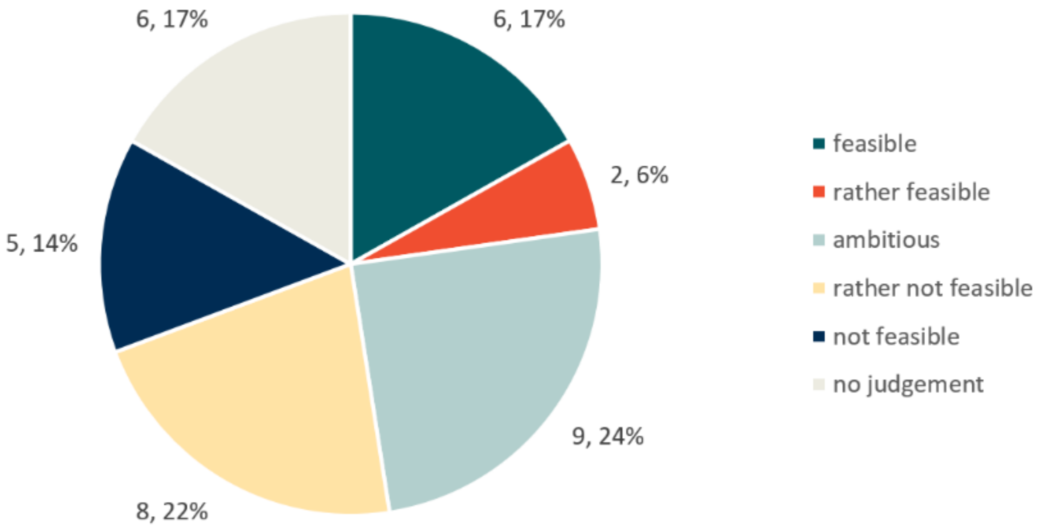
The fifth challenge is financing.

Finally, the REPowerEU plan predicts investment needs for important hydrogen infrastructure of about 50-75 billion Euros for electrolysers, 28-38 billion Euros for EU-internal pipelines and 6-11 billion Euros for storage, all by 2030. In addition to the Fit-for-55 package, this means an additional 27 billion Euros of direct investment in electrolysers and distribution of hydrogen in the EU. Investments are eligible under several EU financial programs: Connecting Europe Facility, InvestEU, Horizon Europe, ETS Funds, Recovery and Resilience Facility, European Regional Development Fund, Cohesion Fund, and Just Transition Fund. Regarding the European Regional Development Fund, Cohesion Fund, and Just Transition Fund, the eligibility refers to renewable hydrogen only, in line with Regulation (EU) 2021/1058.[248] There are – to the best of our knowledge – no studies yet estimating the resulting costs of domestically produced hydrogen under the updated 10 Mton target. A former METIS study, based on the 5 Mtons/a target of purely renewable hydrogen found costs between 3.30 EUR/kg (optimal) and 4.22 EUR/kg (business-as-usual).[249] Many of the surveyed stakeholders mention the prevailing cost gap between renewable hydrogen (without funding) and fossil-based high-emission hydrogen as one of the key barriers for reaching the REPowerEU goal (For example: “There is still a substantial cost gap between renewable hydrogen production cost and off-takers' willingness to pay, which needs to be bridged”). As a consequence, they call for a “supportive regulatory framework” and comprehensive public funding. Most of the surveyed stakeholders claim subsidies are needed in order to achieve the goal.

In the survey, 36 stakeholders provided answers to the question regarding the feasibility and costs of the REPowerEU goal for 10 Mton renewable hydrogen production per year in 2030. As Figure 3-1 shows, there are substantial shares of stakeholders who regard the goal as feasible or rather feasible, as well as stakeholders who believe the goal to be infeasible or rather not feasible. The largest share of stakeholders sees the goal as ambitious. Furthermore, a considerable share of respondents provided some information – e.g. on one country-specific aspect related to the goal – but refrained from any judgement. While the survey is not statistically representative for the view of the European hydrogen stakeholders, it demonstrates that diverse opinions on the topic exist. Most stakeholders provided one or multiple reasons for their judgement.

[245] European Commission (2023) Staff working document on the energy storage - underpinning a decarbonised and secure EU energy system
[246] F. vom Scheidt et al. (2022) Integrating hydrogen in single-price electricity systems: The effects of spatial economic signals
[247] Artelys (2021) METIS study on costs and benefits of a pan-European hydrogen infrastructure – In assistance to the impact assessment for designing a regulatory framework for hydrogen
[248] European Commission (2021) Regulation (EU) 2021/1058 of the European Parliament and of the Council of 24 June 2021 on the European Regional Development Fund and on the Cohesion Fund
[249] European Commission (2021) METIS study on costs and benefits of a pan-European hydrogen infrastructure – In assistance to the impact assessment for designing a regulatory framework for hydrogen

Figure 3-1 Answers regarding the feasibility and costs of reaching the REPowerEU goal of 10 Mtons renewable hydrogen production until 2030



3.4.1.1. Potential effects of non-renewable low-carbon hydrogen

There are several potential effects – positive and negative – of allowing parts of the 10 Mton/a target to be produced from low-carbon sources. In the following, we preliminarily note such factors based on literature research and the survey results. For the final report, the expert interviews and workshops will be used to add final details.

The first potential effect of low-carbon hydrogen is the increased speed of hydrogen scale up.

Firstly, as outlined above, a crucial bottleneck for renewable hydrogen is the speed of renewable electricity production build-out required for the production of that renewable hydrogen. Allowing for any other technology to contribute for the 10 Mton/a goal, will increase the likelihood of reaching the target until 2030, as two respondents claim. For example, one of them states that: “The supply of sufficient volumes of hydrogen, therefore, should consider not only renewable but also low-carbon hydrogen”. This presumably refers to fossil-based hydrogen with CCS. The build-out of additional nuclear electricity plants for hydrogen production until 2030 faces challenges in terms of development, construction and permitting itself.[250] In summary, using fossil-based hydrogen with CCS to achieve the 2030 goals could reduce the availability barrier, assuming both availability of required fossil fuels and CCS technology. The role of low-carbon sources might be more relevant in bidding zones with overall high shares of renewable energy where EU regulation already allows using grid electricity.[251] In such cases, the advantages outlined above can be used to optimise the load factor of electrolysers and reduce hydrogen costs.

The second potential effect of low-carbon hydrogen is the improved compatibility with mature, inflexible electrolysis technology.

Secondly, nuclear plants can provide a base load that is well suited for a relatively steady operation of atmospheric Alkaline electrolysis technology. Atmospheric alkaline electrolysis is

[250] see e.g. World Nuclear Association (2020), Median construction times for reactors since 1981
[251] https://energy.ec.europa.eu/publications/delegated-regulation-union-methodology-rfnbos_en

one type of electrolysis technology. There are other important technologies, in particular, pressurised alkaline electrolysis, proton exchange membrane (PEM) electrolysis, anion exchange membrane (AEM) electrolysis, and solid oxide (SOEC) electrolysis technology. Each of the electrolysis technologies has its own advantages and disadvantages.[252] Atmospheric alkaline electrolysis is the most mature electrolysis technology and offers relatively low CAPEX but has longer cold-start times than PEM and AEM technology and is therefore less suited to be used with fluctuating renewable energy resources. Using nuclear plants to supply electricity for electrolysis could improve the attractiveness of Alkaline technology for project developers and thus could decrease the levelised costs of hydrogen.[253] Since the maturity of the technology is one of the remaining key barriers for hydrogen uptake, using more mature electrolysis technology could alleviate an important barrier.

In addition, a well predicable base load can increase load factors of electrolysers and thus bring down levelised costs of hydrogen (LCOH). However, this can also be achieved through a smart combination of renewable energy plants of different technologies (e.g. onshore wind plus solar) or different geographies.

The third potential effect of low-carbon hydrogen is decreasing costs.

Thirdly, assuming that there are ways to produce low-carbon hydrogen at lower total costs than renewable hydrogen (e.g. from fossil waste streams or low-cost nuclear plants), this could naturally decrease overall costs of reaching the hydrogen production goals. As alternative production means replace renewable generation, those hydrogen-specific renewable generation capacities decrease, presumably starting with the more expensive projects. This makes the overall renewable production cheaper and thus decreases both hydrogen production cost and total system costs.[254] Lower hydrogen costs in turn can lead to larger hydrogen consumption volumes in the EU, as modelling results indicate.[255] However, the world's largest low-carbon hydrogen-based ammonia project (using autothermal reforming with CCS) was just put on hold due to too high costs, indicating that low-carbon hydrogen does not necessarily reduce the cost gap (sufficiently).[256]

3.4.1.2. Conclusion

The REPowerEU ambition of 10 Mtons annual domestic renewable hydrogen production is an important cornerstone of the current EU hydrogen strategy. The extensive review of academic and regulatory literature, and the conducted survey among expert stakeholders indicates that the major bottlenecks are the scaling up of renewable electricity plants, the project development of hydrogen projects, the cost gap and availability of adequate funding, as well as appropriate infrastructure for storage and transportation of the produced hydrogen. Given the overall stakeholders responses reaching the REPowerEU goals with renewable hydrogen is a challenge but may be feasible. While low-carbon hydrogen production alternatives might increase the likelihood of reaching the goal, each of them comes with their own challenges, e.g. regarding permitting or costs.

[252] For an overview of the characteristics of each technology, see e.g. The Oxford Institute for Energy Studies (2022), Cost-competitive green hydrogen: how to lower the cost of electrolysers?

[253] M. Holst et al. (2021). Cost Forecast for Low Temperature Electrolysis-Technology Driven Bottom-up Prognosis for PEM and Alkaline Water Electrolysis Systems.

[254] European Commission (2023) Assessing the balance between direct electrification and the use of decarbonised gases in the 2050 EU energy system

[255] European Commission (2023) 2050 no-regret options and technology lock-ins

[256] See Polly Martin, Hydrogen Insight (2023), 'World's largest' blue hydrogen-based ammonia project shelved due to increased costs and lack of market.

3.4.2. Carbon footprints of hydrogen imports

In the short to medium term, transport mode and country of origin determine the carbon footprint of hydrogen. In some cases, this may lead to a lower carbon footprint of low-carbon hydrogen over renewable hydrogen. Additionally, in some countries of origin the local impacts need to be considered leading to uncertainties for scale-up and communicated timelines. On the long term, however, only renewable hydrogen is compatible with regards to a minimum of carbon emissions.

For the transition to a carbon-neutral economy, the greenhouse gas intensity of hydrogen production and delivery is important. In addition to implementing the local production scale-up,[257] the European Union plans on importing hydrogen and its derivatives from other countries to minimise overall costs.[258] Recent publications discuss the overall uncertainties for scale-up of hydrogen projects outside of Europe due to various reasons including e.g. competition with local grid decarbonisation or carbon sourcing for derivatives[259]. But also, the local and global environmental impacts of these imports need to be considered when setting the strategy. This chapter provides a short overview on greenhouse gas emissions for the different hydrogen import pathways and more detailed analysis can be found in the annex of this report (section 6.5).

The different hydrogen transport pathways considered are pipeline transport and marine transport in the form of different hydrogen derivatives such as liquid hydrogen (LH_2), ammonia (NH_3) and Liquid Organic Hydrogen Carriers (LOHC). The emissions of these pathways are also compared to the alternative of emissions from a fossil fuel-based energy supply.

For import of renewable hydrogen, the breakdown of emissions differs slightly between pathways. Contributions to the carbon footprint come from the distribution via pipeline (compression power), synthesis and conversion emissions for ammonia and also for methanol and in that case also sourcing of CO_2 (which in the cited source was assumed to come from Direct Air Capture from 2041 onwards).

The GHG emissions for the production of hydrogen from natural gas with CCS can vary strongly between the producing countries, with the production of low-carbon hydrogen using CCS from Norway creating far lower emissions than the same type of hydrogen based on natural gas from Russia, China, and Australia.[260] With a high carbon capture rate, hydrogen production using natural gas can be among the production methods with the lowest GHG emissions in some cases, but in other cases with lower capture rates and less strict regulations of the emissions in the fossil fuel production chain, imports of such hydrogen can be linked to high GHG emissions.[261,262]

[257] European Commission (2020) A hydrogen strategy for a climate-neutral Europe
[258] Nunez-Jimenez, A., & De Blasio, N. (2022) Competitive and secure renewable hydrogen markets: Three strategic scenarios for the European Union - ScienceDirect
[259] https://www.transportenvironment.org/wp-content/uploads/2024/02/202402_H2_imports_TE_briefing.pdf
[260] Hydrogen Council (2021), by LBST Hydrogen Council Report Decarbonization Pathways Part-1 Lifecycle-Assessment
[261] Richard Taylor, Ellie Raphael, Chester Lewis, Ross Berridge, Jo Howes (2022). Expansion of hydrogen production pathways analysis – import chains (publishing.service.gov.uk)
[262] Hydrogen Council (2021), by LBST Hydrogen Council Report Decarbonization Pathways Part-1 Lifecycle-Assessment

The emissions from shipping in the values below are based on the baseline trajectory of the average shipping fuel GHG intensities until 2050, given in the IEA Net Zero 2050 report, which predicts an 85% drop by 2050 (compared to 2008 levels; resulting from the increased use of renewable H_2 and ammonia).[263] The following pathways and emissions (in $gCO_2eq/MJ\ H_2$) were calculated for 2030 and 2050:

- Renewable hydrogen, Australia, in the form of ammonia (2030: 25g; 2050: 9 g)
- NG + CCS hydrogen, UAE, in the form of LOHC (2030: 70g; 2050: 50 g)
- NG + CCS hydrogen, USA, in the form of LH_2 (2030: 80g; 2050: 40 g)
- NG + CCS hydrogen, Norway, compressed H_2 via pipeline (2030: 18g; 2050: 17 g)
- Renewable hydrogen, Spain, compressed H_2 via pipeline (2030: 3g; 2050: 1 g)

Not surprisingly, sourcing the energy carriers from e.g. Australia instead of Southern Europe adds additional steps to the supply chain (large distance shipping and unloading). However, under the applied assumption ships are fuelled by e-diesel in 2050, the GHG impact of the change in production location and transport mode is marginal and contributes only a maximum of 0.2 gCO_2eq/MJ. These emissions may be overcompensated by the lower carbon intensity of the renewable electricity used in a country with dedicated or renewable-only electricity grids, making the electricity mix for the synthesis process the dominant factor, even when long distance transportation is involved.

The above listed results of the study by Taylor et al. further show that especially imports of low-carbon hydrogen from SMR using CCS from countries such as the United States of America (USA) and United Arab Emirates (UAE) are bearing relatively high GHG emissions.

Instead of the limited differences in GHG emissions between different renewable energy carriers and between exporting countries of renewable hydrogen, other factors will play a more crucial role in determining the future of European energy imports, such as production and import costs as well as safety considerations related to ammonia.

Much more important in terms of environmental impacts are therefore the decisions to quickly replace current fossil fuels and to do so by preferably importing renewable hydrogen-based products rather than those based on natural gas and CCS. Transport distance is a factor in the short- to medium-term, while in the long-term it is anticipated that ship transport is decarbonised, reducing transport emissions to very low levels. All in all, renewable hydrogen transported by pipeline has undoubtedly the lowest emissions.

3.4.3. Barriers and recommendations to the uptake of biogas and biomethane

In the following paragraphs barriers and recommendations on biogas and biomethane are given based on stakeholder feedback received (i.e. the survey conducted in the framework of this study). However, no detailed analysis was conducted.

Numerous stakeholders highlight in the survey the contributions of biogas and biomethane to the decarbonisation and integration of the EU energy system, which are especially the following:

[263] IEA (2021) Net Zero by 2050. Figure 03.25

- Biogas and biomethane are an enabler of decarbonisation of hard-to-electrify end-uses, such as heavy-duty transport, high temperature heat in industry, or buildings where deep renovations are challenging such as historic buildings
- Biogas and biomethane can provide adequacy and flexibility services to the energy system, being a controllable renewable energy source;
- Biomethane can directly employ existing natural gas transport and storage infrastructure, with no or limited technical modifications required.

The Commission recognises the importance of biogas and biomethane, and has adopted a number of measures recently. The REPowerEU Plan introduced the aim to increase biomethane production in the EU to 35 billion cubic metres annually by 2030, with an associated investment requirement estimated at €37 billion up until that year.

The Commission furthermore launched together with the REPowerEU Plan a biomethane action plan[264] with a number of specific measures:

Promote the sustainable production and use of biogas and biomethane at EU and national/ regional level and the injection of biomethane into the gas grid

- Create a biogas and biomethane industrial partnership/ forum promoting their sustainable production and use;
- Develop national strategies on sustainable biogas and biomethane production and use or integrate a biogas and biomethane component in the National Energy and Climate Plans (NECPs);
- Consider broadening the scope of the fuel supply obligation in the Renewable Energy Directive;
- Promote participatory multi-stakeholder engagement;
- Reduce red tape and speeding up permitting;
- Promote sustainable biogas and biomethane co-operation with neighbouring and enlargement countries;
- Provide incentives for biogas upgrading into biomethane;
- Reduce the costs for economic operators, which currently prevent biogas upgrading into biomethane.

Promote the adaptation and adjustment of existing and the deployment of new infrastructure for the transport of increased shares of biomethane through the EU gas grid

- Carry out regional assessment of network development and matching it with the potential of sustainable biomethane production;
- Assess challenges, bottlenecks and other possible measures from the infrastructure perspective for cost-efficient deployment of biomethane;
- Address gas quality standardisation issues.

[264] European Commission (2023) Implementing the REPowerEU Action Plan: Investment Needs, Hydrogen Accelerator and Achieving the Bio-methane Targets

Address RDN&I gaps

- Provide further support to the development of innovative technologies for the production of sustainable biogas and biomethane;
- Provide further support to innovative solutions and research on barriers and integration of sustainable biomethane to the gas grid;
- Further support the expansion of the sustainable biomass potential to ensure availability of resources for reaching the biomethane production target.

Access to finance

- Provide access to grants and loans;
- Innovation fund;
- Access to other financial instruments.

Many of the actions proposed in the REPowerEU Plan have already been implemented, including the biomethane industrial partnership that has been in place since September 2022, the broadened fuel supply obligation of the Renewable Energy Directive, and recommendations on permitting of renewable energy projects. Moreover, the Waste Framework Directive (2008/98/EC) requires that from 2024 on Member States will have to separately collect organic waste, which could have a positive impact on biogas and biomethane production.

There is therefore a number of already ongoing actions on biogas and biomethane. Stakeholders have proposed a few additional recommendations to further advance the sources as well as their integration with the rest of the energy system. These include:

- **Promote the use of hybrid heating systems** such as hybrid boilers, while ensuring they are aligned to climate and energy objectives and that there are no risks of lock-in in natural gas;
- **Ensure the right-to-inject** from a legal but also practical standpoint at the national level;
- **Define in legislation the 35 bcm objective** in order to set obligations to the Member States regarding the topic, similarly to what has been done for hydrogen;
- **Promote a more integrated energy infrastructure planning** considering all energy carriers in an integrated manner (see section 5.2 for further details);
- Carefully consider the possibility to employ biomethane for the decarbonisation of the built environment in certain regions when **assessing the decommissioning of distribution gas grids**;
- Further **facilitate the collection and utilisation of sustainable feedstock** on environmental and agricultural legislation (ESI-related actions are already ongoing in this regard).

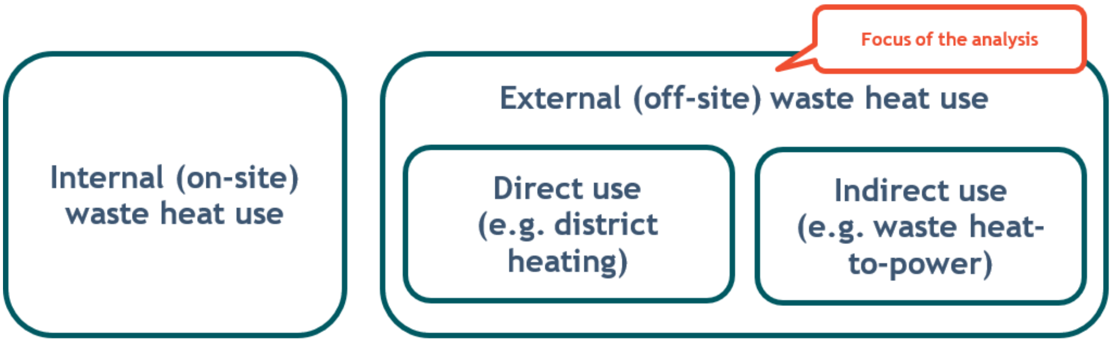
4. Utilisation of waste heat

Disclaimer: The scope of waste heat sources and applications considered in this study is broader than that defined in article 2(9) of the amended Renewable Energy Directive (EU) 2018/2001.[265] The focus remains on unavoidable waste heat or cold generated as a by-product of industrial, power generation or tertiary sector activities. But particularly non-district heating and cold applications such as heat-to-power are considered. Moreover, heat recovery from sewage is considered in the present analysis, which under the REDII is classified as ambient energy (but wastewater treatment plant heat recovery is considered waste heat under the REDII).[266]

4.1. Introduction

This chapter focuses on advancing the utilisation of unavoidable waste heat and cold that would otherwise be dissipated unused in air or water, for direct use of the heat in e.g. district heating and cooling or for indirect use in other applications (for example waste heat-to-power), as illustrated in Figure 4-1. Hence, the analysis does not focus on renewable heat and cold, although synergies or other interactions with waste heat and cold are considered. On-site energy efficiency measures within industry or the built environment are also not discussed in detail (mirroring the waste heat definition of article 2(9) of the Renewable Energy Directive) but constitute nonetheless the first priority in line with the hierarchy for decarbonisation of the energy system as presented in chapter 1.

Figure 4-1 Waste heat scope of this study



Waste heat and cold are also frequently referred to as excess or surplus heat and cold, a term that some stakeholders prefer as it emphasises the potential for recovery and utilisation of the resource. Nonetheless, the term waste heat and cold is employed in this report.

This chapter presents the analysis of barriers for advancing the utilisation of waste heat and cold in the EU, as well as provides preliminary recommendations to address the identified barriers.

The chapter is structured as follows:

- ✓ Section 4.2 analyses the barriers to waste heat utilisation in the EU;

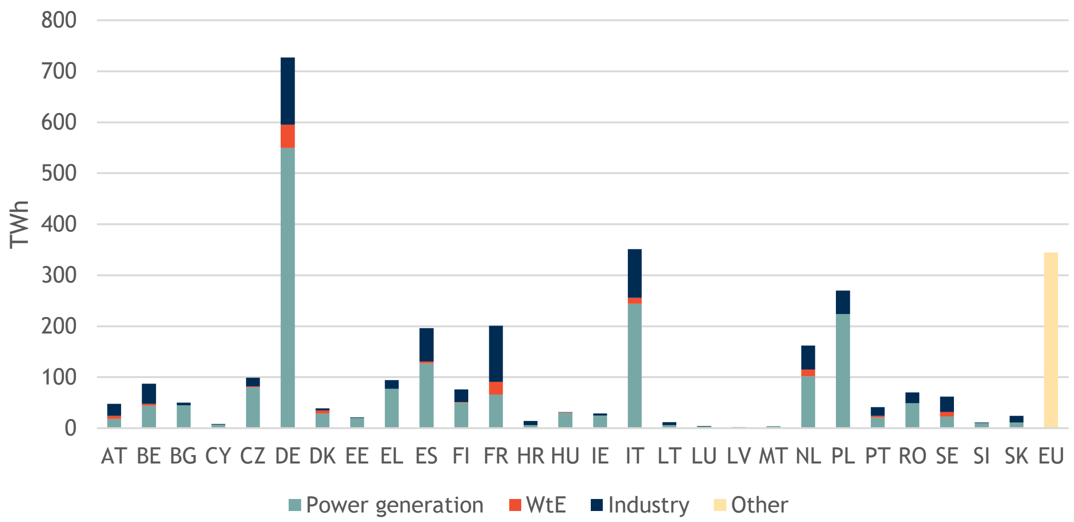
[265] Renewable Energy Directive (EU) 2018/2001 article 2(9) : *'waste heat and cold' means unavoidable heat or cold generated as by-product in industrial or power generation installations, or in the tertiary sector, which would be dissipated unused in air or water without access to a district heating or cooling system, where a cogeneration process has been used or will be used or where cogeneration is not feasible;*
[266] JRC (2021) [Defining and accounting for waste heat and cold]

- ✓ Section 4.3 provides recommendations (focused on the EU-level) for advancing waste heat utilisation;
- ✓ Section 4.4 presents an overview of waste heat utilisation applications in the EU as well as details selected case studies.

4.1.1. Waste heat potential in the EU

Estimates of the potential waste heat and cold (in line with the definition of the REDII) in the EU vary, but stakeholders acknowledge it is very significant. The EU Energy System Integration Strategy recognised the importance of waste heat and indicates that "29% of industrial energy demand dissipates as waste heat".[267] The JRC (2021)[268] reviewed available studies on the waste heat potential in the EU27, which in aggregate indicate a total potential of 3139 TWh/year if the highest potential in the ranges provided are considered. The Heat Roadmap Europe 2 project estimated the waste heat potential in the EU27_2007[269] at 2850 TWh/year.

Figure 4-2 Waste heat potential per year in the EU27 (high estimate)[270]



The sectors with the highest waste heat potential are industry and power generation. However, other sectors still have a non-negligeable potential that could significantly contribute to the decarbonisation of the EU's heating and cooling sector. The JRC's review puts the waste heat potential from power generation at 1869 TWh/year, while industry's potential ranges between 261 and 7535 TWh/year. The total energy input for thermal power plants should significantly decrease towards 2040 - the EU Reference Scenario estimates that the energy inputs to thermal power generation and district heating will decrease by around 42% from 2020 to 2040.[271] Energy inputs to thermal power plants will thus decrease but nonetheless remain significant and constitute an important area for energy efficiency efforts.

Concerning other sources of waste heat, the JRC indicates that waste-to-energy could provide 131 and other sources 344 TWh/year.[272] Other estimates of potentials for certain waste heat

[267] COM(2020) 299 Final. Powering a climate-neutral economy: An EU Strategy for Energy System Integration
[268] JRC (2021) Defining and accounting for waste heat and cold
[269] That is, the EU27 as of 2007, which included the UK but not Croatia, who only joined in 2013
[270] JRC (2021) Defining and accounting for waste heat and cold
[271] E3-Modelling (2021) Reference Scenario 2020 (REF2020) main results
[272] JRC (2021) Defining and accounting for waste heat and cold

sources exist, for example from industry (300 TWh/year),[273] data centres (48 TWh/year), or from tertiary buildings (10 TWh/year). This compares against a final consumption of heat for energy purposes in the EU of 550 TWh in 2021.[274] These figures refer to traded heat, hence do not include heat consumption produced and consumed on-site. This indicates that the available EU waste heat potential would be equivalent to the current district heating demand, or almost the entirety of total space heating and hot water demand in the EU built environment.[275] The recovery and utilisation of waste heat can bring other significant benefits, such as reduced air pollution or heat emissions to the environment, as highlighted in the case studies overviewed in section 4.5.

4.2. Barriers to the utilisation of waste heat

This section analyses the barriers to advancing the utilisation of waste heat and cold in the EU, as well as identifies which barriers are expected to remain in place once existing or planned policies and measures are implemented. Based on the literature review, a list of barriers for the utilisation of waste heat and cold was developed as presented in Table 4-1.

Table 4-1 Summary of barriers for waste heat utilisation

Barrier type	Barrier
Technical	1. Location/temporal/quality mismatch between heat supply and demand
	2. Technical performance of waste heat recovery and district heating/cooling systems
Economic and financial	3. Profitability/long payback period
	4. Inadequate pricing signals
	5. Project uncertainty, complexity, and risk aversion of DHC operators/split incentives
Legislative and regulatory	6. Limited replicability of solutions and lack of standardised contracts/tools
	7. Lack of governance and planning, including information on potentials and integration across carriers and with urban planning
	8. Accounting of climate and environmental footprint/benefits of waste heat utilisation
Societal	9. Knowledge/capacity of actors
	10. Acceptance and behavioural issues

Following further analysis and consultation with stakeholders, almost all barriers identified in the literature review were identified as significant and selected for analysis in this chapter. This highlights how complex the issues affecting waste heat utilisation are. Only barrier 2 (technical performance) is not analysed in more detail in this chapter, for the following reasons:

- The consultations indicated stakeholders do not see the barrier as fundamental for waste heat and cold utilisation and its broader integration with the energy system (although it still ranked as ‘important’ by some stakeholders that replied to the survey);

[273] Heatleap (2023) Waste Heat Recovery - Potentials, applications and recommendations for better policies
[274] Eurostat nrg_bal_c
[275] Heatleap (2023) Waste Heat Recovery - Potentials, applications and recommendations for better policies

- The barrier is less relevant from a system integration perspective, dealing with challenges that can be addressed more readily within the heating and cooling sector;
- There are proposed EU measures that target the barriers.

4.2.1. Technical barriers

4.2.1.1. Location/temporal/quality mismatch between heat supply and demand

The location, temporal, and quality mismatch between heat supply and demand is a fundamental barrier for the utilisation of waste heat, as confirmed by stakeholders and the literature.

The various sources of WH/C will most commonly not match the demand concerning the following aspects:[276]

1. **Temporal profile**: The WH/C source may vary in the short-term (hours to days) and the long-term (seasonally), while demand is typically highly seasonal. Some sources such as waste-to-energy facilities, wastewater treatment plants or certain industrial facilities may provide reasonable constant WH/C, while other sources such as data centres and other industries may be highly variable in the short-term or seasonally. Peak demand in winter is often the main design criteria of heating systems.[277]
2. **Location:** WH/C may be consumed on- or off-site (noting that the definition may vary in legislation, for example with only off-site WH/C counting toward the specific targets in the RED II)[278]. For off-site consumption, which is the focus of the analysis, there will always be by definition some mismatch in location. A number of challenges arise, being discussed in a specific section below;
3. **Quality**: This concerns both the temperature level of the WH/C source as well as the total heat/cold available in comparison to the total demand. Moreover, the waste heat availability will be controllable to a varying extent (i.e. the source may be intermittent), depending on the underlying process generating the waste heat and techno-economic decisions.

Temporal, location, and quality mismatches are challenges that will remain in the long run for all sources, but solutions generally exist to address these mismatches in order to integrate renewable and waste heat/cold distributed sources.

The AIT and Euroheat & Power indicate that while mismatch challenges can typically be overcome (including temperature level issues through the use of large-scale or individual heat pumps), they entail costs that will affect the profitability of the utilisation of WH/C[279] (see the barriers analysed in section 4.3.2). Lygnerud (2023) confirms that solutions exist to address the technical challenges of urban waste heat recovery, with economic and regulatory barriers being more important.[280] This view was shared by a large majority of participants in the project

[276] Austrian Institute of Technology and Euroheat & Power (2020) Discussion Paper - The barriers to waste heat recovery and how to overcome them?
[277] ReUseHeat (2019) Urban excess heat utilization in future energy systems – D1.5 Report on the energy planning analyses on future energy system in the demo countries
[278] JRC (2021) Defining and accounting for waste heat and cold
[279] Austrian Institute of Technology and Euroheat & Power (2020) Discussion Paper - The barriers to waste heat recovery and how to overcome them?
[280] Lygnerud (2023) Urban waste heat recovery as an enabler of the energy transition policy implications and barriers

workshop (see results in annex section 6.4). Survey respondents did note that addressing the quality mismatch involves measures to reduce the operating temperature of district heating networks, which is only possible in combination with the renovation of the building stock.

Waste heat potential from all sources is underutilised in the EU, particularly for current non-conventional sources. The identification of waste heat utilisation projects presented in section 4.5, albeit non-exhaustive, indicates that the industrial waste heat makes up the most important utilisation case in the EU today, which is in line with its significant potential (see section 4.2). Conversely, fewer examples exist of the utilisation of non-conventional waste heat sources such as from tertiary buildings, wastewater or data centres – which is due to their more limited potential compared to industrial waste heat, but also to particular challenges for their utilisation that are detailed below.

New non-conventional sources will bring additional waste heat potential to the 2040 timeframe, with new challenges. One example highlighted by stakeholders was the case of waste heat recovery from operation of electrolysers. A short description of the temperature levels and efficiency of such systems, as well as the potential waste heat available in the future is described in Textbox 1 below. Waste heat from data centres is already currently exploited in a few cases – but further projects will follow with the installation of new data centres, particularly if liquid cooling solutions are deployed (increasing the waste heat temperatures). Further waste heat potential could arise in the future from exothermic process in for example some carbon capture processes[281] and methanation for the production of synthetic natural gas.[282] The combination of waste-to-energy with carbon capture and storage and waste heat utilisation could lead to negative emissions as well as increased overall efficiency (by using the waste heat on-site for the carbon capture process or off-site in other applications).

[281] For example Cui et al. (2023) Waste heat recovery and cascade utilization of CO2 chemical absorption system based on organic amine method in heating season

[282] Mezzera et al. (2021) Waste-heat utilization potential in a hydrogen-based energy system - An exploratory focus on Italy

Textbox 1 Waste heat from future operation of electrolysers

There could be a significant potential for the utilisation of waste heat from electrolysers in the future, with increasing attention on the topic given the ambition of the REPowerEU plan for production of renewable hydrogen in the EU as well as the recently agreed hydrogen consumption sub-targets targets of the amended Renewable Energy Directive.[283]

Van der Roest (2023)[284] indicates that the recovery of such waste heat for district heating purposes can increase the overall system efficiency in around 14-15%, to 90% (high heating value) for a proton exchange membrane (PEM) electrolyser. This would also improve the economic viability of electrolytic hydrogen production and provide heat at a comparable cost to other (low temperature) industrial heat sources.

Jonsson et al. (2022)[285] study waste heat utilisation from a potential 100 MW electrolysis system, considering both PEM and alkaline electrolysers. Waste heat temperatures are similar in both cases (79-80 ºC), which would be a good heat quality for use in 3rd or higher generation systems. Efficiencies of the overall system are also significantly increased: 94.7% and 88.4% for the PEM and alkaline electrolyser, with the systems providing 171 770 MWh_{th} and 310 630 MWh_{th} respectively.

Considering the Commission target to have 40 GW of electrolyser in 2030 as stated in the EU Hydrogen Strategy[286] and assuming the lower waste heat production estimate of Jonsson et al. (2022) of 1.717 $TWh_{th}/y/GW_{electrolysis}$ from PEM electrolysers, this would still represent a potential 68.7 TWh of waste heat to be recovered.

Reuter and Schmidt (2022)[287] estimate the waste heat potential from electrolysers at 250 TWh/y by 2040 in the EU27+UK (for 272 GW installed capacity). This amounts to 64% of the current final heat demand supplied by district heating in the region, although the potential contributions by country will vary – in countries with more limited heat demand from district heating, which could be fully supplied from waste heat from electrolysers, while in others this waste heat would cover a significant share but not all demand. The authors further highlight the role of 4th and 5th generation district heating systems (discussed below) given not all existing district heating networks could accept the waste heat, as its temperature range is 50 – 80 ºC, thus lower than the operating temperature of older networks.

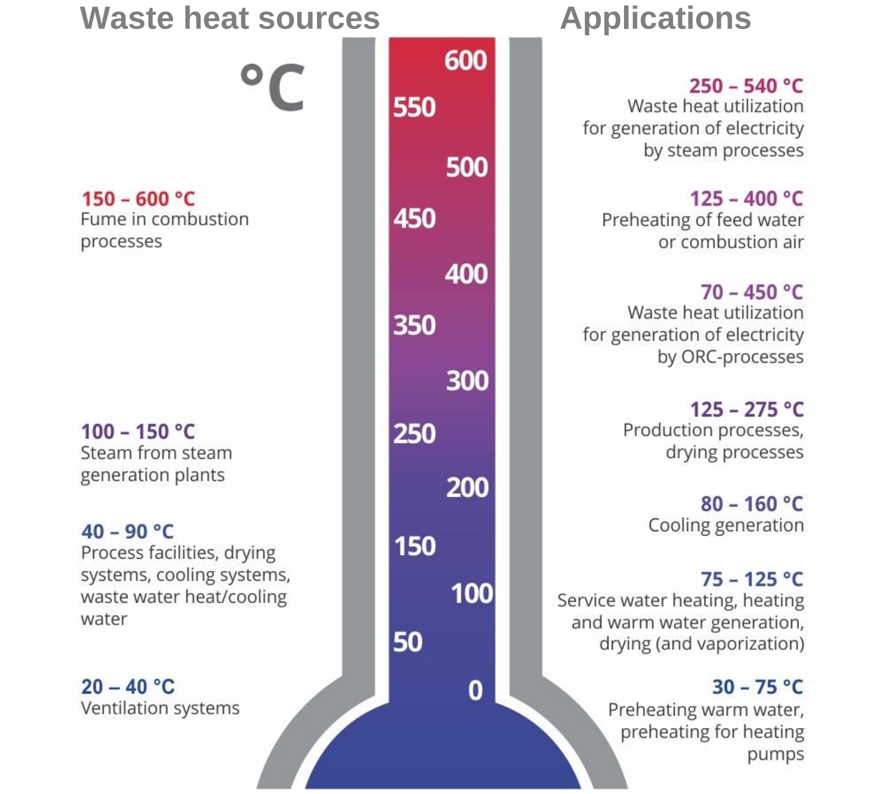
It must also be noted that although the waste heat is a direct consequence of the exothermic reaction, it does not mean that it could not be (partially) recovered and used on-site, which would reduce the unavoidable wate heat potential for off-site use.

Technical challenges particularly affect the development of unconventional waste heat resources,[288] that have not been yet deployed at scale. Most unconventional waste heat sources are characterised by comparatively low temperatures, often requiring the upgrade through large-scale or individual heat pumps for final use, leading to additional barriers for waste heat utilisation. As can be seen in Figure 4-3, non-conventional waste heat

[283] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CONSIL:ST_10794_2023_INIT
[284] Van der Roest (2023) Utilisation of waste heat from PEM electrolysers – Unlocking local optimization. https://doi.org/10.1016/j.ijhydene.2023.03.374
[285] Jonsson et al. (2022) Utilization of Waste Heat From Hydrogen Production: a Case Study on the Botnia Link H2 Project in Luleå, Sweden
[286] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0301
[287] Reuter and Schmidt (2022) Assessment of the Future Waste Heat Potential From Electrolysers and Its Utilization in District Heating
[288] Unconventional used here to refer to unavoidable waste heat from other sources than industry.

temperatures range from 20 to 90 ºC (and lie very often in the lower end of this range). Heat pumps will thus play an important role in facilitating the exploitation of such sources, with large-scale heat pumps for collective heating solutions gaining increasing attention. Individual heat pumps might also be deployed near or at the end-user in low-temperature district heating systems (discussed below). Hence, the utilisation of non-conventional waste heat sources will require not only the deployment of heat pumps but also sufficient (clean) electricity for their operation, which has an impact also on the economic and financial barriers to waste heat utilisation as discussed in section 4.3.2.

Figure 4-3 Temperatures for waste heat sources and potential applications[289]



5th generation district heating systems could in the future strongly facilitate the integration of unconventional sources of waste heat and cold (see Textbox 2), but currently 4th generation systems are considered to be economically more attractive.[290] If 5th generation district heating systems are to be developed at a larger scale, further innovation will be required, including technology to maintain the balance between supply and demand, and for reducing the total costs. This is supported by the survey response of one stakeholder, who argued that while individual technologies for waste heat utilisation are well known, this is not the case for system integration technologies.

Furthermore, 5th generation systems may complement (rather than substitute) 4th generation systems.[291] The former may be excellently placed to integrate distributed sources of both heat and cold, meeting heating and cooling needs locally in an integrated manner, while the latter may in situations be more suitable to decarbonise district heating systems while

[289] waste-heat.eu based on Deutsche Energie-Agentur
[290] Gudmundsson et al. (2022) Economic comparison of 4GDH and 5GDH systems – Using a case study. https://doi.org/10.1016/j.energy.2021.121613
[291] Lund et al. (2021) Perspectives on fourth and fifth generation district heating. https://doi.org/10.1016/j.energy.2021.120520

more easily integrating with the broader energy system (for example by providing flexibility to the power system through the smart operation of large-scale heat pumps).

Textbox 2 4th and 5th generation district heating systems

Figure 4-4 presents the evolution of district heating systems from the first generation in the turn of the 20th century to the 4th generation systems currently being deployed. This evolution is characterised by the shift from fossil-based to renewable and waste heat, the decentralisation of sources (including with the development of prosumers), the reduction of network temperatures and demand, with associated efficiency gains, and integration with cooling systems. While 3rd generation systems were developed with fossil fuels as the main source, 4th generation systems have an explicit decarbonisation objective.[292] Currently, most district heating systems being operated are 3rd or 4th generation.[293] But besides the need to develop 4th generations systems, for decarbonising the heating and cooling sector 5th generation systems are being proposed as a complementary solution to 4th generation systems.

There is no commonly agreed definition of 5th generation district heating/cooling systems. Figure 4-4 below for example does not differentiate between 4th and 5th generation systems. Nonetheless, 5th generation systems can be characterised by near-ground operating network temperatures (30 ºC or lower), requiring the upgrading of the heat/cold at building level.[294] Moreover, such systems are often considered to comprise a double loop or two-pipe network (with each loop at a comparatively high and low temperature). Moreover, they may have a greater focus on the integration of heating and cooling sources, due to the existence of the two-pipe network. A few systems fitting this definition have been in place since the 1990s.[295]

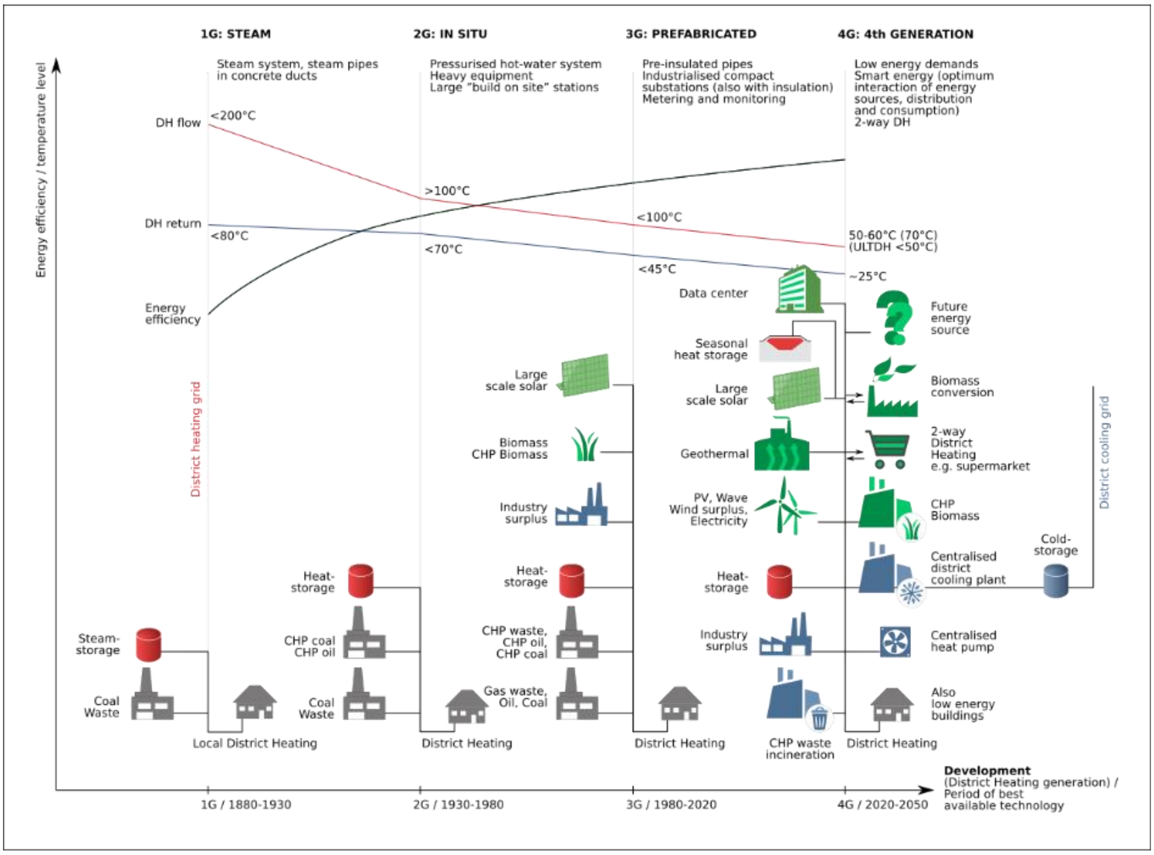
5th generation systems have a number of advantages, given their lower operating temperatures, potential two-pipe network and location of heat pumps at the consumer site, according to Lund et al. (2021):[296]

- Take advantage of the synergy of combined heating and cooling in areas of mixed purpose buildings,
- Minimise the barrier of utilising local waste heat sources and minimise upfront investment cost for the utility company, though the required initial investment at end-users' level will be higher, and
- Enable less restrictive decentralised growth of the system, as central heat supply is not as critical, since new additional end-users will both add and use heat from the network.

However, the authors argue that integration of the heating/cooling system with the broader smart energy system might be more challenging than with 4th generation systems, given 5th generation systems are designed mainly to integrate heating and cooling locally and make the optimisation of investments and operation considering interactions with the electricity system and broader regional heating and cooling system more complex.

[292] Lund et al. (2021) Perspectives on fourth and fifth generation district heating. https://doi.org/10.1016/j.energy.2021.120520
[293] https://www.danfoss.com/en/about-danfoss/articles/dhs/district-energy-generations-explained/
[294] Gudmundsson et al. (2022) Economic comparison of 4GDH and 5GDH systems – Using a case study. https://doi.org/10.1016/j.energy.2021.121613
[295] Lund et al. (2021) Perspectives on fourth and fifth generation district heating. https://doi.org/10.1016/j.energy.2021.120520
[296] Lund et al. (2021) Perspectives on fourth and fifth generation district heating. https://doi.org/10.1016/j.energy.2021.120520

Figure 4-4 Generations of district heating systems[297]



There is EU funding dedicated to waste heat utilisation solutions in order to advance the knowledge and increase deployment, but it is limited and could be further supported by feasibility studies.

The table below provides an overview of EU-supported projects with a focus on waste heat utilisation for district heating and cooling as of 2022, according to Euroheat & Power (2022).[298] Several other projects on district heating and cooling also address waste heat utilisation, although it may not be the primary focus of the project. Nonetheless, the data shows that the EU contribution to projects with a focus on WHU for district heating and cooling amounted to around 19 M€, or 4% of the 493 M€ provided by the EU between 2016 and 2022 to district heating and cooling projects overall. The CO2OLHEAT case study (detailed in the annex) highlights that further EU support for feasibility studies of waste heat projects could be welcome. The project was put on hold after its start because it was identified that the costs for implementing the supercritical CO_2 heat-to-power demonstrator was higher than originally estimated. A project participant indicates that such problems could be mitigated through increase EU funding for feasibility studies of waste heat projects.

[297] Andol (2018) [Generations of district heating systems EN.svg]

[298] Euroheat & Power (2022) Advancing District Heating & Cooling Solutions and Uptake in European Cities. Overview of Support Activities and Projects of the European Commission on District Heating & Cooling

Figure 4-5 EU-supported projects with a focus on waste heat utilisation for district heating and cooling between 2016 and 2022

Programme	Project	Total Budget €	EU contribution €
Horizon 2020	ReUseHeat	4 894 330	3 998 061
Horizon 2020	Heat4Cool	7 934 578	5 703 013
Horizon 2020	EMB3RS	4 245 119	3 984 671
Horizon 2020	INCUBIS	2 049 875	1 999 875
LIFE	Life4HeatRecovery	5 819 377	3 360 079
	Total	**24 943 279**	**19 045 700**

4.2.1.2. Space-related constraints for waste heat utilisation

This section details specific issues related to the location mismatch between waste heat sources and potential end-users.

The distance between waste heat sources and sinks can be an important limitation factor, especially for industrial waste heat sources. Networks typically range from a few hundred meters to tens of kms (see the case studies overview in Table 4-4). The JRC (2021)[299] indicates, based particularly on Kavvadias and Quoilin (2018),[300] that “literature sources use a common threshold for feasible heat transmission distance in the range of 30–50 km, their techno-economic model suggests that longer distances are feasible for specific technoeconomic parameters and market conditions” with one source identifying a maximum delivery distance of 60 or 70 km in existing projects. These distance limitations can be particularly challenging for the utilisation of industrial waste heat, whose sources may be very distant from potential demand. In contrast, unconventional waste heat sources are frequently located closer or within urban environments, mitigating the distance challenge. To one stakeholder, the costs associated with increasing distances to connect waste heat and cold suppliers and consumers is the main barrier to the utilisation of the potential. Challenges related to distance also impact the interconnection of individual DHC networks, a solution that has been applied in some cases, as detailed in Textbox 3.

Member States seem to adopt excessively conservative assumptions regarding the maximum feasible distances for transporting waste heat. Kavvadias and Quoilin (2018)[301] review the Member States assumptions regarding maximum economically-feasible distances mentioned in Article 14(6) of the original Energy Efficiency Directive, as shown in Table 4-2 – now article 26(7) of the recast Directive (EU) 2023/1791. Beyond this distance, Member States can exempt operators of electricity generation plants from conducting a cost-benefit analysis for refurbishment to high-efficiency cogeneration installation, as required by Article 14(5) (article 26(8) of the recast Directive). It can be seen that the maximum distance defined is 20 km, while Kavvadias and Quoilin calculate that under certain conditions distances above 30-50 km can be feasible.

[299] JRC (2021) Defining and accounting for waste heat and cold
[300] Kavvadias and Quoilin (2018) Exploiting waste heat potential by long distance heat transmission: Design considerations and techno-economic assessment
[301] Kavvadias and Quoilin (2018) Exploiting waste heat potential by long distance heat transmission: Design considerations and techno-economic assessment

Table 4-2 Maximum economically feasible distances for heat transport defined by Member States following Article 14(6) of the first Energy Efficiency Directive (as of 2018)

	Austria	Denmark	Finland	Netherlands	Poland
Maximum distance (km)	5	5	5–20	3	20

Textbox 3 Interconnection of DHC networks

A solution for advancing the utilisation of waste heat and cold and the broader integration of various sources is the interconnection of separate district heating networks. A few examples can be identified in this regard among the case studies surveyed in Table 4-4, such as the Dutch WarmtelinQ project and the Greater Copenhagen DHC project in Denmark.

Interconnection projects can have several advantages:

- **Potentially high benefit-to-cost ratio** due to investments being limited to the interconnector (unless other investments are necessary to e.g. adapt temperature levels of one of the DHC networks to be interconnected)
- **Facilitation of the utilisation of excess waste heat sources,** as often the potential of large sources such as large industrial facilities cannot be utilised in individual DHC networks, or faces limitations such as e.g. low demand in summer
- **Increased flexibility** due to the integration of different waste heat sources, demand profiles and potentially thermal energy storage

The interconnection of district heating networks can bring specific challenges such as investments and waste heat losses in the case of long interconnectors covering several kms and the need for cooperation between an increased number of stakeholders, including multiple municipalities and DHC network operators. Nonetheless, especially as DHC networks advance in a region and municipalities comprehensively assess their (waste) heat and cold potential and elaborate heat plans, **interconnection should be considered given the significant potential benefits.**

An example of an interconnected network is the Greater Copenhagen area, one of the largest district heating systems globally. The transmission system comprises 160 km of pipes, which interconnect 20 distribution systems.[302] The system has been undergoing significant changes, including substituting fossil heat supply with biomass and waste heat, switching the remaining steam-based systems to hot water, installing thermal energy storages such as pit and aquifer-based,[303] developing a cooling network and potentially deploy CCS for its waste-to-energy facilities.[304]

In addition to distance, the absence of an adequate district heating/cooling network in the first place is often a barrier to the utilisation of WH/C, although mobile thermal energy storage solutions are being increasingly deployed. The transport of the waste heat

[302] https://www.ramboll.com/projects/energy/district-heating-for-1-million-people
[303] https://stateofgreen.com/en/news/the-integrated-district-heating-system-in-greater-copehagen/
[304] http://carbonneutralcities.org/wp-content/uploads/2020/12/Two-Approaches-To-Buildings-Decarbonization.pdf

will most often require a district heating or cooling system with suitable operating temperatures – a challenge particularly for non-conventional waste heat sources as discussed further below. This means that older district heating systems might not be suitable, even if located in the same region as the waste heat source. Conversely, the availability of a suitable WH/C (or a renewable) source is an important factor in the decision to develop district heating or cooling networks.[305] This is supported by four stakeholders responding to the survey. Mobile thermal energy storage solutions constitute an alternative to district heating networks as a mean to transport waste heat and enable trade, gaining increasing attention recently.[306] Several technology providers are now established offering mobile solutions, which also serve to address some of the dependency risks associated with waste heat utilisation (discussed in section 4.3.2).

The development of new district heating and cooling systems or the connections to waste heat sources can face significant spatial constraints. There are multiple competing uses for the available urban underground space, leading to spatial constraints and complex permitting and spatial planning processes, which are critical for the successful development of a district heating or cooling system.[307] The spatial constraints affect not only heating and cooling pipes, but also other components such as the thermal energy storage necessary to address temporal mismatches – with for example pit thermal energy storage being an upcoming solution but not being feasible in all contexts due to the large space required.[308] Spatial constraints can sometimes make a waste heat utilisation project outright impossible.

4.2.1.3. Modelling of waste heat utilisation for policy analysis

Absent or inadequate representation of waste heat and cold in energy system models used to develop energy scenarios at the EU and national level is an important barrier, as these scenarios are used by policymakers to identify and assess the impacts of policy options. As indicated, the EU ESI Strategy and other policy documents highlight potential of waste heat and cold. Moreover, as reviewed in section 4.4.1 a number of new EU legislative provisions have been introduced focused specifically on the heating and cooling sector and advancing the utilisation of waste heat. Nonetheless, improved representation of waste heat utilisation in energy system models could further highlight to policymakers its decarbonisation potential. This has been raised by multiple participants of the project workshop as one of the most important issues for increasing the utilisation of waste heat (see results in annex section 6.4).

The adequate representation of waste heat and cold in energy system models is a complex task that requires the consideration of a number of aspects:

- **Inclusion of the industrial and non-conventional technical and realisable waste heat potential,** which can be challenging given the lack of appropriate potential assessments at the EU level. EU-wide energy system models need coherent data inputs for all Member States, while as discussed in section 4.2 existing such EU-wide assessments are limited;
- **Representation of waste heat in energy statistics,** as energy scenarios for policymaking should rely on official energy statistics as much as possible;

[305] Austrian Institute of Technology and Euroheat & Power (2020) Discussion Paper - The barriers to waste heat recovery and how to overcome them?
[306] Anandan et al. (2021) A comprehensive review on mobilized thermal energy storage
[307] TNO and DBDH (2021) Best practices for planning and construction of thermal networks identified in the EU
[308] Dahash et al. (2021) Techno-economic and exergy analysis of tank and pit thermal energy storage for renewables district heating systems

- **Appropriate geographical and temporal granularity,** achieving a compromise between representing the location, temporal and quality aspects of (waste) heat and considering the data availability and model feasibility. This is, however, a problem common to all modelling of (district) heating and cooling in the EU, and modelling approaches such as the use of archetypes can be employed;
- **Disaggregation of results for waste heat and cold,** as for policymakers to understand their potential contributions to the EU's heating and cooling sector, it is necessary that these contributions are not aggregated with that of renewable heat and cold.

Eurostat reporting on waste heat is a limiting factor for adequate representation in energy systems models. A review of Eurostat reporting of waste heat is given by the JRC (2021).[309] The JRC highlights that waste heat of high temperature can be used multiple times ('cascading use'), but that "use of waste heat and cold is not easy to account for using the standard energy balances methodology", and that hence each cascaded use of waste heat is accounted for as new energy, with a primary energy factor of 1. Moreover, waste heat is currently categorised under "other sources".[310] In addition to not allowing better analysis of waste heat statistics, this means that Eurostat definitions are not in line with the REDII. Therefore, while explicit accounting of waste heat in Eurostat's energy balance would allow for a better representation of it by energy modellers there are actions to be taken to achieve this.

The analysis of relevant heating and cooling decarbonisation scenarios and other modelling data confirms that waste heat and cold are still insufficiently represented in the main modelling tools used for EU policymaking. The METIS study "Cost-efficient district heating development"[311] demonstrates the capabilities of the METIS heat model by analysing the cost-efficient decarbonisation of the EU district heating systems. Nine district heating systems archetypes are developed, none of which rely on waste heat for some of its needs. The main reason for this seems to be the study maps the archetypes to 2030 based on district heating supply scenarios developed in another study[312], which in turn did not consider the waste heat potential. Moreover, modelling based on archetypes cannot be generalised as waste heat potential are very site specific. This illustrates the importance of realisable waste heat potential assessments as inputs for modelling exercises.

[309] JRC (2021) Defining and accounting for waste heat and cold
[310] Eurostat (2019) Energy balance guide - Methodology guide for the construction of energy balances & Operational guide for the energy balance builder tool
[311] Artelys (2018) METIS Studies - Study S9 - Cost-efficient district heating development
[312] Fraunhofer ISI et al. (2017) Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables) - Work package 3: Scenarios for heating & cooling demand and supply until 2020 and 2030; Work package 4: Economic Analysis

Another example concerns the development of scenarios through the PRIMES energy system model. In the steam-heat model of PRIMES, the power, industrial and district heating sectors are connected, but representation of industrial or other waste heat sources currently is not explicit and falls into the category of ambient heat.[313] Data of policy scenarios developed with PRIMES also does not explicitly report the contributions of waste heat – for example the scenarios employed for the impact assessment of the Fit-for-55 package.[314]

4.2.2. Economic and financial barriers

4.2.2.1. Profitability/long payback period

Profitability-related issues of waste heat utilisation is a fundamental barrier for the utilisation of waste heat. There exists a number of interrelated challenges regarding the economics of waste heat utilisation (with issues related to pricing signals and project complexity/uncertainty addressed in the following sub-sections):[315]

- **High investment volumes:** The recovery and utilisation of WH/C can require significant investments in the form of heat exchanges, monitoring and control, and other on-site equipment. Moreover, depending on the waste heat source further investments are required to address the temporal/location/quality mismatch. Typical solutions will include thermal energy storage, heat pumps to upgrade temperatures (large-scale or at the consumer sites), and refurbishing of the heating/cooling networks to reduce operating temperatures. Bottlenecks in the heat pump supply chain[316] may also increase costs for non-conventional waste heat projects (or delay them);
- **Low valuation of waste heat:** District heating operators typically have a profit motive or a mandate to develop or purchase waste heat only when competitive to other options (while considering other objectives such as decarbonisation of heating systems). Thus, prices paid for waste heat may be low and insufficient to recover investments, especially in summer when heat demand is low and excess waste heat is available from more sources (as highlighted by three survey respondents);
- **Opportunity costs for waste heat providers:** In addition to potentially having a low valuation, providing waste heat according to contractual requirements may in certain situations call for providers changing the operation of their assets (see the EMB3Rs case study in the annex). Hence, an opportunity cost may be associated with waste heat provision that is higher than the potential revenues, making the business case infeasible;
- **Long payback period:** as a consequence of the high upfront costs and potential low prices for the heat, payback periods for associated investments can be high while providing waste heat is not a core business of the companies, which thus require low payback periods, such as 2-3 years. Moreover, district heating operators will have much longer depreciation periods for their investments (10 year or more), creating a divergent view between waste heat suppliers and offtakers.[317]

[313] E3-Modelling (2018) PRIMES model - Version 2018 - Detailed model description
[314] European Commission (2021) Policy scenarios for delivering the European Green Deal
[315] Austrian Institute of Technology and Euroheat & Power (2020) Discussion Paper - The barriers to waste heat recovery and how to overcome them?
[316] European Climate Foundation and European Heat Pump Association (2023) EU Heat Pump Accelerator - A joint plan for boosting heat pump deployment and meeting the REPowerEU targets
[317] Austrian Institute of Technology and Euroheat & Power (2020) Discussion Paper - The barriers to waste heat recovery and how to overcome them?

Profitability is an issue for all waste heat sources, for example data centres. Data centres have most waste heat available in summertime, and while thermal energy storage solutions can be deployed (e.g. aquifer TES in the Netherlands), this is not always the case. Also, frequently district heating operators are not able to price the waste heat for offtake (or are unwilling to offer higher prices considering other alternatives). Moreover, investments are necessary to recover the waste heat, upgrade it (as it is typically low quality in the absence of widespread liquid cooling in data centres) and sometimes provide heat from back-up sources, Hence, data centre operators argue that they often offer waste heat at a loss, but that it is still required to obtain a 'social license to operate'. Five other stakeholders have supported this as a main barrier in their qualitative responses to the survey, highlighting aspects such as waste heat sale not being a core activity of the owners of industrial and unconventional waste heat alike.

Although the profitability and long payback period of many waste heat utilisation projects constitute a barrier to their development, WHU can be a competitive solution.

As Tilia (2021)[318] indicates, the decarbonisation of district heating and cooling systems brings economic benefits, and targeted actions can significantly increase the competitiveness of renewable and waste heat and cold such as technological innovation (particularly in system integration), cost reductions through learning effects and exploitation of synergies with other local and urban infrastructure. Thus, public support to waste heat utilisation projects is not meant to compensate for the lack of competitiveness of the solutions – rather, it aims to achieve dynamic economic efficiency by bringing down the cost of such solutions in the long-term, and to internalise positive climate, environmental and system integration externalities of waste heat utilisation (for example, reduced air pollution, greenhouse gas emissions or, compared to individual heat pump-based solutions, reduced electricity network congestion). As such, Tilia indicates that direct and indirect financial support instruments are a key success factor for the decarbonisation of heating and cooling systems.

Even when subsidies are available to internalise positive externalities and address the profitability issues of WHU, they may be inadequately designed, representing a barrier in practice. The EMB3Rs case study (all case studies are detailed in the annex) highlights that support mechanisms open to various decarbonisation solutions (not only waste heat and cold utilisation) may not be adequate due to the specificities of waste heat utilisation due to for example the higher risks faced by waste heat suppliers and district heating and cooling system operators. Moreover, the period for implementation of the subsidies may be short compared to the long lead time for developing waste heat projects, as illustrated by the Amsterdam Metropolitan Area case study. The StEB Köln / CELSIUS case study shows that subsidy mechanisms targeting larger projects (for example aiming to decarbonise an entire neighbourhood) may not be suitable for smaller projects leveraging non-conventional small waste heat sources for decarbonising individual end-users.

Subsidies can also require that recipients own the subsidised assets, making it more difficult to implement waste heat as service solutions, where a third-party would own and operate the waste heat recovery assets instead of the facility owner. Furthermore, financing mechanisms for heating and cooling are usually targeted at projects, with a lack of support mechanisms for

[318] Tilia (2021) Integrating renewable and waste heat and cold sources into district heating and cooling systems Case studies analysis, replicable key success factors and potential policy implications

planning activities. There is also over-reliance on EU funds (as opposed to national ones) due to the insufficiency of national funds.[319]

4.2.2.2. Inadequate pricing signals

Inadequate price signals - when prices do not internalise all the costs and benefits of the different heat and cold sources - distort competition between the waste heat and other sources. Inadequate pricing signals involves aspects affecting both the costs as well as possible revenue streams (including subsidies) of waste heat and alternative solutions (fossil-based, but also renewable heat and cold). The main issues related to price signals to consider are:

- **Carbon pricing and energy taxation:** Carbon pricing and energy taxation is seen as essential to increase the competitiveness vis-à-vis fossil sources, a challenge shared with renewable heating and cooling sources.[320,321] Thomas et al. highlight the importance of carbon pricing for decarbonising the building sector in EU, while indicating it needs to be combined with other policies in order to incentives the deployment of clean solutions, considering demand for heating is highly inelastic. The authors also indicate that the potential of adequate carbon pricing (and also energy taxation) can be enhanced if the revenues are recycled towards measures incentivising clean heating sources and energy efficiency measures for buildings.[322] Lygnerud et al. (2021)[323] indicate carbon prices should be set at the level of forecasted damages from climate change, and that national carbon pricing schemes have a role to complement the EU ETS. While the CO2 pricing can have incentivising effects to cleaner technologies, economists also acknowledge that in absence of the wide access to cheaper and renewable or clean energy, the cost effectiveness of the excessive measures could put disproportionate burden on industries and on the purchasing power.
  This final cost of energy includes also high electricity excise taxes, other levies and VAT disincentivising the use of heat pumps to upgrade (waste) heat. For example, many Member States apply the standard VAT rate for electricity.[324] Some are however considering tax exemptions on electricity consumption for the operation of heat pumps, such as Finland[325];

- **Subsidies to alternative solutions:** while explicit or implicit subsidies to fossil fuels may exist (e.g. in the form of direct subsidies but also through reduced taxation respectively), this issue also covers the provision of subsidies to alternatives such as renewable heat or high-efficiency cogeneration, when the same or similar subsidies are not available to the utilisation of waste heat.[326,327]

[319] Energy Cities (2023) EU Tracker - Local Heating and Cooling Planning in EU Member States
[320] ETIP SNET and RHC (2022) Coupling of Heating/Cooling and Electricity Sectors in a Renewable Energy-Driven Europe
[321] Trinomics et al. (2021) Policy Support for Heating and Cooling Decarbonisation - Roadmap
[322] Thomas et al. (2021) Pricing is just the icing: The role of carbon pricing in a comprehensive policy framework to decarbonise the EU buildings sector.
[323] Lygnerud et al. (2021) Low-Temperature District Heating Implementation Guidebook. Final Report
[324] EHPA (2023) VAT on heat pumps and electricity in Europe
[325] Council Implementing Decision (EU) 2022/1004 of 17 June 2022 authorising Finland to apply a reduced rate of taxation to electricity supplied to certain heat pumps, electric boilers and recirculating water pumps
[326] Wheatcroft et al. (2020) The Role of Low Temperature Waste Heat Recovery in Achieving 2050 Goals: A Policy Positioning Paper
[327] University of Aberdeen et al. (2023) Overview of Heating and Cooling: Perceptions, Markets and Regulatory Frameworks for Decarbonisation. Deliverable 3 – Overview of monetary and non-monetary incentives for the uptake of District Heating and Cooling and Heat Pumps

- **Valuation of power system flexibility:** In countries where power system flexibility is in high demand, modern district heating systems equipped with multiple sources have the capability to optimise their operations. By responding to pricing signals for electricity and heat supply and demand, these systems can effectively arbitrate between various energy sources.[328] Additionally, by leveraging thermal energy storage, they can provide valuable flexibility to the power system. This flexibility includes services such as balancing the grid and managing congestion effectively. However, this requires that flexibility is adequately valued by systems operators and market parties, while currently there are still multiple barriers for the provision of flexibility from small and new actors across the EU despite improvements, as indicated for example by ACER (2021)[329] and more recently smartEn (2023)[330] and ENTSO-E (2023).[331] Both payment for flexibility provision as well as signals to implicit flexibility (such as appropriate electricity network tariff structures) reflecting the system benefits of the flexibility solutions should be pursued, as highlighted by one survey respondent.
  As the need for power system flexibility grows, this could become a significant source of revenues for waste heat providers and district heating operators, as long as the flexibility services are adequately valued. Moreover, non-monetised longer-term flexibility benefits of collective heating solutions such as avoided electricity network congestion may not be appropriately considering in heating and cooling decarbonisation plans (further discussed in section 4.3.3).

While energy taxation issues refer especially to low energy excise taxes on fossil fuel consumption, the taxation of (waste) heat may also distort pricing signals. For example, in Denmark a surplus heat tax exists, taxing fuel-based waste heat from processes that is used for space heating or cooling or water heating. The purpose of the tax is to incentivise energy efficiency and reduce the surplus heat generation. Since 2022, companies may be exempted from the tax when selling the waste if they are part of an energy efficiency scheme in accordance with the Heat Supply Act. This exemption should facilitate the external utilisation of waste heat while at the same time incentivising energy efficiency measures by the provider.[332]

The most important role of pricing signals is to guide investment decisions in the heating and cooling sector, although price signals also affect the operation decisions of waste heat providers, heat network operators and consumers. Heat and cold production, transport and end-use equipment have long technical lifetimes, and while modern district heating systems operators may arbitrage between different heat sources in reaction to prices, investments will constrain the options available to operators and consumers. Hence, pricing signals will in the future play a role guiding the operational decisions of actors (thus also providing flexibility to the energy system), but first and foremost should effectively signal investments in clean heating and cooling technologies.

[328] Tilia (2021) Integrating renewable and waste heat and cold sources into district heating and cooling systems Case studies analysis, replicable key success factors and potential policy implications
[329] ACER (2021) ACER Electricity Wholesale Market Volume - 2020MMR. Focus: Barriers to efficient price formation and easy market entry and participation for new market entrants and smaller actors
[330] smartEn (2022) The smartEn Map 2022 – Ancillary Services
[331] ENTSO-E (2023) Study on Power and Heat Sectors: Interactions and Synergies
[332] Danish Tax Administration - E.A.4.6.10 Waste heat

4.2.2.3. Project uncertainty, complexity and risk aversion of DHC operators/split incentives

Complexity, uncertainty, and risk aversion for waste heat projects are critical barriers. Even if pricing signals are correctly set and a waste heat utilisation project is demonstrably profitable, it may not go ahead. The uncertainties around a waste heat utilisation project are multiple:[333]

- The **availability and quality of the waste heat source may vary** in the long-term, as it depends on processes in sectors such as industry, services, waste and wastewater management, and transport, as well as on the companies in those sectors not going bankrupt or relocating (so-called termination of the waste heat source).[334] Three stakeholders indicated this as a main issue in their survey responses. This is different than the temporal and quality mismatch discussed in section 4.3.1, although dependency issues are higher for high-temperature waste heat sources, as these are more difficult to replace;
- The **valuation of waste heat and other pricing signals** discussed in the sub-sections above are also uncertain, with prices of waste heat, and competing (fossil) commodity and of ETS emission allowances / national carbon markets varying and impacting investment decisions;
- The **electricity price** also influences waste heat projects, which often depend on heat pumps for upgrading or supplementing the waste heat, thus affecting especially low-temperature waste heat sources.[335] The uncertainty of electricity prices is also linked to uncertainty of flexibility services in the power system, although they are not fully correlated. A survey respondent indicates in this regard that taxes on electricity consumption are also key.

Uncertainty influences investment decisions of waste heat providers. Moreover, it represents a barrier also due to the complexity of the waste heat utilisation projects, which often involved multiple parties (and at least an offtaker party). Heat offtakers such as district heating operators typically prefer heat sale agreements with a long duration, which waste heat providers may be unwilling to provide.[336] Moreover, district heating operators may prefer solutions they are more familiar with, such as renewable heat and large-scale heat pumps.[337] Or certain parties may be best placed to own and operate certain assets for waste heat recovery and transmission, but lack the required expertise to operate in hazardous environments such as industrial facilities or sewers, as highlighted by the StEB Köln / CELSIUS case study (detailed in the annex).

Trade-offs may exist between addressing project uncertainty and complexity. One interesting solution to address waste heat availability and counterparty bankruptcy risks is to source heat from multiple providers (waste and/or renewable-based). But the unbundling of vertically integrated district heating operators and the introduction of third-party access

[333] Austrian Institute of Technology and Euroheat & Power (2020) Discussion Paper - The barriers to waste heat recovery and how to overcome them?
[334] LSE et al. (2021) ReUseHeat D2.3 Efficient Contractual Forms and Business Models for Urban Waste Heat Recovery
[335] Lygnerud (2023) Urban waste heat recovery as an enabler of the energy transition policy implications and barriers
[336] Austrian Institute of Technology and Euroheat & Power (2020) Discussion Paper - The barriers to waste heat recovery and how to overcome them?
[337] Lygnerud (2023) Urban waste heat recovery as an enabler of the energy transition policy implications and barriers

requirements facilitates the connection of waste heat suppliers to networks but contributes to the contracting complexity of the projects.[338] Mobile thermal energy storage solutions can serve to reduce dependency risks, serving as an alternative to heat transport through networks. Mobile thermal energy storage reduces the dependency of both end-users and (waste) heat providers. In this way mobile thermal energy storage solutions allow providers to diversify the heat offtakers, and consumers to diversify their heat supply structure.

In order to address the lack of incentives for district heating and cooling operators to connect third-party suppliers to the network, third-party access (TPA) requirements can be imposed but are not always an appropriate solution. Tilia (2021)[339] indicates TPA rules are one of the national policies critical for the successful decarbonisation of heating and cooling systems. However, TPA rules may not be economically efficient for all networks, as unbundling between heat/cold production and distribution may not be practical in smaller networks, as the lack of coordination between multiple producers and consumers may actually lead to an inefficient system operation, and as other solutions may be more appropriate to reduce costs to consumer and decarbonise the systems. Perhaps most importantly, older district heating systems operating at higher temperatures will just not be suitable for many waste or renewable dispersed, lower-temperature heat sources. In such systems, TPA rules may not be adequate as technical aspects limit the capacity to provide third parties the possibility to inject heat.

TPA rules for heating and cooling systems are not in place in many Member States, and there is significant variation in the exact rules in the Member States that do have TPA. The appropriateness of TPA rules depend among other factors on the ownership structure of the DHC system and any unbundling rules in place, the size of the system and the competitiveness of third-party heating and cooling providers. Moreover, TPA rules are in themselves not sufficient to ensure the integration of third-party sources and need to be combined with other measures.[340]

Policymakers have tried to address uncertainties through other mechanisms besides TPA requirements, such as regulating the (waste) heat price. Since 2022, a regulation is in place in Denmark setting a price ceiling for the tariffs district heating operators can charge for purchasing and supplying waste heat. The price ceiling is based on the average costs of the cheapest renewable heating alternative. The price ceiling should be robust to short-term cost fluctuations and is fixed for the duration of the heat supply agreement. Waste heat providers with a capacity below 250 kW are exempted, and other exceptions exist for temporarily exceeding the price ceiling or for district heating systems with atypical costs. The approach should reduce uncertainty, for example for data centre operators, although a definite methodology for setting the price ceiling should still be developed by the Danish energy regulator.[341]

The involvement of financial investors in waste heat utilisation projects can also constitute a significant financial barrier. Higher availability of funds could help address the profitability barrier, by reducing the cost of capital to financing waste heat projects and

[338] University of Aberdeen et al. (2023) Overview of Heating and Cooling: Perceptions, Markets and Regulatory Frameworks for Decarbonisation. Deliverable 3 – Overview of monetary and non-monetary incentives for the uptake of District Heating and Cooling and Heat Pumps

[339] Tilia (2021) Integrating renewable and waste heat and cold sources into district heating and cooling systems. Case studies analysis, replicable key success factors and potential policy implications

[340] University of Aberdeen et al. (2023) Overview of Heating and Cooling: Perceptions, Markets and Regulatory Frameworks for Decarbonisation. Deliverable 3 – Overview of monetary and non-monetary incentives for the uptake of District Heating and Cooling and Heat Pumps

[341] Monsalves et al. (2022) Regulatory Frameworks and Business Models for Data Centres Integrated to the Energy System: A comprehensive review of the rules and incentives affecting the provision of flexibility and waste-heat recovery by data centres in Denmark

covering a funding gap in the first place. However, waste heat project promotors may lack the knowledge to conduct a risk assessment due diligence in line with standards from the financial sector, while investors typically see the projects as paradoxically too small to attract interest.[342,343] These barriers are confirmed for example in the case of the Irish district heating sector.[344]

4.2.3. Legislative and regulatory barriers

4.2.3.1. Limited replicability of solutions and lack of standardised contracts/tools

Replicating waste heat utilisation solutions is a challenge, especially for unconventional waste heat resources, and the transaction costs can impact the competitiveness of waste heat projects compared to other heat sources.[345] Waste heat projects are characterised by their specificity and locality. While advancements like pre-insulated pipes have facilitated the development of third-generation district heating and cooling systems, the success of these systems and the utilisation of waste heat still rely on several factors. These factors include the location, profile, and quality of heat sources, the condition and quality of the existing building stock, the demand patterns and locations, the status of the heating and cooling networks, and the overall built environment. These considerations, among others, play a crucial role in determining the feasibility and effectiveness of waste heat utilisation in district heating and cooling systems. The projects are also complex, involving a number of actors including equipment and service providers and local authorities, as already discussed. Lygnerud et al. (2021) do note that the number of parties involved in unconventional waste heat projects should decrease as experience is developed.[346]

Limited replicability leads to the need to develop contracts for the heat sale on a case-by-case basis, and permitting procedures for the waste heat utilisation are also not standardised, potentially forming a barrier to the development of the projects. This has been mentioned in detail as a barrier to waste heat utilisation by a survey respondent, and LSE et al. (2021)[347] provide a guide for developing heat supply contracts for urban waste heat projects exactly to address this issue. The importance of this barrier should however not be overstated - a majority of stakeholders interviewed in the ReUseHeat project indicated a preference for tailored contracts, and the StEB Köln / CELSIUS case study indicates that operators are able to develop standard contracts themselves after a few waste heat utilisation projects. This suggests that while publicly available standard contracts could help waste heat utilisation, not all stakeholders agree and furthermore it is important to maintain contractual flexibility to account for the specificities of individual waste heat projects.[348,349]

[342] Lygnerud (2023) Urban waste heat recovery as an enabler of the energy transition policy implications and barriers
[343] Wheatcroft et al. (2020) The Role of Low Temperature Waste Heat Recovery in Achieving 2050 Goals: A Policy Positioning Paper
[344] Government of Ireland (2019) District Heating: Consultation to Inform a Policy Framework for the Development of District Heating in Ireland
[345] Austrian Institute of Technology and Euroheat & Power (2020) Discussion Paper - The barriers to waste heat recovery and how to overcome them?
[346] Lygnerud et al. (2021) Contracts, Business Models and Barriers to Investing in Low Temperature District Heating Projects
[347] LSE et al. (2021) ReUseHeat D2.3 Efficient Contractual Forms and Business Models for Urban Waste Heat Recovery
[348] Tractebel Engineering (2019) ReUseHeat D2.1 Market and stakeholder analysis
[349] Lygnerud et al. (2021) Contracts, Business Models and Barriers to Investing in Low Temperature District Heating Projects

4.2.3.2. Lack of governance and planning, including information on potentials and integration across carriers and with urban planning

A number of governance and planning challenges arise from waste heat utilisation projects being highly specific and complex. More specifically, these planning and governance challenges related to:

- Assessing/mapping the waste heat potential at the national to local levels
- Providing adequate policy signals at the national level to guide regional and local authorities and other stakeholders in planning the decarbonisation of the heating and cooling sector.
- Planning of integrated urban heating and cooling systems,[350] as part of broader urban development / spatial and energy planning activities, anticipating infrastructure synergies[351]

Heating and cooling planning linked to spatial planning and integrated across all levels is critical to facilitate waste heat utilisation. Spatial planning is required to develop waste heat utilisation for district heating and cooling purposes, given the spatial constraints in urban environments detailed in section 4.3.1. The University of Aberdeen et al. (2022)[352] note that heating and cooling planning is a central tool for municipalities to "plan and decarbonise their heat supply within a defined geographic area. It takes into account the local characteristics and potential of heat supply, using an analysis of existing and potential heat supply, scenario modelling and heat strategy development." The authors note also that besides further developing heat planning as part of the broader spatial energy planning in the Member States, it is important to ensure that such planning (particularly if conducted at the national level) has a high resolution as well as involve authorities and stakeholders from the national to the local level, in order to guide the decarbonisation of the heating sector at the local level.

Trinomics et al. (2021)[353] further elaborate on the requirements for integrated planning at national, regional and local level, from the development of a vision and definition of long-term targets, evaluation of renewable (and waste) heat potentials, development of scenarios and enabling local authorities to conduct and implement local heat plans. These issues were viewed as critical by many participants of the project workshop (see results in annex section 6.4).

Heating and cooling planning practices vary significantly across Member States. While some countries are frontrunners in integrated heat planning, notably Denmark and more recently Germany, Austria and Scotland, its broader application in the EU is only starting. A review of the first integrated National Energy and Climate Plans did not find specific mentions of heat planning. Nonetheless, 7 Member States linked spatial energy planning to heat (AT, DK, FR, LU, NL, PL, SI), 7 more implemented or planned a national strategy or programme

[350] Tractebel Engineering (2019) ReUseHeat D2.1 Market and stakeholder analysis
[351] Tilia (2021) Integrating renewable and waste heat and cold sources into district heating and cooling systems - Case studies analysis, replicable key success, actors and potential policy implications.
[352] University of Aberdeen et al. (2023) Overview of Heating and Cooling: Perceptions, Markets and Regulatory Frameworks for Decarbonisation. Deliverable 3 – Overview of monetary and non-monetary incentives for the uptake of District Heating and Cooling and Heat Pumps
[353] Trinomics et al. (2021) Policy Support for Heating and Cooling Decarbonisation - Roadmap

for heat (CY, CZ, DE, HU, IE, LT, and SI), and most Member States referred to the comprehensive assessment required by article 14 of the Energy Efficiency Directive.[354]

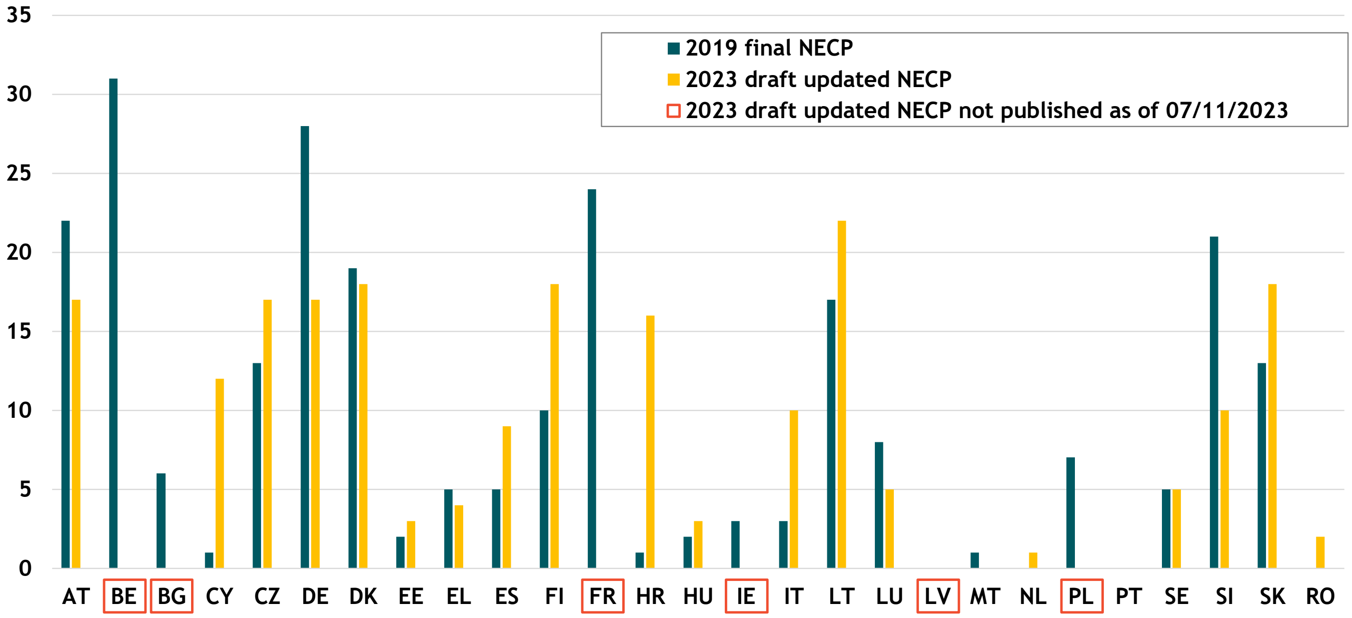
Waste heat utilisation is gaining increasing attention from national authorities. Figure 4-6 presents how many times the terms 'waste heat' or 'surplus heat' are mentioned in the 2019 final NECPs (for all Member States) and 2023 draft updated NEPCs (for those Member States for which one was published by 07/11/2023). The NECPs analysed do not contain relevant mentions of excess heat. Progress can be identified in several aspects:

- 20 out of the 21 Member States with a draft updated NECP mentioned waste heat;
- Total mentions increased from 175 to 205 times (for the 21 Member States for which both NECPs were available);
- Three Member States that did not mention waste heat at all or barely in their 2019 final NECP did so in the draft update (CY, NL, RO), albeit some still to a limited extent;
- Most Member States that mentioned waste heat less often in the draft update started from a high baseline, mentioning waste heat 15 times or more already in their 2019 final NECP.

Waste heat utilisation still requires further attention by national authorities. Five Member States out of 21 with published 2023 draft updated NECPs mentioned waste heat 5 times or less in the documents. Moreover, concrete measures to advance waste heat are necessary more than just mentioning it in the NECPs. An analysis by the JRC of the 2019 final NECPs indicated that "the potential use of waste heat and cold is often overlooked", and that out of the 27 Member States, only seven MSs describe measures "enabling and promoting the use of waste heat from industry" while only four MSs present "an intention to increase the use of waste heat".[355] Another JRC analysis, of the 2018 national comprehensive assessments for heating and cooling, indicates that "several Comprehensive Assessments evaluated only limited number of technologies, namely high-efficiency cogeneration and efficient district heating and cooling, since only those were explicitly required by the EED", recommending that further technologies and heat sources be considered, including waste heat.[356]

[354] University of Aberdeen et al. (2023) Overview of Heating and Cooling: Perceptions, Markets and Regulatory Frameworks for Decarbonisation. Deliverable 3 – Overview of monetary and non-monetary incentives for the uptake of District Heating and Cooling and Heat Pumps
[355] JRC (2021) Assessment of heating and cooling related chapters of the national energy and climate plans (NECPs)
[356] JRC (2018) Synthesis report on the evaluation of national notifications related to Article 14 of the Energy Efficiency Directive

Figure 4-6 Mentions of waste or surplus heat in the 2019 final and 2023 draft updated NECPs



Source: own analysis
Notes: includes 2023 draft updated NECPs published in the Commission website as of 07/11/2023.
NECPs analysed do not contain relevant mentions of excess heat.

Guidance from national and local authorities on the most cost-efficient solutions to decarbonise heating and cooling can be insufficient for private actors making decisions, and additional efforts will be required to increasing the coherence between national and local policies. With the various new obligations in governance and planning arising from the revision of the EED and REDII (see section 4.4.1, a main challenge will be the coordinated development of waste heat assessments as part of the national comprehensive assessments, local heating and cooling plans and NECPs. Moreover, some stakeholders indicate that the indicative nature of the local heating and cooling plans fail to provide sufficient guidance to private actors. For example, the Amsterdam Metropolitan Area case study (detailed in the annex) highlights that the municipality did not have the authority to mandate the implementation of the most cost-efficient solution identified in its heating plan for each area – which in many cases was renewable and waste-based district heating. In the absence of strong coordination from regional and local authorities, assurances that a district heating network will be commissioned on time or even an obligation to connect to it, private actors will often fall back on individual heating solutions. Moreover, in certain Member States, for example some German States, municipalities cannot mandate preferred heating solutions, although this is expected to change in 2024. Further coordination is necessary not only between national and local policies, but also with energy infrastructure planning.[357]

Local planning for heating is still non-existent in almost half of EU Member States, and local planning for cooling in even more countries. As of September 2023, most Member States still lacked an appropriate legal and support framework to assist regional and local authorities in implementing the EED requirements regarding local heating and cooling plans for municipalities above 45 000 inhabitants. Denmark and the Netherlands ranked best in Energy Cities' EU tracker for local heating and cooling plans, but no Member State was ranked as having an ideal mandate and support framework. Support for implementation, when it

[357] Energy Cities (2023) EU Tracker - Local Heating and Cooling Planning in EU Member States

exists, generally consists of guidelines, practice and exchange groups, technical assistance/helpdesks, and coordination platforms at the regional level. But support usually targets supply aspects and even individual topics such as renewable heat, failing to take a more integrated planning approach.[358]

Governance and planning barriers are recognised by a wide range of stakeholders, including potential providers of unconventional waste heat such as data centre operators.[359] Two stakeholders responding to the present project survey highlighted that, in addition to spatial resolution, assessments of the waste heat potential (supporting heat plans) need to have a sufficient temporal and heat quality resolution, given the frequent temporal and quality mismatch of waste heat sources and heat demand, as detailed in section 4.3.1. Another stakeholder highlighted that sometimes the heat potential assessment depends on confidential data from e.g. data centre operators.

4.2.3.3. Accounting of climate and environmental footprint/benefits of waste heat utilisation

The definition of primary energy factors for waste heat by Member States varies and can deviate from EU-level recommendations, disincentivising waste heat utilisation. Several studies highlight the diversity of PEFs and methods used in Member States to define the carbon footprint of district heating systems and specifically of waste heat utilised in such systems, such as the JRC (2023),[360] Trinomics et al. (2021)[361] and Fraunhofer ISI (2022). AIT and Euroheat & Power argue that the primary energy factor (PEF) values of waste heat used in certain Member States such as the Netherlands and Belgium can hinder the utilisation of the resource.[362]

When there is a requirement to raise the temperature of waste heat, and non-renewable electricity is utilised for this purpose or if the waste heat originates from an industrial process reliant on fossil fuels, it can result in a significant carbon footprint. This high carbon footprint associated with waste heat may discourage its utilisation, especially when buildings are striving to meet performance requirements. In such cases, additional on-site renewable energy sources would need to be developed to offset the carbon emissions and achieve the desired sustainability goals. This issue is highlighted in the survey by two stakeholders as a main barrier to waste heat utilisation. There is also an ongoing discussion about whether, and to what extent, excess heat from waste-to-energy combined-heat-and power plants may be counted as waste heat.

Emission requirements for individual networks may in certain cases disincentivise the use of waste heat. Even if the carbon emissions are fully allocated to the industrial processes and not the waste heat**.** For example, when the interconnection of two networks with separate PEFs is hindered as that would lead to them having a single average PEF, thereby increasing that of the network with originally a lower PEF due to the use of renewable and waste heat.[363,364]

[358] Energy Cities (2023) EU Tracker - Local Heating and Cooling Planning in EU Member States
[359] NeRZ and eco (2019) Utilization of Waste Heat in the Data Center
[360] JRC (2023) Consumers in district heating and cooling
[361] Trinomics et al. (2021) Policy Support for Heating and Cooling Decarbonisation - Roadmap
[362] Austrian Institute of Technology and Euroheat & Power (2020) Discussion Paper - The barriers to waste heat recovery and how to overcome them?
[363] DENA (2018) Obstacles and suggestions of external waste heat projects - Panel: 5. Business models, finance and investment in the age of digitalisation
[364] Trinomics et al. (2021) Policy Support for Heating and Cooling Decarbonisation - Roadmap

Further adjustments could be considered regarding EU legislation impacting waste heat utilisation for indirect applications. Stakeholders argue that the definition and recognition in applications other than for district heating and cooling such as heat-to-power applications could be improved. For example, regarding rewarding under the EU ETS of industrial sites that recover waste heat to produce electricity. These issues related to definition are mentioned not only in the literature but also by three survey respondents.

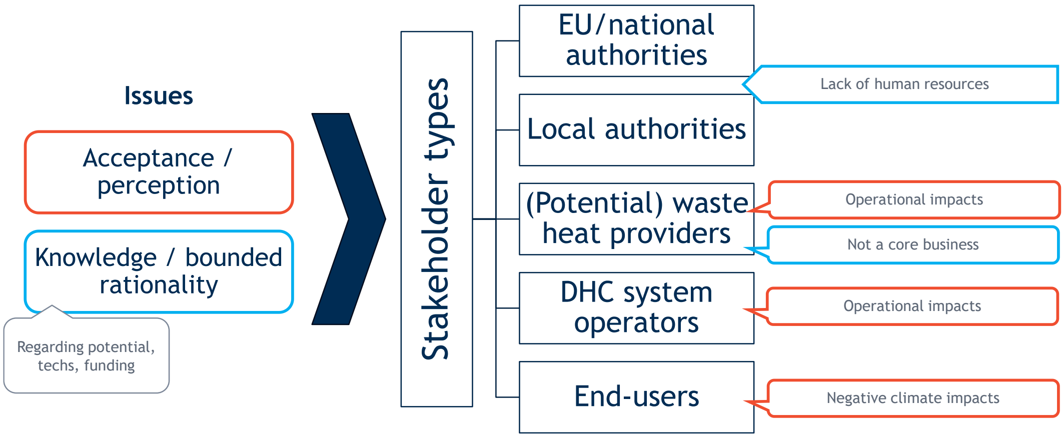
4.2.4. Societal barriers

4.2.4.1. Stakeholders' knowledge and acceptance of waste heat utilisation projects

This barrier can be separated into knowledge and acceptance and knowledge barriers by actors directly affecting waste heat utilisation projects and stakeholders, as illustrated in Figure 4-7:

- **Knowledge** refers to the familiarity/awareness of different actors with waste heat recovery and its utilisation in different applications. It also includes the capacity to properly employ this knowledge in its decision making. Given the inclusion of issues with the decision-making process of stakeholders, the "Overview of heating and cooling - Perceptions, markets and regulatory frameworks for decarbonisation" project refers to this as the **bounded rationality** framework condition[365];
- **Acceptance** refers to the negative perception by various stakeholders of waste heat utilisation projects, due to fear of negative impacts on businesses' operations and revenues, personal expenditures or the climate.

Figure 4-7 Knowledge and acceptance issues of stakeholders



Acceptance issues must be properly addressed by policymakers as part of a coherent approach to facilitate waste heat. To Fontaine et al. (2020)[366] acceptance issues are "the most obvious pitfall of heat recovery" and must be considered at the facility but also societal

[365] Fraunhofer ISI et al. (2023) Overview of Heating and Cooling: Perceptions, Markets and Regulatory Frameworks for Decarbonisation
[366] Fontaine et al. (2020) Energy recovery on the agenda. Waste heat: a matter of public policy and social science concern

level. A number of stakeholders can lack knowledge or show opposition to waste heat recovery, including:

- Authorities across all levels (EU, national and local);
- District heating operators;
- Operators of installations with potential for waste heat recovery;
- End consumers.

Waste heat providers for example can have numerous reasons to not be interested in such projects, including 1) that they are not part of the core business and will provide only limited revenues, 2) limited human and financial resources; 3) fears for the impacts on the assets' operation.[367]

Several studies highlight current and future challenges with the existence of sufficient human resources necessary to deploy waste heat solutions and district heating and cooling solutions more broadly.[368,369] In addition, the knowledge and capacity of public authorities is also highlighted in the literature as well as by two stakeholders in their survey responses. These issues are however not analysed further in this section as they is not an issue specific to energy system integration, and can be solved in the medium-term, thus without an indication that there should be an issue in the long-term (as long as the appropriate measures are adopted). The Energy Cities EU tracker for local heating and cooling planning highlights staffing issues as the key barrier for local administrations.[370]

Many stakeholders consider that despite the significant potential, the barriers to waste heat utilisation limit its economic potential. The results of the stakeholder workshop polls indicate that over half of respondents agree with the statement "waste heat could be a relevant but secondary source, with barriers limiting its potential" (annex section 6.4).

Social acceptance can be an issue for district heating and cooling networks more broadly, whether they employ waste heat or other sources, such as for example disruptions caused by works.[371] Acceptance is indicated in a recent study as one of the most frequently mentioned framework conditions for the deployment of district heating and cooling in the EU. Nonetheless, the perception of district heating is generally high in the EU, although it can vary significantly from country to country. Acceptance is also higher for existing users compared to non-users.[372]

Acceptance issues may arise not only from opposition to waste heat utilisation, but also from a perception that its contributions to decarbonisation efforts are marginal at best. Stakeholders may perceive waste heat as marginal because of a focus on the electricity and gas systems, issues with the representation of waste heat in energy modelling[373] (as detailed in section 4.3.1), or because of the perception that the various barriers to waste heat

[367] Austrian Institute of Technology and Euroheat & Power (2020) Discussion Paper - The barriers to waste heat recovery and how to overcome them?
[368] Trinomics et al. (2021) Policy Support for Heating and Cooling Decarbonisation - Roadmap
[369] Lygnerud (2023) Urban waste heat recovery as an enabler of the energy transition policy implications and barriers
[370] Energy Cities (2023) EU Tracker - Local Heating and Cooling Planning in EU Member States
[371] TNO et al. (2021) Best practices for planning and construction of thermal networks identified in the EU
[372] Fraunhofer ISI et al. (2023) Overview of Heating and Cooling: Perceptions, Markets and Regulatory Frameworks for Decarbonisation
[373] Austrian Institute of Technology and Euroheat & Power (2020) Discussion Paper - The barriers to waste heat recovery and how to overcome them?

utilisation will always severely limit its potential. Poll results during the project workshop indicate that:

- 16 participants agreed with the statement that "waste heat could be a relevant but secondary source, with barriers limiting the economic potential";
- Few participants were of the opinion that "Waste heat will be a marginal resource, with barriers severely limiting the economic potential";
- Twelve stakeholders agreed that "Waste heat could be a major resource for decarbonising the EU energy system, with a significant economic potential".

There are opposing views on how much waste heat should be incentivised and its equivalence to renewable heat:

- **Supporters of waste heat utilisation put forth the argument that the emissions resulting from the activity would happen regardless, and therefore should not be attributed solely to the waste heat.** They contend that in the future, industries and other sources of emissions will be required to decarbonise, largely through mechanisms like the EU Emissions Trading System (ETS). Consequently, waste heat, in the long run, is expected to originate from renewable or low-carbon sources as these decarbonisation efforts take effect. They argue moreover that waste heat can be used multiple times in sequence ('cascading use'), as high temperature heat can be used in cascading applications with gradually lower temperature requirements. This would be a highly efficient application that should not be disincentivised with a high (fossil) PEF. The AIT and Euroheat & Power[374] as well as four survey respondents argue that waste heat is not treated as an equivalent to renewable energy. As noted in section 4.4.1 changes have been made in the revised REDII, although waste heat and cold are still not considered fully equivalent to renewables in the legislation.
- **More critical stakeholders** argue against the equivalence of renewable energy and waste heat and cold. In this regard, a survey respondent provided a critical view on waste heat utilisation, indicating that, in line with the energy efficiency first principle, waste heat should be reduced and, in the future, even fully eliminated, the energy system should not rely on the availability of waste heat indefinitely. The stakeholder indicates district heating networks are assets with a long depreciation period, and that a lock-in into waste heat disincentivising energy moderation or use of renewable heat should be avoided.

Authorities are developing interesting approaches to try to reconcile the objectives of increasing energy efficiency and promoting renewable energy with advancing waste heat utilisation, although further progress is necessary:

- The recently agreed amendments to the Renewable Energy Directive constitute a middle-ground in this regard, allowing Member States to employ waste heat and cold to

[374] Austrian Institute of Technology and Euroheat & Power (2020) Discussion Paper - The barriers to waste heat recovery and how to overcome them?

meet the buildings, industry, heating and cooling, and district heating and cooling renewable targets to varying extents;
The Flanders Heat Plan separately reports on the renewable and non-renewable shares of waste heat. Although currently only waste incinerations facilities are assumed to provide renewable waste heat, the methodology could be expanded in the future for e.g. industrial facilities operating on renewable fuels;

- Denmark has adjusted its surplus heat tax so that providers selling waste heat to district heating networks can be exempted from the tax, waste if they are part of an energy efficiency scheme in accordance with the Heat Supply Act.[375]

Emitting guarantees of origin for waste heat should be possible with the revised European Standard CEN-EN 16325 on guarantees of origin (GOs). The standard revision is currently under approval,[376] having been expanded to include GOs for heating and cooling, likely including waste heat and cold (considering the draft standard developed under the FastGO project.[377] This should allow waste heat providers to differentiate it from fossil-based heat, improving the acceptance of waste heat, for example from data centres.[378]

4.3. Recommendations on the utilisation of waste heat

4.3.1. Recent or planned policies and measures

This section provides an overview of the recent or planned policies and measures at the EU level addressing the topic of waste heat and cold utilisation. The main relevant EU policies and measures for waste heat utilisation include:

- ✓ The 2016 **EU Heating and Cooling Strategy** briefly addresses the utilisation of waste heat and cold, naming barriers that are still relevant today ("lack of awareness and of information on the resource available; inadequate business models and incentives; a lack of heat networks; and lack of cooperation between industry and district heating companies"), with a specific action to promote innovation in the use of renewable and waste heat in CHP;
  The **Renewable Energy Directive II 2018/2001/EU** (REDII) adopted in 2018 already introduced specific measures for renewable and waste heating and cooling. The compromise agreement for the amendment of the REDII agreed in June 2023[379] contains a number of new provisions regarding waste heat and cold as well as district heating and cooling. The revised REDII thus contains provisions on:
  - Specific targets for renewables and waste heat, including rules of how waste heat and cold can be counted, in:
    - Buildings - art 15a(1a)

[375] Danish Tax Administration - E.A.4.6.10 Waste heat
[376] CEN-CENELEC - prEN 16325 - Guarantees of Origin related to energy - Guarantees of Origin for Electricity, gaseous hydrocarbons, Hydrogen, and heating & cooling
[377] https://www.aib-net.org/sites/default/files/assets/news-events/AIB%20Project-Consult/FaStGO/FASTGO%20task%202%20part2%20EN%2016325_revision_carrier-specific_20200525_consultation.pdf
[378] ENTSO-E (2023) Study on Power and Heat Sectors: Interactions and Synergies
[379] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CONSIL:ST_10794_2023_INIT

        - Industry – art. 22a(1)
        - Heating and cooling - art. 23(1)
        - District heating and cooling – art. 24(4)
    - Requirement for Member States to conduct an assessment of their potential of energy from renewable sources and of the use of waste heat and cold in the heating and cooling sector - art. 23(1a);
    - Inclusion of the creation of risk mitigation frameworks to reduce the cost of capital for renewable heat and cooling and waste heat and cold projects as an option for Member State to achieve the heating and cooling sectoral target – art. 23(4-5);
    - Requirement for Member States to ensure operators of district heating or cooling systems above 25 MW_{th} are encouraged to connect third-party suppliers, including of waste heat and cold art. 24(4a);
    - Requirement for Member States to put in place a coordination framework for facilitating waste heat and cold, where needed – art. 24(6);
    - Requirement for Member States on assessing and promoting the valuation of system services from district heating and cooling – art 24(8);
    - Extension of the guarantee of origin system for other carriers than electricity, being implemented for waste heat through the revised European Standard CEN-EN 16325, currently under approval.
- ✓ The recast **Energy Efficiency Directive 2023/1791** (EEDII) contains provisions related to (waste) heat and cold utilisation. The recast version includes thus provisions related to:
    - Metering for heating and cooling- art. 14;
    - Revised rules for the national comprehensive heating and cooling assessment and associated cost-benefit analysis – art. 25;
    - Requirement for regional and local authorities in municipalities with a population higher than 45 000 to prepare local heating and cooling plans – art. 25(6)
    - Revised definition of efficient district heating and cooling systems – art. 26(1);
    - Requirement for Member States ensuring non-efficient district heating and cooling system operators develop a plan to increase energy efficiency and renewable energy – art. 26(5);
    - Requirement for waste heat utilisation for data centres – art. 26(6)
    - Requirements for installation level cost-benefit analysis for specific types of installations above a certain total energy input threshold, with Member States having to remove barriers and provide support for the utilisation of waste heat from new or refurbished facilities – art. 26(7);
    - New requirements for Member States developing the comprehensive assessment of national heating and cooling potentials, including the consideration of waste heat (Annex X).

- ✓ The **Governance Regulation (EU) 2018/1999**, which includes specific Member State reporting requirements on the heating and cooling sector as well as on waste heat specifically – art. 20 and Annex I;
- ✓ The 2020 **EU Strategy for Energy System Integration** highlights the importance of WHU as part of the "circular energy system and 'energy-efficiency-first'" pillar, with a specific action for promoting the reuse of waste heat from industrial sites and data centres "through strengthened requirements for connection to district heating networks, energy performance accounting and contractual frameworks" as part of the revision of the REDII and the EED;
- ✓ **The REPowerEU Plan** explores the impacts of and how to achieve a higher RES target in 2030, including what this would mean for the heating and cooling and district heating and cooling (DHC) sub-targets.[380]
- ✓ The proposed revision of the **Energy Taxation Directive** aims to introduce a new structure for minimum tax rates based on the real energy content and environmental performance of fuels and electricity, which will ensure that the most polluting fuels are taxed the highest;
- ✓ The **new EU Emissions Trading Scheme (ETS 2)** was agreed in 2023 and should price emissions from fuel combustion in the buildings, transport and additionally sectors (especially small industry not covered by the original EU ETS), with a launch scheduled for 2027.

4.3.2. Recommendations to advance waste heat utilisation in the EU

This section provides recommendations to advance waste heat utilisation in the EU. There are many possible measures that could be adopted in the short and medium-term, which need to consider the progress already done. Several new provisions to promote the utilisation of waste heat and cold in the EU have been introduced with the revision of the REDII and EED among others, as indicated in the previous section. These new provisions take into account some of the recommendations from stakeholders put forward in various studies and policy papers and are expected to partially or fully address some of the barriers identified.

The impacts of these new provisions will need to be evaluated in the future before introducing related additional measures to close remaining gaps. But the decarbonisation of the heating and cooling sector requires significant planning and long-term investments, and as such achieving impacts by 2030 will require immediate action, while any projects to be commissioned by 2040 should start planning in the early 2030s. These considerations frame the recommendations detailed in this section, which aim to complement the recently adopted provisions, and monitor their implementation in order to address remaining gaps in the next policy cycle. Recommendations are generally addressing the European Commission, if other stakeholders are needed or addressed, they are explicitly mentioned.

[380] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022SC0230&from=EN

4.3.2.1. Recommendations to address the technical barriers

Recommendation 1: Increase support within research and innovation programming for technologies enabling utilisation of certain waste heat sources
Addressee: European Commission
Related policies & measures: Horizon Europe, SET Plan and Energy Technology & Innovation Platforms
Expected impacts: 2040

The attention dedicated by policy makers, academia and industry to waste heat compared to renewable heat seems to be limited, as evidenced by the proportion of EU funding allocated to waste heat utilisation (see section 4.2.1) and the Renewable Heating and Cooling ETIP Strategic Research and Innovation Agenda,[381] which mentions waste/excess heat only a few times. In the long-term to 2040 and beyond, a number of new challenges should become increasingly apparent for wase heat utilisation.

These include the need for leveraging unconventional sources of waste heat, including from the tertiary sector and hydrogen electrolysers. While the potential and temperatures of such sources are smaller than that of industrial waste heat, they should be explored nonetheless as they could sometimes be more easily exploited – for example new installations could be designed already with the aim to recover waste heat or be combined with the development of low-temperature district heating networks.

Moreover, cooling demand will increase significantly, and thus also the possibility of integration of heating and cooling in 5th generation district heating (and cooling) systems, with low-temperature and possibly double-loop networks. Tilia (2021)[382] highlights that district cooling is a key success factor for the decarbonisation of heating and cooling system, due to the ability to integrate ambient energy and waste cold sources and the synergies with district heating systems.

Hence, further EU support could be given to technologies and applications related to the utilisation of waste heat and cold. Examples where further technological innovation is needed and/or scaling up to commercial levels is required comprise:

- 5th generation district heating and cooling (double-loop) systems;
- Mobile thermal energy storage technologies;
- Liquid cooling technology for e.g. data centre and electrolysers;
- Waste heat recovery from small sources such as wastewater and tertiary buildings;
- Waste heat recovery from future sources, including electrolysers, methanation processes and waste-to-energy with CCS and other CCS applications.

[381] https://www.rhc-platform.org/content/uploads/2020/10/EUREC-Brochure-RHC-SRI-06-2022-WEB.pdf
[382] Tilia (2021) Integrating renewable and waste heat and cold sources into district heating and cooling systems. Case studies analysis, replicable key success factors and potential policy implications

Recommendation 2: Provide guidance for Member States revising the maximum feasible distances for transporting waste heat and other thresholds related to the CBA exemptions under Article 26(8) of the Energy Efficiency Directive (EU) 2023/1791.
Addressee: European Commission
Related policies & measures: Energy Efficiency Directive
Expected impacts: 2030/2040

Member States can exempt installations from the installation-level cost-benefit analysis defined in Article 26(7) of the Energy Efficiency Directive (EU) 2023/1791. However, Member States tend to consider that waste heat utilisation is economically feasible within at most around 20 km from the source, while that distance could be significantly higher depending on specific technical and economic conditions. The Commission could provide a technical guidance for Member States to use when defining the distance and other thresholds so that a larger number of installations where waste heat utilisation would be economically feasible fall under the Article 26(7) CBA requirement.

Recommendation 3: Improve waste heat accounting in Eurostat's energy balance.
Addressee: European Commission, particularly Eurostat
Related policies & measures: Energy Statistics Regulation, Renewable Energy Directive
Expected impacts: 2040

It is difficult with the current energy balance methodology to account for the 'cascading' nature of waste heat, and moreover waste heat sources are categorised as 'other sources.' The latest energy balance methodology has been published in 2019.[383] The revision of the methodology and (based on a Commission proposal) of the Regulation on Energy Statistics (EC) No 1099/2008 could introduce a number of improvements that would not only allow to identify the specific contributions of waste heat but also facilitate the development of databases for energy system modelling. The improvements could include a way to identify how many times a GWh of (waste) heat is used in cascaded manner, as well as introducing specific source categories (such as 'industrial waste heat' and 'non-conventional waste heat'). Discussions regarding waste heat statistics have taken place as part of the Concerted Action on the Renewable Energy Directive,[384] but a clear path should still be identified.

Recommendation 4: Improve the representation of waste heat in EU policy scenarios.
Addressee: European Commission
Related policies & measures: Energy Statistics Regulation, Renewable Energy Directive
Expected impacts: 2040

Current major energy system models used to develop EU policy scenarios still insufficiently represent the potential and contributions of waste heat. This is due to both data limitations (see for example the recommendation 3) and how waste heat is represented within the models. Moreover, the reporting of modelling results often does not provide data for waste heat separately. The Commission plays a central role in the development of these major models by indicating priorities and specifying the improvements to be made in modelling contracts. In conjunction with efforts to improve the data availability, the Commission can require and fund the better representation of waste heat utilisation in energy system models.

[383] Eurostat (2019) Energy balance guide - Methodology guide for the construction of energy balances & Operational guide for the energy balance builder tool
[384] CA-RES Core Theme 3: Decarbonising Heating and Cooling. CT3 Session Highlights of the 1st, 2nd, 3rd and 4th Plenary Meeting

4.3.2.2. Recommendations to address the economic and financial barriers

It is important to emphasise that EU-level actions aimed at addressing economic and financial barriers must be developed in strong collaboration with Member States. This principle applies to all EU measures, but it holds particular significance for those targeting economic and financial barriers. The recent revisions of the Renewable Energy Directive (REDII) and the Energy Efficiency Directive (EED) include measures that directly tackle many of the identified economic and financial barriers. These measures generally provide incentives, rather than imposing obligations, for Member States to implement specific actions. For example, Member States must implement measures to advance the heating and cooling renewable energy target of the REDII, among whose options is included the creation of risk mitigation frameworks to reduce the cost of capital for renewable heat and cooling and waste heat and cold projects.

Member States should also incentivise larger DHC network operators to connect third-party heat suppliers, but not necessarily mandate third-party access. Thus, how far reaching are the measures that address the low profitability, uncertainty and complexity of waste heat utilisation projects is largely a choice of the Member States, with EU provisions providing high-level requirements in this regard. Moreover, funding for waste heat utilisation projects comes disproportionately from EU instruments, particularly in countries with no dedicated instruments to district heating systems. This rationale underpins most of the recommendations of this section.

Recommendation 5: Provide additional funding for planning and feasibility studies, in cooperation with Member States.
Addressee: European Commission
Related policies & measures: Renewable Energy Directive, Energy Efficiency Directive, EU funding for the energy sector
Expected impacts: 2030

Waste heat utilisation faces many profitability and financial challenges. Assessing the feasibility of waste heat projects is central to not only identifying the opportunities, but also correctly assessing the associated benefits, costs, and other constraints. The lack of a proper assessment leads to delays, cost overruns and frequently the cancellation of projects. Hence, feasibility studies can significantly improve the chances of success for waste heat utilisation. But as shown, there is a general lack of funding instruments supporting waste heat projects more broadly and feasibility studies specifically, particularly in countries with no tradition in district heating. Regional and local authorities have also been assigned new responsibilities regarding the local heating and cooling plans and will require the financial resources to develop them. By increasing funding for heating and cooling planning and waste heat utilisation feasibility studies, the EU can support waste heating and cooling utilisation uptake in a cost-efficient manner. Member States are then in turn best placed to provide the bulk of the support for construction of the projects (although this could also be supported through EU funds managed by the Member States, such as was done among others with the Recovery and Resilience Facility).

Recommendation 6: Provide technical assistance for Member States designing and implementing support schemes, including risk mitigation measures such as through insurance/guarantee schemes.
Addressee: European Commission, Member States
Related policies & measures: Renewable Energy Directive, Energy Efficiency Directive
Expected impacts: 2040

In many cases, national funding schemes for waste heat and cold are either nonexistent or have significant drawbacks. These drawbacks can include the lack of support for local planning or feasibility studies, limited availability to larger projects only, or excessively short timeframes for project completion. These issues pose challenges, particularly considering the extensive lead time required for waste heat projects. Funding schemes where only other sources of heat are eligible may distort competition, further deteriorating the business case for waste heat. And implementing waste heat projects is challenging in the first place, even without considering these factors, given their complexity and the significant associated uncertainties. Moreover, paragraph 23(4) of the amended Renewable Energy Directive II requires Member States to implement measures to mainstream renewable energy in heating and cooling, including "risk mitigation frameworks to reduce the cost of capital for renewable heat and cooling".

Therefore, an opportunity exists for Member States introducing or improving support schemes for waste heat utilisation, through direct grants or loans, but also de-risking mechanisms. However, there have been limited studies dedicated to the best way to design such support, no EU-level guidance on the matter exists, nor is there a repository of examples in the Member States. The Commission could therefore support Member States in complying with article 23(4) of the Renewable Energy Directive by providing technical assistance to develop the risk mitigation frameworks and other support schemes. These could address the different types of risks waste heat suppliers, network operators and consumers are subject to, including for example counterparty (e.g. bankruptcy), disruption of supply, and opportunity cost risks.

Recommendation 7: Disseminate good practices for improving pricing signals to waste heat utilisation between Member States
Addressee: European Commission
Related policies & measures: Energy Taxation Directive, EU ETS 2, Electricity Regulation and Directive
Expected impacts: 2030

The economic and financial barriers to the utilisation of waste heat arise from factors which are inherent to it but also factors which are external. External factors include how GHG emissions are priced, energy consumption is taxed, which subsidies are available the different energy carriers and applications, and how flexibility services are valued.

As there exists several EU-level initiatives aimed at improving such price signals, including the ongoing reform of the electricity market design, revision of the Energy Taxation Directive, and creation of a new EU ETS to buildings and transport. Nonetheless, Member States still have an important role to address the economic and financial barriers for waste heat utilisation. Furthermore, they can anticipate some of the ongoing EU initiatives, particularly the Energy Taxation Directive.

While attention to improving price signals for the heating and cooling sector is increasing, there is limited information on how to address issues specific to waste heat utilisation. Good practices do exist – recent examples of Member States which have sought to incentivise the utilisation of waste heat and increased energy efficiency include the Danish reform reducing taxes and removing administrative barriers for the consumption of waste heat[385] and the reduction in Finland of the electricity tax for data centres which comply with certain energy efficiency requirements, including regarding waste heat recovery.[386] The Commission could

[385] https://www.emb3rs.eu/danish-parliament-cuts-taxes-on-excess-heat/
[386] https://www.motiva.fi/files/20768/Energy_Efficiency_of_Data_Centers_in_Finland_-_November_2022.pdf

play a role in disseminating such practices and highlighting how they align with already existing EU principles for ensuring a level playing field in the energy sector.

Recommendation 8: Research regulatory and price-based mechanisms to reduce heat emissions
Addressee: European Commission
Related policies & measures: Industrial Emissions Directive
Expected impacts: 2040

The taxation of heat emissions was mentioned frequently by stakeholders as a measure to incentivise waste heat recovery for on- or off-site utilisation. The underlying principle for restricting heat emissions should be the aim to internalise negative externalities.

Clear externalities exist related to the consumption of the energy products necessary for heat production, which could warrant measures restricting heat emissions to increase energy efficiency. However, such externalities may already be priced in the cost for acquiring these energy products. In any case any non-internalised negative externalities upstream of the value chain should be priced in that purchase cost.

Hence the restriction of heat emissions should be based on the direct negative externalities caused by the emissions themselves. The question thus arises whether heat emissions are a form of pollution or not. This is clearly the case of heat emissions to water, which impact biological processes. But is also the case of heat emissions to air. Positive feedback exists between heat waves and the urban heat island effect caused by heat emissions from buildings due to air conditioner use.[387] Europe will see more frequent and severe heat waves, with important impacts on health,[388] which could be worsened by positive feedback between heat emissions and the urban island effect.

There is therefore a rationale for limiting heat emissions – although this needs to be confirmed by an impact assessment weighing the costs of environmental and health impacts from the heat emissions versus the costs of limiting these emissions. But by incentivising on-site energy efficiency measures and the utilisation of waste heat, it is possible measures targeting heat emissions would show a net societal benefit and even a net financial gain for the actors implementing them.

Disincentivising emissions could use regulatory (that is, establishing emission limits) or price-based mechanisms (such as a heat emission tax). There are many challenges with introducing either approach to limit heat emissions. The Commission could initiate a study on the topic, covering aspects such as:

- Determining the societal cost of heat emissions to water, air and soil;
- Advantages and disadvantages of a regulatory vs price-based approach;
- Sources covered, such as industry, power generation, the built environment and others.

Given the novelty of such measure, it is unlikely it would be in force by 2030. Moreover, there should be a clear reason why the EU should act. Therefore, any study should also assess the EU added value as well as consider the subsidiarity principle. There could be an argument for

[387] Luo et al. (2020) City-Scale Building Anthropogenic Heating during Heat Waves
[388] EEA (2021) Europe's changing climate hazards — an index-based interactive EEA report

action by Member States separately instead of the EU, but the Commission could still start the debate and guide interested Member States in adopting similar measures.

4.3.2.3. Recommendations to address the legislative and regulatory barriers

Challenges related to the governance and planning of waste heat projects are a central barrier from the system integration perspective. Appropriate governance and planning are critical to identify the most beneficial options for utilisation of waste heat and decarbonisation of the EU heating and cooling systems. Tilia (2021)[389] among others highlights appropriate governance and planning as key success factor for the decarbonisation of heating and cooling systems.

Recommendation 9: Clarify the contributions of waste heat and develop principles for its utilisation towards the upcoming 2040 climate & energy targets.
Addressee: European Commission
Related policies & measures: Climate Target Plan 2040, European Climate Law, Renewable Energy Directive, Energy Efficiency Directive
Expected impacts: 2040

The EU Energy System Integration Strategy explicitly recognises the importance of waste heat. Moreover, the potential contributions of waste heat are recognised in e.g. the Renewable Energy Directive and the Energy Efficiency Directive.

But on one hand, there are arguments to minimising waste heat creation. The energy efficiency 1st principle sets the reduction of energy consumption as the first priority, which means that heat production should be first and foremost reduced and waste heat recovered for on-site use. Only unavoidable waste heat should be traded and used off-site. Moreover, achieving full net decarbonisation of the EU economy by 2050 means that unabated fossil fuel consumption should be phased out (potentially with consumption in very hard-to-decarbonise sectors being offset by negative emissions elsewhere – but this will likely not be the case for any sector producing waste heat). Hence waste heat from unabated fossil fuel consumption should not be incentivised in any manner whatsoever.

On the other hand, utilisation of unavoidable waste heat (renewable or fossil-based) can make a significant contribution to decarbonisation by substituting fossil heat generated through other means. Moreover, it is impossible to eliminate waste heat altogether - as industry and other sectors decarbonise, there will be a supply of renewable-based waste heat which should be utilised whenever cost-efficient.

Such apparently conflicting policy aims are at the heart of stakeholder positions towards or against waste heat utilisation. The EU should walk therefore a tight rope regarding its policy towards waste heat:

- Avoidable waste heat should be disincentivised and unavoidable but fossil-based waste heat phased out;
- But unavoidable waste heat utilisation should be incentivised (as long as it is a by-product, i.e. that the main aim of the process was generating the waste heat), including in the long-term in the case of renewable-based waste heat.

[389] Tilia (2021) Integrating renewable and waste heat and cold sources into district heating and cooling systems. Case studies analysis, replicable key success factors and potential policy implications

Achieving our decarbonisation targets will benefit from a clear EU policy which indicates under which conditions waste heat utilisation is deemed beneficial. The Commission could thus refine its policy towards waste heat utilisation by detailing the main principles for waste heat utilisation, in order to guide the adoption or revision of waste heat-related measures as proposed in other recommendations of this section (e.g. revision of the energy statistics methodology or representation of waste heat in energy systems modelling and scenarios). This should be paired with overall increased attention to the topic in new or revised heating and cooling and system integration-related policy documents, such as the upcoming Heat Pump Action Plan.[390]

Recommendation 10: Support national and local authorities in coordinating assessment and planning efforts.
Addressee: European Commission, Member States
Related policies & measures: Renewable Energy Directive, Energy Efficiency Directive
Expected impacts: 2030/2040

The recent revision of the EED and amendment of the REDII introduced or updated several provisions regarding the assessment of waste heat potentials and heating and cooling planning. These measures are applicable to national and local authorities, as well as different categories of operators above a certain annual energy input (as indicated in section 4.4.1).

A main challenge arising will be the coordinated development of the national comprehensive assessments, the local heating and cooling plans, and installation-specific cost-benefit assessments. Such policy initiatives will need be coordinated with others such as spatial plans, the NECPs and the Long-Term Renovation Strategies. The present analysis indicates it is critical these employ the right data and assumptions, including regarding the temporal, locational and temperature granularity.

The new requirements will require additional resources from national and local authorities, but as seen many Member States to not have yet the regulatory or support framework to empower and help local authorities meet their obligations. Member States are nonetheless required under the revised EEDII article 30(5) to “promote the establishment of local expertise and technical assistance, where appropriate through existing networks and facilities, to advise on best practices with regard to achieving the decarbonisation of local district heating and cooling”.

Hence the Commission can play a role by facilitating the sharing of best practices in national/local level planning and coordination activities taking place at the various levels, as well as providing direct financial assistance for planning and coordination (see recommendation 5). This could also include providing common guidance on e.g. how to consider positive externalities of collective heating solutions (such as electricity network investment deferral) in local heating and cooling plans.

[390] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13771-Heat-pumps-action-plan-to-accelerate-roll-out-across-the-EU_en

Some related initiatives are already ongoing. For example, as part of the Concerted Action on the Renewable Energy Directive, a specific heating and cooling session discussed in 2023 aspects related to the update of the NECPs, with further discussions planned for 2024.[391]

Recommendation 11: Evaluate and compare the latest and upcoming national reports related to heating and cooling, providing recommendations for advancing the utilisation of waste heat and cold.
Addressee: European Commission
Related policies & measures: Renewable Energy Directive, Energy Efficiency Directive, Governance Regulation
Expected impacts 2030

National-level plans and assessments for the basis for guiding stakeholders from the national to the local level on how to decarbonise heating and cooling. The EU already evaluates and provides recommendations on many of such documents, for example the evaluation of the national comprehensive assessments conducted or of the heating and cooling related chapters of the national energy and climate plans (NECPs) by the JRC.[392,393]

The latest national comprehensive assessments have not been evaluated yet. Member States should publish new comprehensive assessments in the future, which will need to be evaluated. Regarding NECPs, the assessment of heating and cooling related chapters of the 2019 NECPs only briefly covered waste heat and cold due to the lack of attention of Member States to its potential in the NECPs, with the JRC assessment including a dedicated recommendation in this regard.[394] The ongoing 2nd JRC evaluation faces a lack of data, particularly for cooling.[395] As of November 2023, some Member States had yet to submit their 2023 draft updated NECPs, and revised final versions were due in 2024.

Hence, there is an immediate opportunity for the Commission dedicating increased attention to waste heat utilisation aspects in evaluating the national comprehensive assessments and the NECPs, as well as supporting the Member States in improving them in this regard. The evaluation and comparison of these reporting milestones could incentivise Member States to address waste heat and cold utilisation more extensively and coherently.

Recommendation 12: Structurally gather data and monitor the efficacy of the new provisions regarding local heating and cooling plans and make the provisions stricter if necessary.
Addressee: European Commission
Related policies & measures: Energy Efficiency Directive
Expected impacts: 2040

The co-legislators have opted not to make obligatory the implementation of the measures proposed in the local heating and cooling plans within the revised EED. It remains to be seen to which degree local authorities will follow-up with the implementation of the measures recommended in the heating and cooling plans – this will strongly depend on the available financial resources and expertise, among other factors. The Commission is required according

[391] CA-RES Core Theme 3: Decarbonising Heating and Cooling. CT3 Session Highlights of the 1st, 2nd, 3rd and 4th Plenary Meeting
[392] JRC (2018) Synthesis report on the evaluation of national notifications related to Article 14 of the Energy Efficiency Directive
[393] JRC (2021) Assessment of heating and cooling related chapters of the national energy and climate plans (NECPs)
[394] JRC (2021) Assessment of heating and cooling related chapters of the national energy and climate plans (NECPs)
[395] CA-RES Core Theme 3: Decarbonising Heating and Cooling. CT3 Session Highlights of the 1st, 2nd, 3rd and 4th Plenary Meeting

to the article 35(2) of the EEDII to “evaluate the existing measures to achieve energy efficiency increase and decarbonisation in heating and cooling” by 31 October 2025 and every 4 years thereafter.

The periodic monitoring of the implementation of the local heating and cooling plans would provide useful information on good practices and common challenges faced by regional and local authorities. While the evaluation of the relevant provision of the EEDII should consider its efficacy, by the time the Commission launches an evaluation of the relevant provisions as part of its obligation under article 35(2), it will be challenging to gather the necessary evidence. Evaluating the efficacy of the local heating and cooling plans is also a challenging task given the multitude of plans that will exist across the EU. Hence, pro-actively monitoring the efficacy of the plans in a structured manner will provide immediate benefits in the sharing of best practices as well as in eventually revising the relevant provisions the EEDII. At that time, the monitoring exercise would indicate whether the provisions are effective, or whether they should be strengthened by e.g. making the implementation of cost-efficient measures mandatory. Further measures could also then be considered, for example requiring the publication of (parts of) the results of the installation level cost-benefit analysis defined in article 26(7) of the recast Energy Efficiency Directive.

4.3.2.4. Recommendations to address the societal barriers

Recommendation 13: Ensure that waste heat and cold is included in the curricula for initiatives aiming to increase the skills available in the heating and cooling sector.
Addressee: European Commission
Related policies & measures: Net-Zero Industry Act, Heat Pump Action Plan, funding opportunities addressing skills such as LIFE calls
Expected impacts: 2030

Skills-related barriers in clean energy technologies have gained much attention. The proposed Net-Zero Industry Act[396] proposes to, among other measures, enhance skills for net-zero energy technologies and create Net-Zero Europe Platforms for discussions with industry and other stakeholders. The proposed net-zero technologies comprise heat-related technologies such as heat pumps and geothermal energy, solar thermal, and storage. Other specific heating and cooling skills initiatives exist, such as LIFE calls[397] and the upcoming Heat Pump Action Plan.[398]

Waste heat projects face shortages related to skills as much as other heating and cooling decarbonisation projects. Moreover, the analysis has shown that stakeholders, from potential waste heat providers to network operators and consumers, may have a negative perception of waste heat utilisation. Increasing waste heat-related skills would improve both issues, and in anyway the curricula for waste heat projects overlaps significantly (but not fully) with other heating and cooling areas. Projects have sought to increase skills in waste heat utilisation directly, but if the EU is to significantly accelerate it, further human resources will be necessary. Hence, while a dedicated large-scale initiative may not be necessary, it would be worthwhile to dedicate further attention to waste heat and cold in the curricula for initiatives aiming to increase the skills in the heating and cooling sector more broadly.

[396] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/green-deal-industrial-plan/net-zero-industry-act_en
[397] European Commission (2023) District heating and cooling: Enabling modernisation and fuel switch through support for investment plans and skills development
[398] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13771-Heat-pumps-action-plan-to-accelerate-roll-out-across-the-EU_en

Recommendation 14: Expand energy source mix disclosure obligations to include gas and heat, and provide guidance regarding the carbon footprint of waste heat
Addressee: Member States, European Commission
Related policies & measures: Renewable Energy Directive, Energy Efficiency Directive
Expected impacts: 2030

Addressing perception issues for waste heat and cold utilisation involves among other aspects increasing its visibility to consumers and communicating on its benefits. The EU has already adopted measures in this regard for renewable electricity through the guarantees of origin system (which should be expanded to renewable fuels and heat with the upcoming approval of the revised standard CEN-EN 16325) and energy source mix disclosure obligations as set in the Electricity Directive and Regulation.[399]

The extension of the electricity supply mix disclosure obligation to other energy carriers would increase consumer knowledge and facilitate the comparison of various collective and individual heating and cooling options from a sustainability perspective. Moreover, as waste heat is the proposed revised standard CEN-EN 16325, it would improve perception as the source would be classified jointly (but reported separately) with renewable heat sources. Although many heat suppliers already do so, including such requirement would ensure all disclosed their energy source mix, including a minimum number of parameters to ensure comparability among suppliers.

4.4. Case studies on the utilisation of waste heat

This section details concrete projects on waste heat utilisation in the EU, in order to identify barriers, best practices and recommendations arising from these projects and thus provide inputs to the main analysis conducted in sections 4.2 and 4.3. The projects are detailed at different levels:

- Table 4-3 presents a **non-exhaustive overview of waste heat and cold projects in the EU**, with summary information on aspects such as technical capacities, waste and renewable heat/cold sources employed, best practices, energy production/savings, economic aspects and climate and environmental benefits reported;
- The annex (section 6.6) presents detailed case studies on four projects aiming to advance waste heat and cold in Europe. The case studies are based desk research as well as interviews with the actors involved in the projects, leading to an in-depth analysis and presenting information not available in published reports. Table 4-3 presents four projects selected for the case studies.

[399] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32019L0944

Table 4-3 Waste heat utilisation case studies

Case study	Project detailed
Matching waste heat sources with potential demand	EMB3Rs
Urban WHU at different levels for DHC (building, sewage, treatment plant)	StEB Köln and the Celsius project
Utilisation of waste heat for non-district heating applications	CO2OLHEAT waste heat-to-power
Data centre waste heat utilisation	Digital Heat in the Amsterdam Metropolitan Area

Various publications already overview district heating and cooling or waste heat and cold projects, such as the study “District heating and cooling in the European Union” for DG ENER[400], the JRC study “Efficient district heating and cooling markets in the EU”[401] or the study “Integrating renewable and waste heat and cold sources into district heating and cooling systems”[402] for the JRC. It must be noted that such analyses often do not focus only on waste heat utilisation, rather focusing on renewable heat or its coupling with waste heat sources to decarbonise heating and cooling systems.

Considering the projects listed in Table 4-3, the following high-level conclusions can be drawn:

- ✓ Most projects are focused on the utilisation of a single waste heat source for district heating and cooling applications;
- ✓ A limited number of projects explores synergies such as the interconnection of individual district heating and cooling systems or the simultaneous utilisation of waste heat and cold;
- ✓ The projects are of medium size, frequently involving investments of up to tens of million Euros, but rarely requiring investments in the order of a hundred or more million Euros;

[400] Tilia et al. (2022) District heating and cooling in the European Union - Overview of markets and regulatory frameworks under the revised Renewable Energy Directive
[401] JRC (2022) Efficient district heating and cooling markets in the EU: Case studies analysis, replicable key success factors and potential policy implications
[402] Tilia (2021) Integrating renewable and waste heat and cold sources into district heating and cooling systems - Case studies analysis, replicable key success, actors and potential policy implications

Table 4-4 Overview of case studies for the utilisation of waste heat and cold

Name	MS	Commis-sioning[403]	Technical capacities	Waste/RE heat sources	Best practices	Energy production/savings	Investments/ cost savings	Environmental/ Climate benefits
Graz DH[404]	AT	2010-2018	712 MW DH WHR 51 MW	Industry Waste-to-heat	WHR + RES Thermal energy storage	35 MW (paper mill WHR)	23 M€ inv. (paper mill WHR)	GHG, NOx,hydrocarbons, SO2, dust emission reductions 20 kt CO_2/y (paper mil WHR)
Eneregio SOBOS[405]	AT, DE	Feasibility stage	Unspecified	CHP Industry Other energy production processes	Cross-border DH system Diverse WHR + RES sources	2 TWh /y production	200 000 € (feasibility study)[406]	GHG emission reduction
Antwerp North heat network[407]	BE	2022-2026[408]	60 MW	Industrial waste processing	Integrated roadmap Regulatory framework analysis	59 GWh demand (2030)	210 M€ inv.[409]	12 kt CO_2/y (2030)
CO2OLHEAT Prachovice[410]	CZ	2023	16 MW	Industry (cement)	Waste heat-to-power		2.5-3 M€ inv. 750 k€/y savings[411]	GHG emission reduction Water and material use savings

[403] Of relevant waste H/C utilization solution
[404] https://op.europa.eu/en/publication-detail/-/publication/5e1fd499-eabf-11ec-a534-01aa75ed71a1/language-en
[405] https://r-cr.de/files/medien/230110%20CEF%20Energy%20Abstract%20Basic%20Presentation%20SOBOS%20DHC%20PMM%20.pdf
[406] https://cinea.ec.europa.eu/news-events/news/cef-energy-eu-invests-around-eur-300000-studies-future-cross-border-renewable-energy-projects-2022-08-30_en
[407] https://indaver.com/expertise/heat-networks/north-antwerp-heat-network
[408] https://indaver.com/fileadmin/Indavercom-files/Documents/Roadmap2030_Warmtenetten_GK_college__3_.pdf
[409] Including all projects of the Antwerp district heating roadmap
[410] https://co2olheat-h2020.eu/demonstration-site/
[411] https://co2olheat-h2020.eu/about-the-project/expected-impacts/

Name	MS	Commis-sioning[403]	Technical capacities	Waste/RE heat sources	Best practices	Energy production/savings	Investments/ cost savings	Environmental/ Climate benefits
Berlin Qwark[412]	DE	2022	8 MW HP	District cold network	Integrated use of cooling and heating	55 GWh of heat/y		6.5 kt CO_2/y 120 000 m3/y cooling water
Geothermal energy from lignite mining[413]	DE	2014	865 kW heat pump 314 kW CHP 1860 + 2300 kW gas-fired boilers 25 m3 TES	Open pit sump water (27 ºC)	WHR + HP + CHP + gas-fired boilers	Reduced fossil fuel demand by 26%	Not mentioned	CO_2 emission reduction by 32% Decreased groundwater temperature
Celsius Cologne[414]	DE	2013[415]	200 + 158 kW	Municipal wastewater	WWHR at 3 different levels (building, sewage, treatment plant)	1.7 GWh/y production (497 MWh/y savings)	-	42 kt CO_2/y
Odense DHC[416]	DK	2019-2020	1509 MW DH	Data centres Industry CHP Waste-to-energy	WHR + RES Thermal heat storage Coupling with electricity sector	65 MW HPs for WHR	Data centre: 17.5 M€ inv (data centre WHR) 9.4 M€/y savings	71% CO_2 emissions reduction 28% increased energy efficiency

412 https://assets.siemens-energy.com/siemens/assets/api/uuid:7fd9f82d-0c66-4768-aaba-a76953f79f73/SE-Euro-Heat-and-Power-May-22_original.pdf
413 https://www.euroheat.org/resource/excess-heat-from-lignite-mining-in-bergheim-germany.html
414 https://smart-cities-marketplace.ec.europa.eu/projects-and-sites/projects/celsius/celsius-site-cologne
415 https://celsiuscity.eu/wp-content/uploads/2020/02/126-Guidelines-for-the-replicability-of-the-Cologne-Wahn-Demonstrator.pdf
416 https://op.europa.eu/en/publication-detail/-/publication/5e1fd499-eabf-11ec-a534-01aa75ed71a1/language-en

Name	MS	Commis-sioning[403]	Technical capacities	Waste/RE heat sources	Best practices	Energy production/savings	Investments/ cost savings	Environmental/ Climate benefits
Greater Copenhagen DHC[417]	DK	2019 (new incinerator)	3000 MW DH 70 MW DC Waste-to-energy 400 MW	Tertiary buildings Ambient energy Wastewater treatment Waste-to-energy Electrolyser waste heat (project)	Interconnection of DHC networks State-of-the-art waste-to-energy facility DC clusters BECCS/methane production project	Waste-to-energy: 30% of energy production	-	-
Kalundborg wastewater as heat source[418]	DK	2017	10 000 kW heat pump	Municipal wastewater (20-25 ºC)	WHR + HP Waste heat for biogas catalysation	Decommissioning of 5.1+8.7 MW fossil-fired boilers	7.25 M€ investment Savings of 33.6 k€/week in 2017-2019	Not mentioned
EMB3Rs[419]	DK, EL, PT, SE	Feasibility stage	Various	Industrial Waste-to-energy Data centre	Heat/cold resource and demand mapping Industry-to-industry exchange Industrial waste hot waster recovery to DH WHR + RES	Various	Various	Various
Aranda del Duero[420]	ES	2019	24 MW DH Industrial WHR 12 MW	Thermal storage Industry CHP	WHR + RES	Industrial WHR: 3.6 GWh/y (potential 15-40 GWh/y)	1 M€ inv. 25-30% heating bill savings	1.6 kt CO_2/y emission reductions (expected to grow to 11 kt CO_2/y)

417 https://op.europa.eu/en/publication-detail/-/publication/5e1fd499-eabf-11ec-a534-01aa75ed71a1/language-en
418 https://www.euroheat.org/resource/waste-water-as-heat-source-in-kalundborg.html
419 https://www.emb3rs.eu/case-studies/
420 https://op.europa.eu/en/publication-detail/-/publication/5e1fd499-eabf-11ec-a534-01aa75ed71a1/language-en

Name	MS	Commis-sioning[403]	Technical capacities	Waste/RE heat sources	Best practices	Energy production/savings	Investments/ cost savings	Environmental/ Climate benefits
Tallaght District Heating[421]	IE	2023	4 MW waste heat[422] 3 MW heat pump[423] 3 MW electric boiler	Data centre	WHR	-	-	1.5 kt CO_2/y
Paris-Saclay district heating	FR	2022	50 MW total H/C supply[424]	Data centre Geothermal	WHR	26 MW (heating) 7 MWh (cooling)	51.7 M€ (1st phase)[425]	6.1 kt CO_2/y[426]
Grenoble Pont-de-Claix[427]	FR	2018	30 MW industrial waste heat	Chemical industry	Bidirectional (winter/summer) heat trade with chemical cluster WHR + RES	30 MW waste heat recovery (winter) 8 MW heat provision to industrial cluster (summer)	7 M€ inv.	150 t SOx/y 5000 tCO_2/y[428]
WarmtelinQ (Rotterdam harbor heat regional distribution[429]	NL	2025	23 km (Vlaardingen-Den Haag) 20 km (Rijswijk-Leiden)	Industrial waste heat	WHR + RES Integrated design for future expansion to whole of South Holland[430]	-	Rijswijk-Leiden: 108.3 M€ in investments[431]	CO_2 emission reduction by 60%[432] Rijswijk-Leiden:[433] 102 kt CO_2/y by 2030 32 t NOx/y by 2030

[421] https://www.codema.ie/projects/local-projects/tallaght-district-heating-scheme/
[422] https://www.philiplee.ie/south-dublin-county-council-district-heating-project/
[423] https://www.seai.ie/publications/District-Heating-and-Cooling.pdf
[424] https://epa-paris-saclay.fr/nos-missions/amenager-durablement/le-reseau-dechange-de-chaleur-et-de-froid-de-paris-saclay-un-modele-innovant-au-service-de-la-transition-energetique/
[425] https://epa-paris-saclay.fr/wp-content/uploads/2021/12/Mission-Ame%CC%81nager-durable-DOC-1-20190624_DP_Re%CC%81seau-de%CC%81change-de-chaleur-et-de-froid-Paris-Saclay_VDEF.pdf
[426] https://www.ecologie.gouv.fr/francois-rugy-inaugurera-nouveau-reseau-dechange-chaleur-et-froid-paris-saclay
[427] https://www.compagniedechauffage.fr/2346-innovation.htm
[428] http://oteenga.com/synergies-reseaux-chaleur/
[429] https://www.warmteling.nl/
[430] https://www.warmteling.nl/uploads/fckconnector/1cd481f5-b5d3-5881-8ba1-d6ecdc18c4f4
[431] https://www.zuid-holland.nl/publish/besluitenattachments/evaluatie-warmtelevering-leidse-regio/evaluatie-verkenningsfase-warmteling-rijswijk-leiden.pdf
[432] https://www.zuid-holland.nl/onderwerpen/energie/warmtelingtrace-vlaardingen-den-haag/
[433] https://www.zuid-holland.nl/publish/besluitenattachments/evaluatie-warmtelevering-leidse-regio/evaluatie-verkenningsfase-warmteling-rijswijk-leiden.pdf

Name	MS	Commis-sioning[403]	Technical capacities	Waste/RE heat sources	Best practices	Energy production/savings	Investments/ cost savings	Environmental/ Climate benefits
Hengelo DH	NL	2018[434]	60 MW[435]	Waste-to-energy	Waste heat and steam utilisation (heat cascading) Industry-to-industry exchange	140 GWh	-	40 kt CO_2/y[436]
Hensingborg DH Evita interconnector[437]	SE	2015	DH 320 MW Evita pipe: 60 MW Waste-to-energy CHP 73 MW Chemistry industry WHR 45 MW WWHR 30 MW	Thermal storage Industry Wastewater treatment Waste-to-energy	Interconnection of DH networks Joint feasibility studies for WHR WHR + RES Thermal energy storage	182 GWh exchange through Evita (2018)	31.3 M€ inv. 2.45 M€/y savings	Reduction of carbon footpring to 48 g/kWh

434 https://www.greendeals.nl/green-deals/warmtenet-hengelo-backbone-en-htsp-campus
435 https://ennatuurlijk.nl/zakelijk/blogs/hengelo-het-meest-innovatieve-warmtenet-van-nederland
436 https://www.1twente.nl/artikel/235539/warmtenet-enschede-gestookt-met-afval
437 https://op.europa.eu/en/publication-detail/-/publication/5e1fd499-eabf-11ec-a534-01aa75ed71a1/language-en

5. Cross-cutting topics on energy system integration

5.1. Introduction

This chapter addresses additional cross-cutting aspects of energy system integration that are not covered in detail in the analysis of specific aspects but are still considered as important challenges.

The section provides an analysis of barriers and recommendations to issues of 1) more integrated energy infrastructure, 2) energy storage 3) digitalisation and innovation, 4) monitoring and reporting, as well as 5) issues not addressed in the ESI strategy, such as resource use and skills/employment. It also lists pending actions of the ESI strategy.

For a more integrated energy infrastructure, issues such as the currently insufficient utilisation of interconnector capacities and the lacking interoperability of grid technology solutions need to be addressed, and overall better integration and coupling of different energy vectors is needed. The recommendations also emphasise the importance of addressing the increasing complexity of balancing distribution systems, necessitating improved coordination between DSOs and TSOs. The need to accelerate the expansion and reinforcement of the electricity networks, and to enable investments in decentralised renewable electricity generation as well in demand-side assets, is identified as a key factor to tackle delays to further electrification and DER integration. Additional integration benefits can be reaped in collaboration is fostered between ENTSO-E and ENTSOG (and in the future ENNOH), with a focus on revising their respective models to include short and long-term resolutions.

To facilitate cross-border trading and create a level-playing field for market participants, a harmonisation of regulatory frameworks is needed, including rules on grid access, tariffs, trading, and capacity allocation; as well as rules for compliance, permitting and licensing for cross-border projects. The Commission should also support Member States better in the implementation of regulatory frameworks and investments into dedicated cross-border CO2 transport infrastructure.

Concerning energy storage, the most important barriers are the long permitting procedures, the lack of consideration of the double role of storage and inadequate capacity mechanisms. An update of existing regulatory frameworks combined with lifting fiscal barriers for energy storage is recommended. As an economic driver, the value of storage could be more transparent if adequate assessments and valuations of storage needs would be done.

While digitalisation in the energy sector is already underway and a series of actions have been defined on EU level, the implementation of these can benefit from the harmonisation of legislative acts, standards and regulations on the EU and MS level. This will help to create a safe European-level data-sharing infrastructure to support a vast integrated energy system.

For many topics of the study as well as for the cross-cutting issues, the focus should be on implementation of existing policies and measures. A monitoring framework to assess the effectiveness of these measures is recommended, with indicators that focus on electricity grids, energy storage and digitalisation. Periodic reports could be distributed to aid stakeholders in understanding progress and identifying remaining actions. As many of the specific recommendations of this study, e.g. regarding the deployment of distributed energy resources, will have socio-economic impacts – positive or negative – further attention from the

Commission is necessary to ensure acceptance and accelerate deployment of the technologies while minimising potential negative impacts.

5.2. Barriers to a more integrated energy infrastructure

This section assesses barriers to one of the pillars of the EU ESI Strategy: energy infrastructure integration. The assessment of barriers and subsequent recommendations is based on a literature review, as well as survey replies to the following questions (with the majority of answers coming from business associations and industry):

- *What are relevant barriers to developing the integration of energy infrastructure in your member state or at member state level?*
- *What are relevant overarching barriers to developing the integration of energy infrastructure on EU-level?*

Table 5-1 presents the list of barriers (apart from those raised in previous chapters) hindering energy infrastructure integration as well as relevant EU policies and measures (existing or proposed) which could address the barriers partially or fully. Only EU provisions which represent a mandatory requirement for the Commission or Member States are mentioned.

Table 5-1 Barriers for integrated energy infrastructure

Pillar	Barrier type	Barrier	Relevant EU policies and measures
5	Regulatory, economic	Insufficient utilisation of interconnector capacity	Electricity Market Reform
5, 6	Technical, governance	Lack of interoperability across grid technology solutions	Net Zero Industry Act, Climate target plan, Offshore Network Development Plans
5	Regulatory, technical	Electricity network to further integrate other vectors and flexibility solutions at the transmission and distribution level	Electricity Market Reform, TEN-E regulation
2,5	Technical, governance	Current scenarios used for assessing infrastructure projects not sufficiently driven by climate goals	Hydrogen and Decarbonised Gas Market Package, TEN-E regulation, TYNDPs
1,2, 5	Regulatory, technical, governance	Lack of provisions for dedicated CO_2 transport and storage infrastructure for CCU/S	Net Zero Industry Act, TEN-E Regulation

Below we highlight some important barriers to be considered for future policy actions, and propose corresponding recommendations, and discuss whether the listed policy measures are sufficient to address the barrier.

1. **Availability and better utilisation of interconnector capacity by grid operators:** availability of existing interconnector capacity for market trade in the EU is still below the

70% requirement[438] due to issues such as structural congestion in some geographies and for specific network elements. To alleviate congestion, lifting of certain constraints like the reconfiguration of bidding zones, further market coupling and fine-tuning product definitions are possible solutions. For planning purposes, TYNDPs should also include information on internal network elements with significant cross-border impacts.[439] The issue of insufficient interconnector capacities is significant as the need for costly remedial measures for managing congestion is expected to increase in the future, in the absence of other interventions. Solving it requires thinking about long-term solutions beyond the 2030 horizon to increase interconnector availability and to contain the costs of congestion management.

2. **Lack of interoperability across power grid technology solutions[440]** from different technology providers and pace of Research & Innovation could hamper plans for increased cross-border integration of infrastructure, especially with energy islands or offshore hubs;[441] Siloed industry standards, including data management systems and APIs pose a barrier for creating a digital ecosystem of integrated services for the sector.
3. **Electricity network planning does not yet sufficiently integrate other vectors (renewable and low-carbon methane gases and H_2), and flexibility solutions at the transmission and distribution level**, partially due to lack of coordination between TSO and DSO levels. Synergies between electricity, H_2 and storage infrastructure need special focus when aiming at integrated planning,[442] of a mostly renewable-based electricity system. Next to increased electrification, system integration also calls for sector coupling with renewable-based district heating and cooling networks, as set out in Article 20(3) of the revised REDII.[443]
4. **Current processes and scenarios assessing infrastructure projects (notably in the scope of the TYNDP) are not sufficiently driven by climate neutrality and resilience imperatives:**[444]
    - Despite harmonisation efforts, TYNDPs and the TEN-E process needs to be further improved to take adequate account of the EU's decarbonisation objectives while also safeguarding the EU's energy infrastructure against the impacts of climate change, including via shared scenarios and Cost-Benefit Analysis (CBA) methodologies which consider the whole energy system, its various vectors and their interaction with climate goals and risks.[445]
    - If the EU were to set out achieving EU net emission reductions of 90-95% before 2040 as advised by the European Scientific Advisory Board on Climate Change (ESABCC), this would imply a 2040 energy system largely dependent on a fully decarbonised electricity supply, to the support of which no European

[438] ACER (2023), Assessment of emergency measures in electricity markets https://acer.europa.eu/Publications/2023_MMR_EmergencyMeasures.pdf
[439] ACER (2021), Opinion 05-2021 on electricity national development plans
[440] Including both hardware (high-voltage substations, solid-state transformers, HDVC circuit breakers etc.) and software (system operation solutions)
[441] Based on consultation feedback from industry on the EU 2040 climate target
[442] Based on consultation feedback from industry on the EU 2040 climate target
[443] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023L2413&qid=1699364355105
[444] European Scientific Advisory Board on Climate Change (2023): Towards a decarbonised and climate-resilient EU energy infrastructure: recommendations on a harmonised EU energy system-wide cost–benefit analysis
[445] ENTSO-E (2022): RDI monitoring report, Cross-sector integration

grid model currently exists – there is need for 'decarbonisation reference grids', that are compatible with carbon budgets.[446]

5. **Scarce provisions for and investments into dedicated cross-border CO_2 transport infrastructure.** While the importance of carbon capture, utilisation and storage (CCU/S) in the energy transition is recognised in the ESI strategy, and the inclusion of related infrastructure in EU-wide planning via TEN-E has commenced, concrete plans and investments for dedicated pipelines for transporting CO_2 (and networks of these) are scarce. Apart from transport pipelines and underground storage facilities, infrastructure serving ships, barges, trucks and trains is referenced, but not picked up further in TEN-E[447]. Investment appetite depends a lot on industrial emitters' commitment to decarbonisation, and carbon capture projects and storage sites are attracting more investments than transport networks.[448] The new List on PCIs and PMIs released on Nov 28[449] already includes 14 cross-border carbon dioxide network projects, which if successfully permitted, will partially help tackle this barrier.

From the barriers listed in Table 5-1, the following ones were reflected on most often by stakeholders during the survey (see Annex), and thus will be looked at in more detail:

- ✓ Availability and better utilisation of interconnector capacity
- ✓ Lack of interoperability across grid technology solutions
- ✓ Electricity network to further integrate other vectors and flexibility solutions at the transmission and distribution level
- ✓ Scarce provisions for dedicated CO_2 transport and storage infrastructure for CCU/S

Recommendations to overcome barriers

For the barriers mentioned above, stakeholders have formulated recommendations in the survey responses, summarised below.

In November 2023 the EU Action Plan for Grids was published, as the present report was being finalised. The Action Plan contains numerous actions which aim to address many barriers indicated above:[450]

- Accelerating the implementation of Projects of Common Interest and developing new projects through political steering, reinforced monitoring and more proposals;
- Improving the long-term planning of grids to accommodate more renewables and electrified demand, including hydrogen, in the energy system by steering the work of system operators as well as national regulators;
- Introducing regulatory incentives through guidance on anticipatory, forward-looking investments and on cross-border cost sharing for offshore projects;
- Incentivising a better usage of the grids with enhanced transparency and improved network tariffs for smarter grids, efficiency, and innovative technologies and solutions by

[446] Based on consultation feedback from industry on the EU 2040 climate target
[447] IEA (2022): TEN-E CCUS
[448] EC DG ENER (2023), Report on EU regulation for the development of the market for CO2 transport and storage
[449] https://energy.ec.europa.eu/system/files/2023-11/Annex%20PCI%20PMI%20list.pdf
[450] European Commission (2023) Grids, the missing link - An EU Action Plan for Grids COM(2023)

supporting the cooperation between system operators and recommendations by the Agency for the Cooperation of Energy Regulators (ACER);

- Improving access to finance for grids projects by increasing visibility on opportunities for EU funding programmes, especially for smart grids and modernisation of distribution grids;
- Stimulating faster permitting for grids deployment by providing technical support for authorities and guidance on better engaging stakeholders and communities;
- Improving and securing grid supply chains, including by harmonising industry manufacturing requirements for generation and demand connection.

Recommendation 1: Mandate electricity DSOs to upgrade interfaces with electricity TSOs
Addressee: European Commission
Related policies & measures: EU Action plan for Grids, Electricity Directive (EU) 2019/944
Expected impacts: 2030

The interfaces between the DSOs and TSOs should be further enhanced and guidelines for their cooperative approach, including planning, grid and congestion management, data exchange and IT compatibility need to be provided at regulatory level.

This recommendation also includes the improvement of interoperability of technologies and set common standards, the development of sector coupling and integrated solutions, electricity distribution grid reinforcement and improvement of capacity planning.

Further electrification and DER will make the balancing of the distribution system an even more complex process, which is not possible to address cost-efficiently at the local level alone. This means that DSOs need to develop market operation abilities and further coordinate and integrate their practices and actions with the concerned TSOs and neighbouring DSOs. The DSOs should be prepared to have a more active role including by supporting the reliability and security of the system.

Moreover, active involvement of DERs is transforming power markets, from managing single direction flows of energy and money to multidirectional exchanges of energy and other products. In traditional centralised energy networks, energy producers, transmission and distribution operators, and suppliers work together in this order to bring electricity to consumers. Advances in DERs and digitalisation allows for a more active role for the consumer, providing tools to become active on buying and selling energy, storing or redistributing energy, at local/decentralised or centrally managed levels.

The role of the DSO starts to have similar characteristics with the role of the TSO, managing the balancing of the system at local level, and being equally involved on supporting energy exchanges at decentralised level, similarly to the way the TSO is managing energy exchanges at the central level. For this reason, the coordination of the two operators, TSO and DSO, who need to support energy exchanges to central and local level respectively, ensure that participants exchange products across levels.

Member States need to ensure that DSOs are empowered to manage at local level the increasing number of players like demand side response, local decentralised generation, storage and energy sharing.

Technical challenges can be addressed by establishing common technical standards that ensure interoperability of technologies within the power sector. This includes compatibility of different renewable technologies and grids, as well as their management systems, addressing energy storage and conversion issues, and enabling seamless integration. The Net Zero Industry Act,[451] building on the Green Deal Industrial Plan and the Climate target plan already paves the way for a simpler and more predictable legal framework for grids and renewable technologies in the power sector, and specific connection types and standards for e.g. the wind industry could be introduced in Offshore Network Development Plans. Data sovereignty concerns by industrial players have to be addressed before establishing shared ecosystems, with their increased involvement in the developments of standards.

Develop and implement technical solutions that enable seamless integration of different energy carriers. This includes finding ways and smart solutions to link and interdependently operate electricity, methane, hydrogen and heat markets and infrastructures within an integrated EU energy system. Future market designs should underpin this interdependency by allowing for flexibility tools to optimise the value of growing shares of intermittent generation and to balance increased volatility.

Next to EU-wide and regional transmission grid enforcements that are essential for a renewables-based electricity system, there is a need to recognise distribution grids as enablers of the energy transition. With the connection of numerous decentralised renewable generators, focus on the accelerated expansion of electricity grids and simultaneous transition of gas grids (as discussed in more detail in chapter 2).

Adequate planning of electricity and (low-carbon) gas transmission and distribution networks is crucial to ensure that capacity exists in the networks to reinforce the integration of new renewables. This applies to both internal and cross-zonal capacities. The current Electricity Market Design reform proposal already includes the possibility to reserve interconnection capacities over longer terms in power markets, which helps this issue.

Recommendation 2: Incentivise anticipatory development of the electricity grid/network and review connection principles
Addressee: European Commission
Related policies & measures: EU Action plan for Grids, Electricity Directive (EU) 2019/944
Expected impacts: 2030/2040

The need to accelerate the expansion and reinforcement of the electricity networks, to enable investments in decentralised renewable electricity generation as well in demand-side assets, is identified as a key factor to tackle delays to further electrification and DER integration.

This recommendation also includes enhancing cross-border collaboration and fostering collaboration between ENTSO-E and ENTSOG (and in the future ENNOH).

Many participants in the survey expressed concerns for delays in investments for increasing the capacity of the networks to accommodate the anticipated increased bidirectional energy flows. Balancing supply and demand also at distribution level is becoming an increasingly challenging and complex task. The current modes of operation are still considered to be functioning reasonably well in the short term but are certainly not adequate for the medium

[451] https://single-market-economy.ec.europa.eu/industry/sustainability/net-zero-industry-act_en

and long term. Limited electricity network capacity also leads to delays in accommodating the increasing number of connection requests for renewable electricity production and storage assets; in many Member States bottlenecks in ensuring connection capacity to RES facilities and new loads have been reported.[452] Although the technical constraints coming from limited network capacity are already evident, further electrification and DER will continue to put pressure on the need for continuous investments and innovation in the distribution and transmission systems in the medium and long term.

As referred to in the EU Action plan for Grids,[453] published on 28 November 2023, anticipatory grid investments are specifically relevant, for instance for offshore networks to allow future expansions of meshed and hybrid grids, or for onshore networks in zones with high untapped renewable energy potential (e.g. such as renewable energy acceleration areas defined in accordance with the RED). Network development plans should strongly encourage anticipatory investments[454] and ensure that different technical solutions (e.g., demand response or utility-scale dispatchable storage solutions such as batteries, pumped hydro and hydrogen production & storage) are treated on an equal footing through a systematic and more integrated approach.[455]

In this regard, the Electricity Directive (EU) 2019/944 already requires TSOs in their TYNDPs and DSOs in their Distribution National Development Plans to consider the potential of using demand response, energy storage, and other resources as alternatives to traditional wire-based solutions. Moreover, the EU DSO Entity has legal tasks to promote the coordinated planning of distribution and transmission networks and to cooperate with ENTSO-E in this respect and adopt best practices on the coordinated planning of transmission and distribution systems. The EU Action Plan for Grids outlines the need for specific actions at EU level, including mandating the EU DSO Entity, by mid-2024, to explore case studies and best practices and publish recommendations to improve distribution network planning. Moreover, NRAs, in cooperation with ACER and CEER, are mandated, by Q4 2024, provide guidance to DSOs on planning and promote consistency among plans.

The magnitude of the investment needs requires a new approach to the way networks are developed and operated. Distribution system operators used to prepare their Development Plans following an incremental approach, additions and reinforcements are based on historic and statistical data from the past, and mainly focused on the short term. This approach should be replaced by an anticipatory development approach, according to which new projects are not only to serve the actual and short-term needs but also aim at much larger scale plans, to accommodate future needs, such a bidirectional flows and local supply and demand balancing.

A key element of anticipatory planning is that the DSOs need to have a clear view of the projects that market participants are planning for in the short and medium term, and their level of engagement. In this regard the Action Plan outlines the need for network users to provide data on their respective power capacities and project locations to support DSOs in understanding new power flow patterns within their grids. Market participants' projects should be included in the DSOs Development Plan as an integral part of it. The DSOs should design and plan projects in such a way that they can efficiently combine their own projects with projects developed by system users. To produce similar effects and offering substitute products and services to the system as compared to the projects developed by the operators. Projects like home storage facilities may efficiently support the operation of distribution

[452] IEA (2023) Electricity Grids and Secure Energy Transitions
[453] EUR-Lex - 52023DC0757 - EN - EUR-Lex (europa.eu)
[454] Eurelectric (2023) Power System of the Future: Keys to delivering capacity on the distribution grid
[455] FSR (2021) The modernisation of the energy infrastructure to ensure consistency with the Green Deal objectives

systems, reducing congestion and improving reliability, reducing overall system costs. This approach may result in the deferral of transmission and distribution network investments, as third-party projects may efficiently offer services to the system operation, which otherwise should be supported by further investments in grid reinforcement and expansion.

Critical prerequisites for operators to integrate third party projects into anticipatory planning, are the following:

1. Incentivise DSOs to include third party projects in their planning. Inherently, this is in conflict with the business objectives of the distribution operator, as it entails that the DSO will not invest in and receive return on capital through new projects (that are part of its ‘Regulated Asset Base’), but instead purchase services from third parties, the cost of which will be recovered through network tariffs.
2. Set up the framework to organise platforms in order to ensure: (a) the availability of reliable data regarding system operation, project planning, level of engagement and participation (b) efficient coordination and synchronisation of projects’ execution.

Anticipatory development should include plans for projects for the expansion, modernisation, and digitalisation of the network, with a longer-term view to 2040. The DSOs should be incentivised by regulatory authorities to prepare their Network Development Plans with a forward-looking approach, aligning this preparation with the National Energy and Climate Plans.

Changing the way how the development plans for networks are prepared and new projects are implemented, including infrastructure, new services, training and reskilling personnel projects, is lengthy and needs time to produce visible results. It has also to be aligned with the way DSOs are remunerated, to ensure the bankability of their development plans, and manage the impacts of higher grid costs on the electricity bills. In this regard, the EU Action Plan on Grids mandates NRAs to regularly review their network tariff setting or methodologies, including how they set long-term incentives, support peak demand shifting and incentivise the deployment of technologies that increase the efficiency and operability of the grids.

Regarding the electrification of road transport in particular, the growing number of electric vehicles already today poses a challenge for DSOs to connect the necessary recharging infrastructure. A challenge that will intensify in the coming years when more electric vehicles enter the market, including heavy duty vehicles with a much greater need for high power recharging infrastructure of up to 1 MW per recharging point. This will put further pressure on the DSOs to accommodate a higher electricity demand from charging stations. This requires anticipatory investments in sufficient grid capacity, in line with the aspects highlighted in the EU Action Plan for Grids, to connect high power recharging pools but also employing innovative technical solutions, including smart charging, boosting, combining local storage with fast charging stations.

Anticipatory design is a necessity and DSOs should take all preliminary actions to develop structures and skills to gradually implement new processes and procedures. This process needs significant time to mature, and in the meantime, the DSOs should accelerate the implementation of no regret projects, to achieve “easy wins” and to ensure a higher level of assurance to market participants and users of the network that projects will be delivered on time and the planning and execution of grid projects is aligned to the business plans of grid users.[456]

Harmonise regulatory frameworks, technical requirements, and administrative procedures at the EU level, and support their implementation by Member States. This harmonisation should include the following: rules on grid access, tariffs, trading, capacity allocation; as well as rules for compliance, permitting and licensing for cross-border projects. These measures would facilitate cross-border trading and create a level-playing field for market participants.

ACER's latest market monitoring report[457] still finds that interconnector capacity for cross-zonal electricity trade is below the 70% target, and that lifting both internal and cross-zonal trade constraints would help getting closer to this requirement. Lessons learned from emergency measures in 2022 once again confirm the essential role of cross-border capacity in guaranteeing system resilience, and how non-aligned measures between Member States can cause costly divergences. Ultimately, the current EU regulation on network codes and permitting, complemented by measures in the Electricity Market Design reform proposal, should allow for system operators and Member States to fully maximise their efficiency and mitigate market shocks, difficulties lying with the implementation of these.

Foster collaboration between ENTSO-E and ENTSOG (and in the future ENNOH), with a focus on revising their respective models to include short and long-term resolutions. Quantify the benefits of gas and hydrogen infrastructure in terms of additionality, temporal correlation requirements, flexibility needs, and security of supply, and further integrate models used for the TYNDPs. TYNDPs and the TEN-E process needs to be further improved to take adequate account of the EU's decarbonisation objectives while also safeguarding the EU's energy infrastructure against the impacts of climate change, including via Cost-Benefit Analysis (CBA) methodologies which consider the whole energy system, its various vectors and their interaction with climate goals and risks. The revised TEN-E (Regulation (EU) 2022/869) already created the legislative basis for collaboration with requiring ENTSO-E and ENTSO-G to develop common scenarios for their TYNDPs.

Recommendation 3: Support Member States better in the implementation of regulatory frameworks and investments into dedicated cross-border CO2 transport infrastructure
Addressee: European Commission, Member States
Related policies & measures: Electricity Market Reform, TEN-E Regulation
Expected impacts: 2030/2040

With all the above regulations and provisions already in place, and especially the Electricity Market design reform proposal, there is a supportive regulatory framework that can help stimulate flexibility and facilitates the integration of energy infrastructure. Member States must themselves ramp up implementation and enact structural reforms to address issues such as scarce capacity on the power grid and integrated planning of energy networks (electricity, gas, hydrogen and heat) as well as CO_2 networks.

Even though the inclusion of related infrastructure in EU-wide planning via TEN-E has commenced, investments into dedicated CO_2 pipeline networks are scarce, and transport via ships, barges, trucks and trains is referenced but not picked up further in TEN-E. CO_2 infrastructure will enable[458] the widespread deployment of carbon capture, including direct

[456] E.DSO (2023) E.DSO Agenda for Strategic Grid Investments
[457] ACER (2023) Assessment of emergency measures in electricity markets https://acer.europa.eu/Publications/2023_MMR_EmergencyMeasures.pdf
[458] https://www.iea.org/energy-system/carbon-capture-utilisation-and-storage/co2-transport-and-storage

removals and CCU/S, and this essential role calls for better government and private sector collaboration. Just as in the case of waste heat utilisation, easing scrutiny over carbon-related infrastructure (e.g. repurposed NG pipelines) is essential to attract more investments into these networks. The 6th Union List released on Nov 28[459], publishing key PCIs and PMI infrastructure projects under the revised TEN-E Regulation, already includes 14 cross-border carbon dioxide network projects, which if successfully permitted and commissioned, would partially fulfil this recommendation.

5.3. Barriers to energy storage

5.3.1. Summary of survey results on the energy storage aspects

The most important barriers to energy storage are the long permitting procedures, the lack of consideration of the double role of storage and inadequate capacity mechanisms. The lack of flexibility assessments and insufficient remuneration for certain system services are also still perceived as hindering factors.

The assessment of barriers and subsequent recommendations is mainly based on open answers obtained in the survey to the following questions:

- *Please detail the most important barriers highlighted in the previous question.*
- *Are there specific barriers to long-duration energy storage technologies? Please specify which technologies*
- *What priority policies and measures are required to address the above-mentioned barriers in your member state or at member state level?*
- *What overarching policies and measures are required to address the above-mentioned barriers at EU-level?*

Open answers give more insights into perceived barriers:

- One fundamental challenge is the lack of awareness regarding the optimal storage of energy as molecules like CH4 and H2, rather than as electrons in batteries. This perspective underscores the importance of harnessing the unique qualities of each energy vector for optimal integration. Some responses emphasise the importance of addressing the role discussion, especially when DSOs are involved, as it poses a blocking issue.
- Efforts to enhance energy storage also face technical barriers. These include the need for more efficient batteries with low EU-rare materials, the acceleration of salt cavern capacity preparation, clarity in optimising storage strategies and efficiency, as well as addressing rare material issues in technologies like membrane-less electrolysers.
- The assessment of flexibility needs emerges as a key barrier, although we note that a more structured EU-wide approach on this is expected, including mandatory assessments by Member States. These analyses should encompass various time scales, from intra-day to inter-seasonal, and should avoid being overly technology oriented. Addressing issues related to capacity mechanisms, remuneration for system

[459] https://energy.ec.europa.eu/system/files/2023-11/Delegated%20Regulation%20PCI%20PMI%20list.pdf

services, and market-based investments is crucial in promoting a balanced and fair approach to energy storage development.

Regulatory and financial barriers are also significant: complex permitting procedures for renewable energy projects and related infrastructure hinder timely investments. The value of energy storage is intrinsically linked to dispatchable capacity, necessitating the development of appropriate financing schemes to support such projects. In some Member States, electricity storage (e.g., **EVs and V2G technologies**, pumped hydro storage) and power-to-gas systems are exposed to double taxes and levies and/or to grid tariffs. The revised REDII[460] already introduces accelerated permit-granting procedures for storage installations too, which should help mitigate this barrier.

Lastly, an integrated approach to infrastructure resilience is crucial, while there is need for better planning and realisation of long-term storage requirements as electrification advances. Furthermore, addressing financing difficulties, complex permitting processes, and awareness gaps around energy storage's potential as a renewable source is essential.

Specifically related to **long-duration storage technologies**, the stakeholders highlighted the following barriers:

- **Limited experience:** A lack of experience and expertise in the field hinders effective implementation.
- **Capacity preparation:** Accelerating the readiness of salt caverns for storage is crucial, particularly for hydrogen.
- **Financing uncertainty:** The business models for long-duration storage rely on uncertain seasonal price gaps, requiring measures like financial support and contracts to mitigate risk.
- **Integration challenges:** Proper integration into the energy system is vital for optimising efficiency and benefits.
- **Infrastructure conversion:** Converting and utilising existing gas storage capacity for hydrogen and biomethane storage is promising, but conversion risks (financial, environmental) need to be addressed.

5.3.2. Recommendations to overcome barriers

For the barriers mentioned above, stakeholders have formulated a few recommendations in the survey responses, which we summarise below. If existing EU provisions already address these barriers, this will be outlined.

[460] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023L2413&qid=1699364355105

Recommendation 4: Further integrate energy system planning and provide guidance on the needs for and development of EU energy infrastructure
Addressee: European Commission, Member States
Related policies & measures: Electricity Directive, Regulation
Expected impacts: 2030

Many EU Member States are facing challenges related to the timely reinforcement and extension of EU electricity networks, and ACER raises increasing congestion management costs as a main issue in its latest wholesale market monitoring report.[461] This highlights the challenges for energy networks as central enablers of the energy transition. As seen, after reducing energy demand the main step for decarbonising the energy system is to choose and implement the technology and energy carriers that are best suited. This choice is intrinsically linked to the development of energy networks. Section 5.2 provides specific recommendations on the planning and operation of EU energy infrastructure.

Member states should prioritise comprehensive integration and planning to effectively address the absence of a transverse view across various energy vectors and scales. Policies that encourage the seamless integration of electricity, heat, and other energy vectors will help optimise the deployment and operation storage technologies, especially that of long-duration energy storage (LDES). A truly integrated vision for the EU energy system could consider an even closer structural cooperation between electricity, gas and hydrogen TSOs and their EU associations regarding the planning of cross-border energy infrastructure.[462] For example, a higher integration of the energy systems modelling for the planning of energy infrastructure at the EU level could be sought, beyond the use of common scenarios and the consideration of sector interlinkages. At the same time, planning for each sector will still need to have a higher granularity to consider its own specificities, requiring a fine balance.

Recommendation 5: Carry out assessment and valuation of storage needs to make its value more transparent
Addressee: European Commission, Member States
Related policies & measures: Electricity Directive, Regulation
Expected impacts: 2030

A critical step to overcome barriers is the provision of financial support to storage operators. Offering financial guarantees can expedite the preparation, testing, and deployment of long-duration storage solutions.

Member states should establish mechanisms to accurately assess storage needs at the Member State level. This entails evaluating both electricity and heat storage requirements based on the local energy landscape. Policymakers can then align incentives and regulations to support the development of production methods that effectively utilise storage systems, such as solar thermal and electric boilers.

To incentivise the development of thermal underground storage, Member States should devise clear mechanisms for recognising the value of these systems. Proper remuneration and valuation will encourage stakeholders to invest in and operate thermal storage facilities, which are crucial for maintaining grid stability and meeting inter-seasonal flexibility needs.

[461] ACER (2023) Progress of EU electricity wholesale market integration - 2023 Market Monitoring Report
[462] Meeus et al. (2023) Energy policy ideas for the next European Commission: from targets to investments

Member States should establish transparent and fair rules for market participation and compensation mechanisms for investors in energy storage projects. Clear guidelines on participation in capacity mechanisms and other incentives will attract private investment and reduce economic barriers to entry for long-duration storage solutions. Currently, ACER finds[463] that important flexibility resources - like storage and demand response - receive significantly lower, to marginal, support in remuneration in existing capacity mechanisms compared to conventional fossil fuel assets (CHPs, OCGTs and CCGTs, despite providing low-carbon flexibility solutions in critical times.

Despite this, batteries are getting increasingly popular on CRM auctions[464] for future periods, bringing system adequacy benefits. All Member States should fully implement the June 2019 market design directive (EU/2019/944), as well as the various provisions of the electricity market design reform once stepping into force[465], by adopting a definition for energy storage, removing price caps, reducing minimum bid sizes, and developing new flexibility services where needed. Is it key to avoid non-remunerated, non-frequency ancillary services as these can bring significant socio-economic benefits.

Recommendation 6: Update regulatory frameworks and lift fiscal barriers for energy storage
Addressee: Member States
Related policies & measures: EPBD, revised REDII
Expected impacts: until 2030

Member States should actively align their regulatory frameworks with the latest electricity market recommendations[466] to define storage and address challenges such as double grid tariffs for storage facilities. Furthermore, fostering a clear and supportive regulatory environment for the conversion of energy infrastructure, especially for methane and hydrogen systems, will encourage private investments and technological innovation.

In Member States where electricity storage is still exposed to double taxes or tariffs, these need to be lifted (in line with article 15 of the Electricity Directive).[467] Energy storage needs to be recognised as an independent pillar of energy supply, with adequate recognition for its double generator-consumer role, and storage facilities (especially those that provide decentralised consumer flexibility, like EVs or V2G) should not be taxed. The elimination of double taxation for storage is also set out to be included in the revised Energy Taxation Directive, once agreed on and adopted.

The Directive on Deployment of Alternative Fuels Infrastructure (AFIR) should be effectively implemented too, as well as dedicated provisions in the recast Energy Performance of Buildings Directive (EPBD),[468] to deploy and mainstream private EV charging in residential buildings. Implementation of the revised REDII is also needed to facilitate investments in innovative charging technologies, such as smart and bidirectional charging. Access to in-vehicle data is required to properly account for the flexibility provided by vehicles, and good data management practices are needed avoid vendor lock-in and bring this technology to the wider markets.

[463] ACER (2023), Security of EU security of supply
[464] See, for example, Elia's latest CRM auction report for the 2027-2028 delivery period
[465] Provisional agreement reached between the Council and Parliament on 14.12.2023
[466] European Commission (2023) Energy Storage - Underpinning a decarbonised and secure EU energy system
[467] calling for MSs to ensure that active constomers who own storage are not subject to any double charges, incl. network charges: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32019L0944
[468] Provisional agreement reached between the Council and Parliament on 7.12.2023

On the EU level, stakeholders highlight the need for financial support and research stimulation, binding targets and roadmaps for storage (an EU-level electricity storage strategy), which combined with a supportive and harmonised regulatory framework could well advance the deployment of storage technologies. The Commission's recommendation on storage[469] already points at important regulatory barriers and calls for better consideration of storage in grid planning and financing, but a stricter framework would better incentivise the actual take-up of these recommendations, as well as the scale-up of available technologies.

5.4. Barriers to digitalisation and innovation in the energy sector

5.4.1. Summary of survey results on the digitalisation and innovation aspect

The assessment of barriers and subsequent recommendations was based on the survey replies to the following questions, with the majority of answers coming from business associations and individual companies:

- *What are relevant barriers to developing the integration of energy system digitalisation and innovation in your member state or at member state level?*
- *What are relevant overarching barriers to developing the integration of energy system digitalisation and innovation on EU-level?*
- *What priority policies and measures are required to address the above-mentioned barriers in your member state or at member state level?*

Solely based on the survey responses from stakeholders, the below are the most prevalent barriers for energy system integration regarding digitalisation and innovation, and the recommended actions to overcome them.

Identified barriers:

1. **Lack of interoperability and data sharing:** Limited cross-sector data sharing and collaboration, siloed standards preventing integrated services.
2. **Lack of regulatory support and incentives:** Absence of regulatory support for innovation, insufficient incentives for digitalisation and technology adoption.
3. **Data privacy and security concerns:** Stringent data privacy regulations hinder data sharing; cybersecurity concerns require attention.
4. **Lack of clear business models**: Lack of clear business models for sector coupling and integrated energy system development. This is partially due to a fragmented regulatory landscape and the lack of harmonised standards and regulations across EU Member States. This concerns district heating and cooling networks especially, which pursuant to Article 20(3) of the revised RED II should provide RES-based heating and cooling via a variety of cost-effective and flexible sources, yet are mostly fossil-fuel based to date.
5. **Insufficient infrastructure and grid modernisation:** Ageing energy infrastructure and outdated equipment hinder integration of new digital technologies.
6. **Lack of knowledge and education:** Limited understanding of energy systems and digital technologies, insufficient skilled workforce.

[469] https://energy.ec.europa.eu/topics/research-and-technology/energy-storage/recommendations-energy-storage_en

7. **Lack of EU framework for R&D and Innovation:** Lack of EU-level support for regulatory sandbox-promoting research and development activities, hindering new business models. More consideration needed to source critical materials and intellectual property from Member States to reduce supply dependence from non-EU countries.

5.4.2. Recommendations to overcome barriers related to digitalisation and innovation

The following recommendations are based on the survey results.

Recommendation 7: Promote the harmonisation of standards and regulations
Addressee: European Commission, Member States
Related policies & measures: EPBD, Data Act
Expected impacts: until 2030

Harmonise regulations and standards through legislative tools like the Data Act[470], Codes of Conduct (interoperability of Energy Smart Appliances[471]), electricity market design, self-monitoring and the EPBD to avoid additional administrative burden.

Accelerate the standardisation process for data-exchange languages like ESDL (TNO) to enhance interoperability.

Mandate open and standardised Application Programming Interfaces (APIs) for communication from distributed energy resource devices with grid operators to minimise integration costs.

Recommendation 8: Promote the coordination at the European level of data-sharing via digitalisation
Addressee: European Commission, Member States
Related policies & measures: SEEG, D4E, Data Act
Expected impacts: until 2030

Develop a European data-sharing infrastructure for energy data spaces, focusing on common data representations, semantic models, and secure data sharing.

Establish more coordination mechanisms like the EU's Smart Energy Expert Group (SEEG) and its D4E working group to create synergies between data-related initiatives and avoid duplication.

Ensure consistent interoperability requirements for connected devices across EU markets. Balance grid investments between physical reinforcements and digitalisation.

Strengthen education and training programs to develop a skilled workforce capable of managing digital transformation.

[470] https://digital-strategy.ec.europa.eu/en/policies/data-act
[471] https://ses.jrc.ec.europa.eu/development-of-policy-proposals-for-energy-smart-appliances

Recommendation 9: Enhance R&D on cybersecurity and smart grid KPIs
Addressee: Member States
Related policies & measures: Network Code on Cybersecurity
Expected impacts: until 2030/2040

There are higher risks stemming from an increasingly digitalised energy system that accommodates an increasing number of participants. Implement systemic cybersecurity standards and rules to ensure end-to-end security of interconnected power systems.

Introducing regulatory sandboxes would encourage research, development, and innovation projects by TSOs. These need to account for necessary infrastructure investment costs.

Grid operators should be remunerated based on smart grid Key Performance Indicators (KPIs) to incentivise efficient grid capacity increase.

The responsibility to take actions for overcoming the barriers seems to mainly lie with national governments (as answered by 44% of the respondents) and EU institutions (42%) followed by NRAs (39%) and EU agencies like CEN or CELENEC (33%). Standardisation bodies seem to have much less power (15%) in addressing them according to the stakeholders asked.

Digitalisation in the sector is already underway, and the Commission recognises smart, interconnected energy systems facing most of the challenges identified. The digitalisation of the energy system as policy priority is linked to the European Green Deal and the Digital Decade Policy Programme 2030, and a series of actions, including **establishing a common European energy data space, and attention to cybersecurity issues,** have already been outlined in the **EU Action Plan on Digitalising the energy system**[472]. As suggested above too, the Data Act, the Data Governance Act[473] can both be further leveraged to strengthen and securitise data sharing mechanisms. Implementing digitalisation-relevant legislation by the Member States will require a coordinated approach by both the EU and the public authorities, given the complex set of legal and operational arrangements that need to be in place once standardisation processes start, along with the right technical requirements and guidelines.

5.5. Monitoring and reporting

The analysis of this study allows to draw a few high-level recommendations regarding energy system integration in the EU, which would complement the more specific recommendations provided in subsequent chapters and illustrated in the above figure.

Recommendation 10: Develop indicators to monitor the progress towards energy system integration
Addressee: European Commission
Related policies & measures: EU Action Plan for Grids, EU Action Plan for Digitalisation
Expected impacts: until 2030/2040

This study discusses multiple barriers specific to certain topics or cross-cutting, affecting the whole EU energy system, and identifies a number of adopted or proposed EU policies and measures. These should address many of the barriers fully or partially, but often were only recently adopted and still need to be implemented at the EU and Member State level (see

[472] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022DC0552&qid=1666369684560
[473] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022DC0552&qid=1666369684560#footnote12

section 6.5 for a list of relevant policies and measures). The development of indicators to monitor the status of the multiple barriers identified would provide an overview of the progress of energy system integration in the EU and of the effectiveness of the policies and measures being implemented and serve to highlight the need for any additional action at the EU level.

In particular, electricity grids, energy storage and digitalisation are important topics which have gained increased attention from policymakers recently, including at the EU level. As detailed in the chapter, the Commission has adopted recently an EU Action Plan for Grids,[474] and EU Action Plan for Digitalising the Energy System,[475] and a staff working document and recommendations to Member States on energy storage.[476] The actions and recommendations should address the identified barriers to a significant extent. Hence, as for many topics of this study, the focus should be on implementation. To support this, the Commission could specifically monitor and report on progress on the action plans and recommendations. The Commission already tracks the progress of actions proposed in its plans, and publishing this periodically will help stakeholders to assess progress and drawn attention to the remaining actions and barriers. For energy storage, monitoring implementation of the (frequently non-binding[477]) recommendations at the national level will again serve as a means to bring attention to remaining issues.

Recommendation 11: Specifically address societal aspects in studies and legislation related to energy system integration
Addressee: European Commission
Related policies & measures: EU Social Climate Fund, new EU ETS for transport and buildings
Expected impacts: until 2030/2040

Social impacts of the energy transition are already increasingly recognised for example with the adoption of the EU Social Climate Fund to mitigate the socio-economic impacts of the new EU ETS for transport and buildings. These impacts have been exacerbated with the recent energy crisis. Many of the specific recommendations of this study, e.g. regarding the deployment of distributed energy resources, will have a socio-economic impact – positive or negative – which needs to be considered. Not all consumers have the capacity to adopt specific clean energy technologies without public support such as financing, and we should not expect all consumers to adopt such technologies in the first place – in which case they should not be 'left behind'. Moreover, we discuss in this study a number of other societal issues related to the knowledge and acceptance of various system integration-related energy technologies. Further attention is thus necessary to the social aspects of energy system integration to ensure acceptance and accelerate deployment of the technologies while minimising potential negative impacts.

5.6. Pillars and challenges not addressed in the EU ESI Strategy

In this section an assessment is made of further pillars or challenges that are relevant for ESI in the EU, which were not included in the Strategy. We focus on three issues in more detail: that of raw material cost and availability, and skills and employment aspects, to consider as potential new areas being considered as elements of energy system integration.

[474] https://ec.europa.eu/commission/presscorner/detail/en/ip_23_6044
[475] https://ec.europa.eu/commission/presscorner/detail/en/ip_22_6228
[476] https://energy.ec.europa.eu/news/commission-recommendations-how-exploit-potential-energy-storage-2023-03-14_en
[477] Noting that some recommendations such as on national flexibility needs assessments have become binding in the electricity market reform provisionally agreed in December 2023.

These issues were raised especially by businesses and their associations. For example, the ESI Strategy **mentions the challenge of promoting the circular economy, thus increasing not only energy - but also resource efficiency**, but the listed actions in the Strategy concern only energy - and not resource efficiency. There could thus be room for further considering resource efficiency across the energy value chain, in line with the recent attention paid to critical raw material dependencies of clean energy technologies. Other areas that could be developed are that of **skilled workforce and employment,** the energy-water nexus, and the interaction between nature protection and the development of energy infrastructure. Raw materials and skills aspects are discussed in more detail below.

5.6.1. Raw materials' cost and availability

Resource efficiency is a critical consideration in planning a low-carbon energy infrastructure, and this extends to the responsible extraction of critical raw materials.[478] These materials, often essential for technologies like batteries, solar panels, and wind turbines, are vital for the success of a low-carbon transition, as also emphasised in the EU's Critical Raw Materials Act[479]. Prioritising responsible extraction not only mitigates environmental damage but also ensures a stable supply chain. A combined approach of sustainable mining in the EU and green procurement practices with suppliers is necessary to guarantees the long-term viability of the low-carbon energy infrastructure. The revised SET Plan[480] will also have more focus on critical raw materials' availability and circularity in relation to the manufacturing of clean energy technologies.

Stakeholders have voiced the below concerns regarding material use efficiency and scarcity in the survey:

- Scarcity and dependency on third countries for rare materials and metals for solar PV, storage and wind turbines can result in higher LCOE than predicted (as is already the case today). The EU's new competitiveness report on clean energy technologies[481] also concludes that albeit clean energy technologies still remain highly cost competitive in the EU, the EU's manufacturing industry is facing increasing competition from non-European producers, concerning raw materials to key intermediate components and final technologies.
- Heterogeneity of industrial sub-sectors presents a barrier for widespread electrification in terms of process design and development.
- The EU industry for critical raw materials processing and for manufacturing of key components for RES systems is underdeveloped, and in need of harmonised administrative procedures.
- Promotion of responsible critical raw materials extraction: Development in EU of industry for critical raw materials processing and for manufacturing of key components for RES systems.

[478] Including but not limited to lithium, cobalt, graphite, copper, nickel etc.
[479] https://ec.europa.eu/commission/presscorner/detail/en/ip_23_1661, as adopted in 2023 November, legislation coming into force after adoption by the Parliament and the Council
[480] https://research-and-innovation.ec.europa.eu/system/files/2023-10/com_2023_634_1_en_act_part1.pdf
[481] Published as part of the 2023 State of the Energy Union Report

5.6.2. Employment needs/skilled workforce

The availability of skilled workers has also been raised by respondents as possible bottleneck for system integration and needs more attention in the ESI strategy. As global focus intensifies on reducing carbon emissions and embracing renewables, a workforce equipped with specialised knowledge is vital for the **planning, development, and maintenance of these innovative technologies**. In EU alone, it is estimated that 18 million people will need to be retrained or reskilled to reach climate goals, mainly in the solar and wind sector.[482] This may require a more integrated approach to developing the necessary skills across the energy sector, and the Commission indicates that labour shortages could slow downs the energy transition.[483]

The need for various specialised jobs will emerge, spanning over various sectors such as:

- ✓ In solar energy, photovoltaic system installers are pivotal in setting up solar panels efficiently, while heat pump installations also require specialised technicians.
- ✓ Wind turbine technicians ensure the smooth operation and maintenance of wind farms, optimising their energy output.
- ✓ Regarding the mining and processing of critical materials, future skilled workers who can adopt environmentally responsible methods while extracting these valuable resources: metallurgical and mining engineers need to be trained and proficient in sustainable extraction techniques, and ethical supply chain managers need to comply with increasingly strict environmental rules.
- ✓ For increased demand-side participation in energy markets, technicians are needed who can install demand-side flexibility technologies such as smart meters, smart charging facilities or behind the meter storage.

This issue is partially addressed on the EU level by the Pact for Skills Initiative and its **large-scale RES skills partnership** set up for the renewable energy industrial ecosystem. The partnership[484] was established by renewable energy trade associations and representatives of installers of clean technologies and will contribute to the Net Zero Industry Act objectives. **The EU Heat Pump Action Plan**[485], aiming to accelerate the heat pump market and currently waiting for Commission adoption, will also contain a dedicated industry partnership which can foster exchanges on re-and upskilling needs in the sector.

5.6.3. Pending actions of the ESI strategy

One action of the ESI Strategy, as referred to at the beginning of this section, is only partially implemented. Action 20 sets out to "consider additional measures to support renewable and low-carbon fuels, possibly through minimum shares or quotas in specific end-use sectors (including aviation and maritime), through the revision of the Renewable Energy Directive and building on its sectoral targets, complemented, where appropriate, by additional measures assessed under the REFUEL Aviation and FUEL Maritime initiatives (2020). The support

[482] https://www.weforum.org/agenda/2023/05/europe-green-skills-solar-wind/
[483] European Commission (2023) Progress on competitiveness of clean energy technologies
[484] https://energy.ec.europa.eu/news/pact-skills-launch-large-scale-renewable-energy-skills-partnership-2023-03-21_en
[485] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13771-Heat-pumps-action-plan-to-accelerate-roll-out-across-the-EU_en

regime for hydrogen will be more targeted, allowing shares or quota only for renewable hydrogen."

Currently, no end-use specific minimum shares or quotas for low-carbon fuels are set in the revised REDII. Member States can choose between "(i) a new binding target of 14.5% reduction of greenhouse gas intensity in transport from the use of renewables by 2030 or a binding target of at least 29% share of renewables within the final consumption of energy in the transport sector by 2030 (instead of 14%); (ii) a combined binding sub-target of 5.5% for advanced biofuels and renewable liquid and gaseous transport fuels of non-biological origin (RFNBOs – which include renewable hydrogen and synthetic fuels), including a minimum binding 1% level for RFNBO." Additional measures to support low-carbon fuels in the RED, with extra sectoral targets, should be considered. Thus, this is suggested in recommendation 5. For a more detailed assessment of the progress with the ESI strategy's different provisions, see chapter 6.4 Status of actions in the EU Energy System Integration Strategy.

6. Annexes

6.1. Overview of recommendations

Table 6-1 Recommendations on electrification of end-uses and decentralised renewable energy integration

Recommendation:	Addressee:	Related policies & measures:	Expected impacts:	Relevant sectors:
1: Provide guidelines to maximise benefits of smart meter networks	European Commission	JRC Guidelines for cost-benefit analysis of smart metering deployment, Commission Recommendation for the roll-out of smart metering systems, Electricity Directive, Regulation (EU) 2023/1162	2030	Building and transport sectors
2: Review electricity grid connection principles	European Commission	JRC Guidelines for cost-benefit analysis of smart metering deployment, Commission Recommendation for the roll-out of smart metering systems, Electricity Directive, Regulation (EU) 2023/1162	2030	Building, industry and transport sectors
3: Further promote R&D to improve efficiency of heat pumps at (very) high temperatures for electrification of industrial processes	European Commission	Energy Efficiency Directive, Renewable Energy Directive	2030	Building and industry sectors
4: Promote pilot projects and develop works protocol/ manual for replacing AC to DC	European Commission	Energy Efficiency Directive, Electricity Directive	2040	Building sectors
5: Support emerging business models for financing of upfront equipment and installation costs	European Commission, Member States	Renewable Energy Directive, Energy Efficiency Directive	2030/ 2040	Building and transport sectors
6: Implement dynamic electricity commodity pricing to enhance competition at the supply side	European Commission, Member States	Electricity Regulation and Directive	2030/ 2040	Building and transport sectors
7: Implement cost-reflective Time of Use (ToU) grid tariffs to provide adequate price signals for demand response	European Commission, Member States	Electricity Regulation and Directive	2030/ 2040	Building and transport sectors

Recommendation:	Addressee:	Related policies & measures:	Expected impacts:	Relevant sectors:
8: Promote flexible and partial industrial electrification	European Commission, Member States	Electricity Regulation and Directive	2030/ 2040	Industry sectors
9: Formulate an actionable strategy for Electrification	European Commission	Electricity Directive	2030	Building, Industry and transport sectors
10: Monitoring report concerning the access of DERs in markets, and progress on business models (ESCOs, Aggregators)	European Commission/ ACER	Electricity Directive	2030	Building, Industry and transport sectors
11: Support national and local authorities in coordinating assessment and planning efforts	European Commission, Member States	Renewable Energy Directive, Energy Efficiency Directive	2030/ 2040	Building, Industry and transport sectors
12: Adopt and implement common European standards to ensure interoperability, including for smart and bidirectional charging	European Commission, Member States and manufacturers	AFIR Regulation	2030	Transport sector
13: Develop training programmes for sector professionals on electrical equipment and EVs	European Commission	Net-Zero Industry Act, Heat Pump Action Plan, funding opportunities addressing skills such as LIFE calls	2030	Building, Industry and transport sectors

Table 6-2 Recommendations on uptake of hydrogen

Recommendation:	Addressee:	Related policies & measures:	Expected impacts:	Scope:
1: Further R&D on technical challenges	European Commission and Member States	Clean Hydrogen Partnership, Horizon Europe, other R&D programs	2040	Overarching
2: Consider water scarcity issues	European Commission and Member States	Industrial Emissions Directive, Clean Hydrogen Partnership, Horizon Europe	2030	Renewable
3: Address upstream methane emissions.	European Commission and Member States	CCS Directive, Methane Emissions regulation, Horizon Europe	2030/ 2040	Low-carbon
4: Share risks for infrastructure build-out through regulated markets and appropriate financing and funding schemes also considering energy system integration aspects	European Commission and Member States	Hydrogen and Gas Market Decarbonisation Package, Electricity Market Design	2030	Overarching
5: Support Hydrogen storage development through geological surveys, additional revenue streams and adjusted transmission fees to storage operators.	European Commission and Member States	Clean Hydrogen Partnership, Hydrogen and Gas Market Decarbonisation Package, Electricity Market Design	2030/ 2040	Overarching
6: Better understand the implications of CCU/S through scientific evaluations, and if needed, consider a CO2 infrastructure build-out.	European Commission and Member States	CCS Directive, Methane Emissions Directive, Hydrogen and Gas Market Decarbonisation Package, Net-Zero Industry Act, Clean Hydrogen Partnership	2040	Low-carbon
7: Remove fossil fuel subsidies	European Commission and Member States	European Trading System, Energy Taxation Directive, Competition Policy	2030	Overarching
8: Further develop existing subsidy concepts and sufficiently fund the respective financial pots to achieve the 2030 hydrogen targets	European Commission and Member States	EU Taxonomy, European Hydrogen Bank, Innovation Fund, Connecting Europe Facility, IPCEIs and (other funding schemes)	2030	Overarching

Recommendation:	Addressee:	Related policies & measures:	Expected impacts:	Scope:
9: Consider expanding funding opportunities to low-carbon H_2 and provide clarity on conditions.	European Commission	European Hydrogen Bank, EU Taxonomy	2030	Low-carbon
10: Enable additional revenue streams for electrolysers and consider electricity network tariff exemptions.	European Commission and Member States	Electricity Market Design, Network Codes	2030	Renewable
11: Consider defining binding targets for low-carbon hydrogen types and specific to industry sectors.	European Commission	EU Taxonomy, Amended Renewable Energy Directive, ReFuelEU Aviation, FuelEU Maritime	2030	Overarching
12: Further improve gas market through transparency and protection of consumer interests.	European Commission and Member States	Hydrogen and Gas Market Decarbonisation Package	2040	Overarching
13: Adopt rapidly DAs on GHG methodology for low-carbon hydrogen.	European Commission	Hydrogen and Gas Market Decarbonisation Package	2030	Low-carbon
14: Strive for harmonisation where possible	European Commission and Member States	n.a.	2040	Overarching
15: Develop EU-level regulatory sandboxes for hydrogen.	European Commission and Member States	Net-Zero Industry Act, Hydrogen and Gas Market Decarbonisation Package, Amended Renewable Energy Directive	2030	Overarching
16: Consider (further) differentiation of low-carbon hydrogen into at least fossil + CCS and electrolytic low-carbon hydrogen.	European Commission	Hydrogen and Gas Market Decarbonisation Package, EU Taxonomy	2040	Low-carbon
17: Address global competition and hold further Q&A sessions on applicability of EU requirements in non-EU countries.	European Commission	Amended Renewable Energy Directive, Carbon Border Adjustment Mechanism	2030	Overarching

Recommendation:	Addressee:	Related policies & measures:	Expected impacts:	Scope:
18: Expand on the concept of PPAs (long-term) to enable long-term procurement of electricity and reduce associated planning risks of hydrogen projects.	European Commission	Electricity Market Design, Hydrogen and Gas Market Decarbonisation Package	2030	Renewable
19: Further accelerate permitting processes especially through increasing hydrogen competence in NRAs and digitalisation.	European Commission and Member States	Emergency Regulation on Permit-Granting, European Hydrogen Academy, Net Zero Industry Act	2030	Overarching
20: Expand on concepts such as the European Hydrogen Academy.	European Commission	European Hydrogen Academy	2030	Overarching
21: Transparent testing of safety of hydrogen and derivatives and CO2-related infrastructure.	European Commission and Member States	Horizon Europe, Union certification framework for carbon removals	2030/2040	Overarching
22: Keep emphasising the opportunities for a just transition by hydrogen technologies.	European Commission and Member States	Just Transition Fund, Recovery and resilience Facility, European Regional Development fund	2030	Overarching

Table 6-3 Recommendations on waste heat utilisation

Recommendation:	Addressee:	Related policies & measures:	Expected impacts:
1: Increase support within research and innovation programming for technologies enabling utilisation of certain waste heat sources	European Commission	Horizon Europe, SET Plan and Energy Technology & Innovation Platforms	2040
2: Provide guidance for Member States revising the maximum feasible distances for transporting waste heat and other thresholds related to the CBA exemptions under Article 26(8) of the Energy Efficiency Directive (EU) 2023/1791.	European Commission	Energy Efficiency Directive	2030/2040
3: Improve waste heat accounting in Eurostat's energy balance.	European Commission, particularly Eurostat	Energy Statistics Regulation, Renewable Energy Directive	2040

Recommendation:	Addressee:	Related policies & measures:	Expected impacts:
4: Improve the representation of waste heat in EU policy scenarios.	European Commission	Energy Statistics Regulation, Renewable Energy Directive	2040
5: Provide additional funding for planning and feasibility studies, in cooperation with Member States.	European Commission	Renewable Energy Directive, Energy Efficiency Directive, EU funding for the energy sector	2030
6: Provide technical assistance for Member States designing and implementing support schemes, including risk mitigation measures such as through insurance/guarantee schemes.	European Commission, Member States	Renewable Energy Directive, Energy Efficiency Directive	2040
7: Disseminate good practices for improving pricing signals to waste heat utilisation between Member States	European Commission	Energy Taxation Directive, EU ETS 2, Electricity Regulation and Directive	2030
8: Research regulatory and price-based mechanisms to reduce heat emissions	European Commission	Industrial Emissions Directive	2040
9: Clarify the contributions of waste heat and develop principles for its utilisation towards the upcoming 2040 climate & energy targets.	European Commission	Climate Target Plan 2040, European Climate Law, Renewable Energy Directive, Energy Efficiency Directive	2040
10: Support national and local authorities in coordinating assessment and planning efforts.	European Commission, Member States	Renewable Energy Directive, Energy Efficiency Directive	2030/2040
11: Evaluate and compare the latest and upcoming national reports related to heating and cooling, providing recommendations for advancing the utilisation of waste heat and cold.	European Commission	Renewable Energy Directive, Energy Efficiency Directive, Governance Regulation	Expected impacts 2030
12: Structurally gather data and monitor the efficacy of the new provisions regarding local heating and cooling plans, and make the provisions stricter if necessary.	European Commission	Energy Efficiency Directive	2040
13: Ensure that waste heat and cold is included in the curricula for initiatives aiming to increase the skills available in the heating and cooling sector.	European Commission	Net-Zero Industry Act, Heat Pump Action Plan, funding opportunities addressing skills such as LIFE calls	2030
14: Expand energy source mix disclosure obligations to include gas and heat, and provide guidance regarding the carbon footprint of waste heat	Member States European Commission	Renewable Energy Directive, Energy Efficiency Directive	2030

Table 6-4 Recommendations on assessment of cross-cutting topics

Recommendation:	Addressee:	Related policies & measures:	Expected impacts:
1: Mandate electricity DSOs to upgrade interfaces with electricity TSOs	European Commission	EU Action plan for Grids, Electricity Directive (EU) 2019/944	2030
2: Incentivise anticipatory development of the electricity grid/network and review connection principles	European Commission	EU Action plan for Grids, Electricity Directive (EU) 2019/944	2030/2040
3: Support Member States better in the implementation of regulatory frameworks and investments into dedicated cross-border CO2 transport infrastructure	European Commission, Member States	Electricity Market design reform proposal, revised TEN-E Regulation	2030/2040
4: Further integrate energy system planning and provide guidance on the needs for and development of EU energy infrastructure	European Commission, Member States	Electricity Directive, Grids regulation	2030
5: Carry out assessment and valuation of storage needs to make its value more transparent	European Commission, Member States	Electricity Directive, Grids regulation	2030
6: Update regulatory frameworks and lift fiscal barriers for energy storage	Member States	EPBD, revised REDII	until 2030
7: Promote the harmonisation of standards and regulations	European Commission, Member States	EPBD, Data Act,	until 2030
8: Promote the coordination at the European level of data-sharing via digitalisation	European Commission, Member States	SEEG, D4E, Data Act,	until 2030
9: Enhance R&D on cybersecurity and smart grid KPIs	Member States	n.a.	until 2030/2040
10: Develop indicators to monitor the progress towards energy system integration	European Commission	EU Action Plan for Grids, EU Action Plan for Digitalisation	until 2030/2040

Recommendation:	Addressee:	Related policies & measures:	Expected impacts:
11: Specifically address societal aspects in studies and legislation related to energy system integration	European Commission	EU Social Climate Fund, new EU ETS for transport and buildings	until 2030/2040

6.2. Stakeholder survey

Between 1/6/2023 and 10/7/2023 an online survey has been open for responses from key stakeholders on energy system integration to request their responses on the key barriers and policy solutions to overcome these barriers. The project team created a list of stakeholders and DG ENER also forwarded the link to the questionnaire to their network. This section will summarise the key responses received.

6.2.1. Overall survey results

In total 120 responses were received, 37 responses were considered invalid since these were either (almost) empty or were initially double counted, leading to 83 valid responses. Table 6-5 shows the spread of responses over the EU MSs:

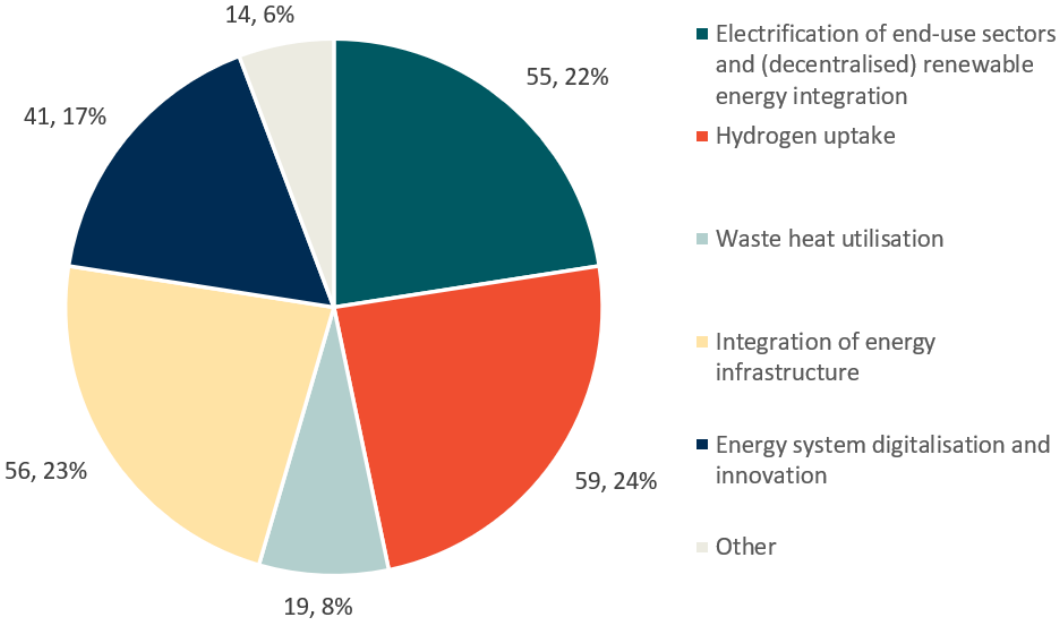
Table 6-5 Representativeness of the responses over the EU MSs

EU-27	17	France (FR)	16	Netherlands (NL)	8
Austria (AT)	4	Germany (DE)	10	Poland (PL)	3
Belgium (BE)	7	Greece (EL)	2	Portugal (PT)	8
Bulgaria (BG)	4	Hungary (HU)	1	Romania (RO)	2
Croatia (HR)	1	Ireland (IE)	2	Slovakia (SK)	1
Cyprus (CY)	0	Italy (IT)	6	Slovenia (SI)	1
Czechia (CZ)	2	Latvia (LV)	0	Spain (ES)	9
Denmark (DK)	5	Lithuania (LT)	1	Sweden (SE)	5
Estonia (EE)	3	Luxembourg (LU)	0	Other	5
Finland (FI)	4	Malta (MT)	0	**TOTAL**	**127**

Note: here respondents may be active in more than one MS and/or in EU27 as a whole.

Figure 6-1 presents the number of responses to transversal aspects of energy system integration:

Figure 6-1 Number of responses and percentages related to the survey aspects on energy system integration



The above graph shows that hydrogen uptake received the highest number of responses closely followed by integration of energy infrastructure and electrification and decentralised RES integration. Interestingly, a relatively low number of responses was received for waste heat utilisation. The information provided by stakeholders is incorporated directly into the relevant aspects detailed in chapters 2 to 5, both through dedicated sections on the stakeholder feedback in each aspect analysis; and it is mentioned throughout the analysis when a particular information is derived from the survey.

6.2.2. Stakeholder views on the electrification and decentralised RES integration

The barriers to electrification of end-uses and renewable energy integration are complex and multifaceted. Figure 6-2 presents the responses from the stakeholder survey on the main barriers for electrification and decentralised RES integration per stakeholder category. All three elements are equally considered to be barriers to the electrification and RES integration: The “quick roll out of smart meters” is seen as the most fundamental, however by a small margin compared to the other two elements. However, that implies that the different stakeholders –the DSO, the vendor and the end-consumer – must equally be able to accomplish their roles. This is also one of the biggest challenges because it requires orchestration and a clear roadmap for all stakeholders to feel confident that everyone is on the same page with regard to the desired outcome.

Figure 6-2 Responses on barriers to electrification and decentralised RES integration per stakeholder category

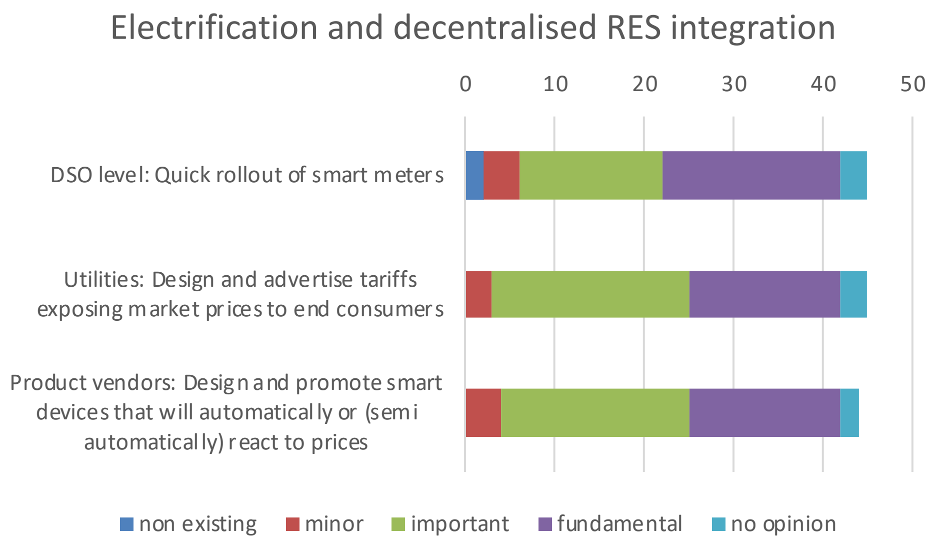


Figure 6-3 summarises the responses on the barriers to electrification in the three key sectors. The building sector is perceived to face the greatest barriers to electrification. The barrier groups with the greatest concern among survey participants for all categories were the economic and financial issues including funding. The legislative and regulatory aspects followed along with and the societal challenges. Technical issues in general were perceived to be the least critical category.

Economic and financial issues also represent the major barriers in the industry and transport sectors, but to a lesser degree than in the building sector, where this is assessed as being "fundamental" by most respondents. Among the three different sectors, stakeholders from the transport sector have less concern on the regulatory and legislative framework, which implies that more regulatory effort is needed in industry and building sectors than in transport.

Figure 6-3 Responses on barriers to electrification and decentralised RES integration for three sectors

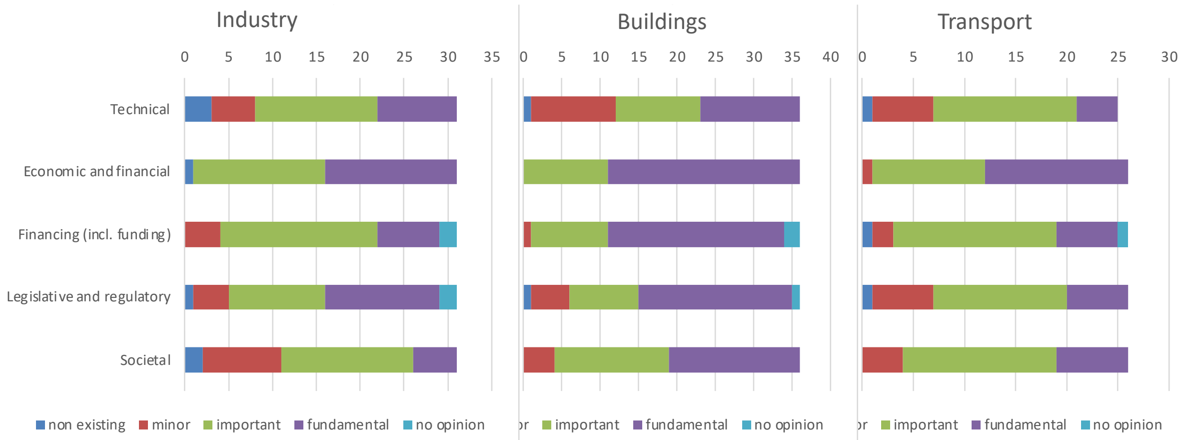
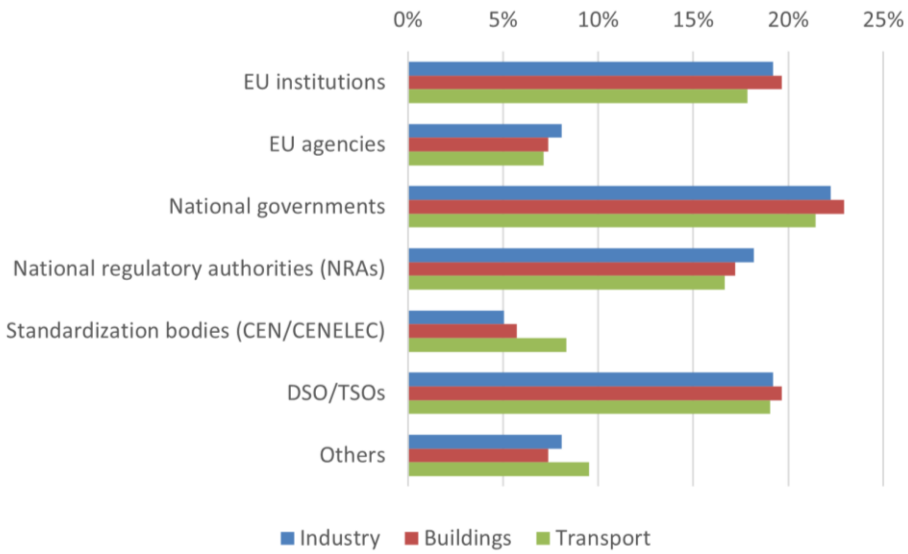


Figure 6-4 breaks down the responses for each barrier category. Some of the elements that stand out are mentioned below. The grid development is identified as a major bottleneck for the industrial sector. Lack of financing mechanisms/market remuneration (especially for industry) and lack of incentives (mainly for industry and buildings) are perceived as important barriers. High cost of equipment is considered by stakeholders as the key barrier in the transport sector.

Figure 6-4 Responses on detailed barriers to electrification and decentralised RES integration for three sectors

Figure 6-5 presents the responses on who should take action to overcome the barriers in the three sectors of the electrification and decentralised RES integration transversal aspect. In this case national governments are identified as the main actor to take action to overcome the barriers, closely followed by EU institutions, and DSOs and TSOs. NRAs can also play an important role in overcoming the barriers. Differences between the sectors are small.

Figure 6-5 Responses on who should take action to overcome the barriers in the three sectors of electrification and decentralised RES integration



6.2.2.1. Stakeholder recommendations to advance electrification and decentralised renewable energy integration

Stakeholders have proposed in their survey responses the following policies and measures to advance electrification and decentralised renewable energy integration, as shown in the table below. While some recommendations are specific, others are more general and refer to the need for policy makers at the EU, national or local level to address the barriers identified. The topic recommendations are presented in section 2.4.2.

Table 6-6 Recommendations to advance electrification and decentralised renewable energy integration

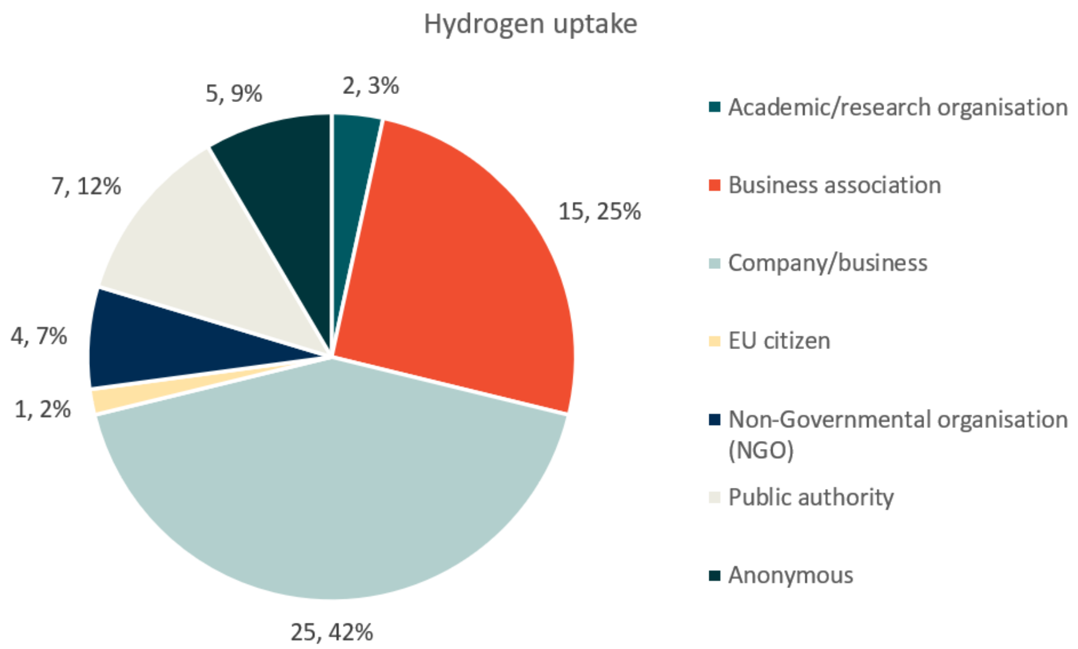
Recommendation	Level	Stakeholders
Common		
Address the lack of skilled workforce - Stakeholder engagement and training campaigns - Cooperation between relevant national authorities, vocational education and training institutions and training platforms	EU/National	8
Accelerate investments in grid reinforcement and expansion	National	7
Timely transpose EU legislative and regulatory framework	National	4
Raise public awareness on and acceptance of electrification solutions	National	4
Revise grid related administrative and permit procedures	EU/National	3
Terminate subsidies and tax reliefs for fossil fuels	EU/National	3
Accelerate and complete the roll out of smart meters	National	3
Promote demand-side flexibility automation	National	2
Provide more favorable financing options for installation of decentralised RES units	National	2
Enhance incentives/signals for demand flexibility (dynamic tariffs, flexibility services, EV fleet)	EU/National	2
Set EU-wide standards for grid-connected equipment	EU	2
Harmonise functionalities and use cases for smart meters in Europe	EU	1
Support the development of manufacturing base in Europe for clean energy technology	EU	1
Require network tariffs to take into account flexibility functionalities	EU	1
Harmonise flexibility and capacity mechanisms principles across the EU	EU	1
Ensure standardisation of communication protocols for grid-connected smart devices	EU	1
Support digitalisation of distribution grid	National	1
Remove barriers on energy data access and sharing	National	1
Implement EU provisions for flexible consumption and generation	National	1
Provide guidance to consumers on new ways of contracting services for electricity supply (PPA aggregation, flexibility mechanisms, etc.)	National	1
Provide financial support (e.g. subsidies) for EVs and storage	National	1

Buildings		
Increase subsidies and incentives (e.g. reduce taxes/levies) as well as access to credit for heat pump equipment and installation	National	5
Phase out the sale of stand-alone fossil fuel boilers and mandate an increasing share of clean heating	EU	3
Set mandatory requirements for installation of PVs in rooftops of public buildings	EU	1
Promote innovative ways of financing heat pumps, like heat as a service and pay-as-you-save schemes	EU	1
Provide financial incentives to stimulate building renovation rates	National	1
Industry		
Provide financial incentives for electrification of energy intensive industries (e.g. guarantee fund for supply interruptions/failures)	National	3
Promote R&D on conversion from fuel-based to electrical technologies for integrated industrial processes	EU	1
Develop EU Industrial Heat Electrification Strategy	EU	1
Regulate the phase down of fossil fuel use in industrial heat applications	EU	1
Promote industrial support policies for early deployment of electrification technologies	EU	1
Prioritise grid reinforcement for industrial electrification in network development plans	National	1
Transportation		
Require bi-directional charging capability of EVs and recharging infrastructure	EU	1
Increase subsidies for electric vehicles	National	1
Support expansion of EV recharging infrastructure network	National	1

6.2.3. Stakeholder views on the uptake of hydrogen

This section presents the stakeholder views on the uptake of hydrogen based on the responses to the survey carried out in May-July 2023. The overall number of responses received for the aspect reach 59 for the multiple-choice questions and up to 42 answers for the specific (free text) questions. A large majority (67% or two thirds) comes from business backgrounds (associations or companies) of which a majority is already active in (natural) gas related activities. Of the received answers, also a large majority of Member States was covered.

Figure 6-6 Number of responses per user category for the hydrogen uptake aspect



In line with the project plan as set out in the inception report, the survey asked for differentiated views on barriers for hydrogen uptake from different sources:

- Renewable electricity production allowing to produce renewables based hydrogen
- Three types of low-carbon feedstocks for hydrogen production:
  - Nuclear energy
  - Fossil fuels with CCS technology
  - Recycled carbon fuels

The results are presented in the aggregated Figure 6-7. As the overall context of the survey was asking for hydrogen as means to enable energy system integration, not surprisingly a large majority of answers was given in the context of renewable hydrogen, which is intrinsically tied to the increasing need for renewable electricity in the energy system. The most important barrier identified for renewable hydrogen is the (remaining) cost gap.

Hydrogen from nuclear energy faces the largest challenges from missing certification opportunities. The same holds true for fossil & CCS low-carbon hydrogen. For hydrogen sourced from fossil sources with CCS technology, permitting is further identified as important or even fundamental by all stakeholders.

Availability levels across the differently sourced hydrogen types differ such that it is generally seen as a smaller problem for fossil & CCS sourced hydrogen, while hydrogen as RCF is seen as currently not available (in line with the relatively recent uptake into the discussion). Regarding technological development, fossil-based hydrogen with CCS is clearly seen as the most advanced with over half of the stakeholders considering it to be of "minor" importance in terms of barriers. Regarding other barrier categories, no fundamental differences or clear trends can be identified. To further elaborate on the differences between hydrogen types, the survey asked: "If you have checked the list of barriers for both renewable and low-carbon hydrogen above, where and why have you decided to differentiate your answers?"

Figure 6-7 Multiple-choice answers to indicate prioritisation of different barrier categories - for hydrogen from different sources (renewable, nuclear, fossil with CCS, RCF)

In the provided responses, two distinct types of responses can be identified: The first type of response addresses the different barriers that renewable and low-carbon hydrogen are exposed to, while the second one addresses the overarching question regarding the recognition and inclusion of low-carbon hydrogen. Concerning the recognition of low-carbon hydrogen, different perspectives become apparent. Seven of the respondents are of the opinion that low-carbon hydrogen should be given greater recognition and better integration within the EU targets. On the other hand, three participants believe that low-carbon hydrogen should not be promoted, meaning that while it may exist it should not profit from subsidies or other incentives. The other answers are on the topic of the difference in barriers between renewable and low-carbon hydrogen and basically restate the findings from the multiple-choice answers: 45% of the respondents highlight differences between renewable and low-carbon hydrogen concerning the situation of the economic barriers (and thus cost gap). The barrier regarding the availabilities is mentioned in four responses. Further respondents mention the distinctions between barriers of the different hydrogen types concerning certification and standards, as well as sourcing.

Next to the simple categorisation through multiple-choice answers, stakeholders also had the opportunity to explain and elaborate their thinking in further free-text questions. Since the overall number of responses (42 on overarching barriers on EU- level and 18 on recommendations to address these barriers) was also high for this part of the survey, we have evaluated these answers in detail:

Generally, it is evident that barrier categories from free-text answers in the survey correspond to the same categories that were mentioned in the literature review and were provided in the multiple-choice options of the survey.

Most frequently mentioned were the missing infrastructure, funding and financing, and a missing regulatory framework[486]. With regards to differentiated answers between MS- and EU-level, respondents slightly emphasised more the technical barriers such as missing infrastructure and technical developments for the MS-level. E.g. for the Czech Republic (and representative for other MSs with little activities with regards to hydrogen), it is emphasised that hydrogen as energy vector is not defined from a legislation point of view, leading to difficulties to access funding. In that context, the importance of a harmonised understanding across all Members States is emphasised: “There is a huge risk that hydrogen types are not transferrable to another Member State when it comes to being eligible for the targets of that Member State (as we can observe today for biomethane and biofuels for transport)”.

Interestingly, while highly emphasised in the multiple-choice answers, the cost-gap (of renewable hydrogen) received less attention (still mentioned by about a third of the stakeholders). This is in line with the recommendations which see the cost gap as a complex and intertwined issue to be addressed by a general development consisting of many components.

The survey also provided some inputs regarding which entities are perceived as being mainly responsible for promoting system integration through actions. As already shown in Figure 6-7 the stakeholders still see it as the responsibility of the legislative bodies, reflecting the fact that significant parts of the regulatory framework are still under development. It may, however, be mentioned that the lay-out of the survey clearly mentioned the commission as the studies’ initiator, thus providing a pre-bias with regards to addressees of the stakeholders’ comments.

In the paragraphs of section 4.2 we explain the barriers in more detail and highlight where stakeholders have provided additional inputs beyond the literature analysis.

6.2.4. Stakeholder views on waste heat utilisation

This section presents the stakeholder views on waste heat and cold utilisation based on the responses to the survey implemented in May-July 2023. 19 responses were received (14 completed, i.e. submitted, and 5 partially filled), although not all respondents filled in all questions. As can be seen in Figure 6-8, almost half (9 out of 19 respondents) were business associations, with individual companies making up the next largest group of respondents (5 responses).

[486] The regulatory framework is under development in the EU and while there are still ongoing discussions many of the barriers may in fact be addressed already. This will be considered when drafting the concluding recommendations.

Figure 6-8 Number of responses per user category for the utilisation of waste heat

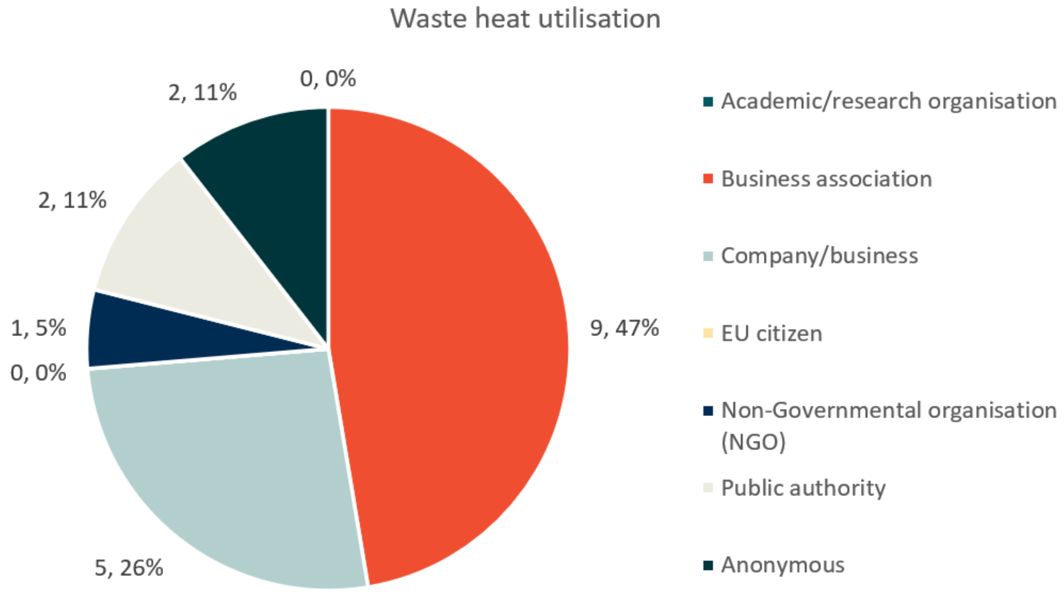
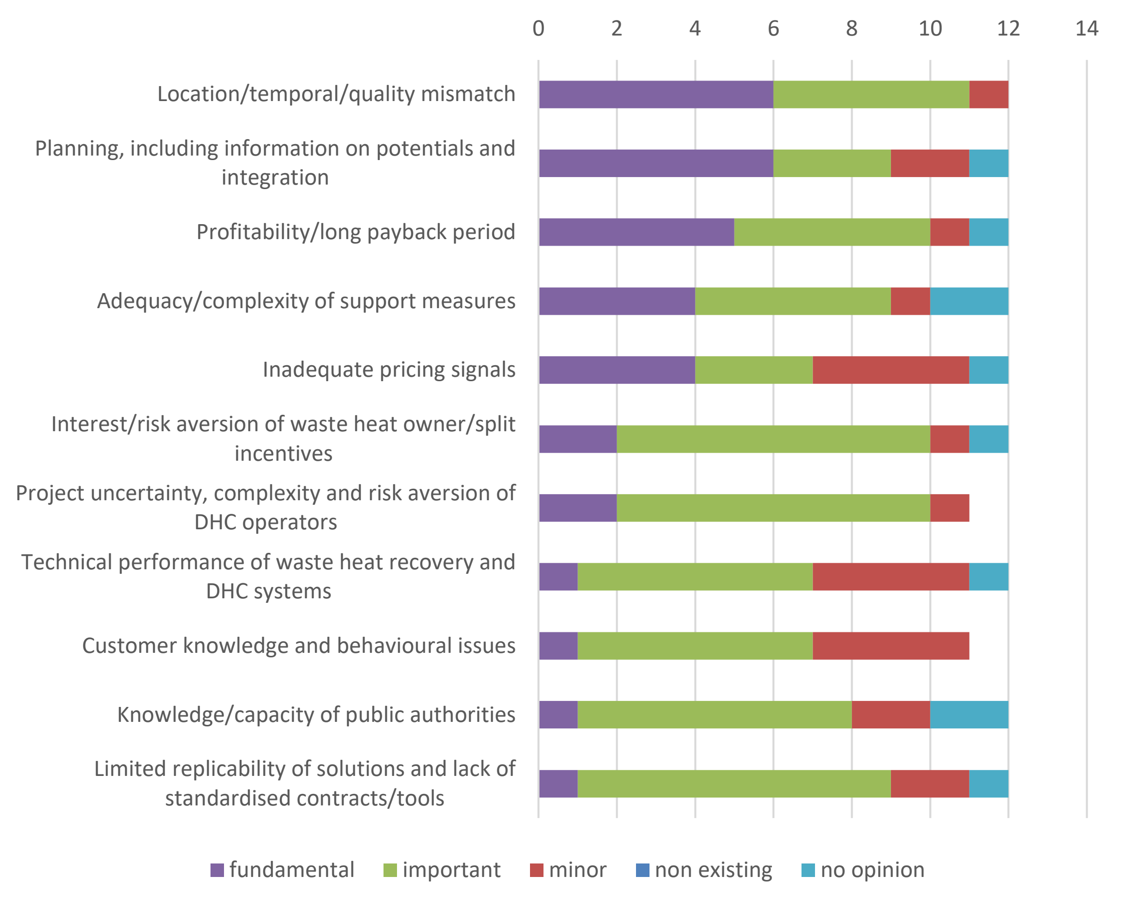


Figure 6-9 presents the responses on qualifying the barriers for developing waste heat projects (out of a total of 12 respondents who filled in the question). It can be seen that the barriers which are ranked most frequently as fundamental include:

- Location/temporal/quality mismatch (6 stakeholders considering it a fundamental barrier)
- Planning aspects (6 stakeholders)
- Profitability and long payback period issues (5 stakeholders)
- Adequacy/complexity of support measures (4 stakeholders)
- Inadequate pricing signals (4 stakeholders)

Figure 6-9 Responses on qualifying the barriers for developing waste heat projects



In contrast, technical performance issues, replicability, knowledge and capacity of public authorities as well as customer knowledge and behavioural issues are not considered as fundamental barriers (although they are still considered important by a large number of respondents, with at least 6 out of 12 respondents considering it important).

It is also important to analyse the qualitative inputs provided by the respondents. Barriers mentioned by stakeholders include the following (without barriers mentioned first being more important):

- Further promoting ESI including new sources and carriers, such as biomethane (and CHP), waste heat, geothermal and solid biomass, switching among them based on prices;
- Use of electrolysis waste heat and the ability of district heating systems to cope with its variability;
- Existence, profitability of and access to district heating networks;
- Accounting of energy and climate impacts (e.g. primary energy factor-related issues), definition of waste heat and issues regarding it societal acceptability as sustainable
- Competition of collective vs individual heating solutions
- Identification, quantification and maintenance of register on potential waste heat sources and sinks, particularly for unconventional and small sources
- Barriers for market participation of sector integration technologies and lack of internalisation of positive and negative externalities

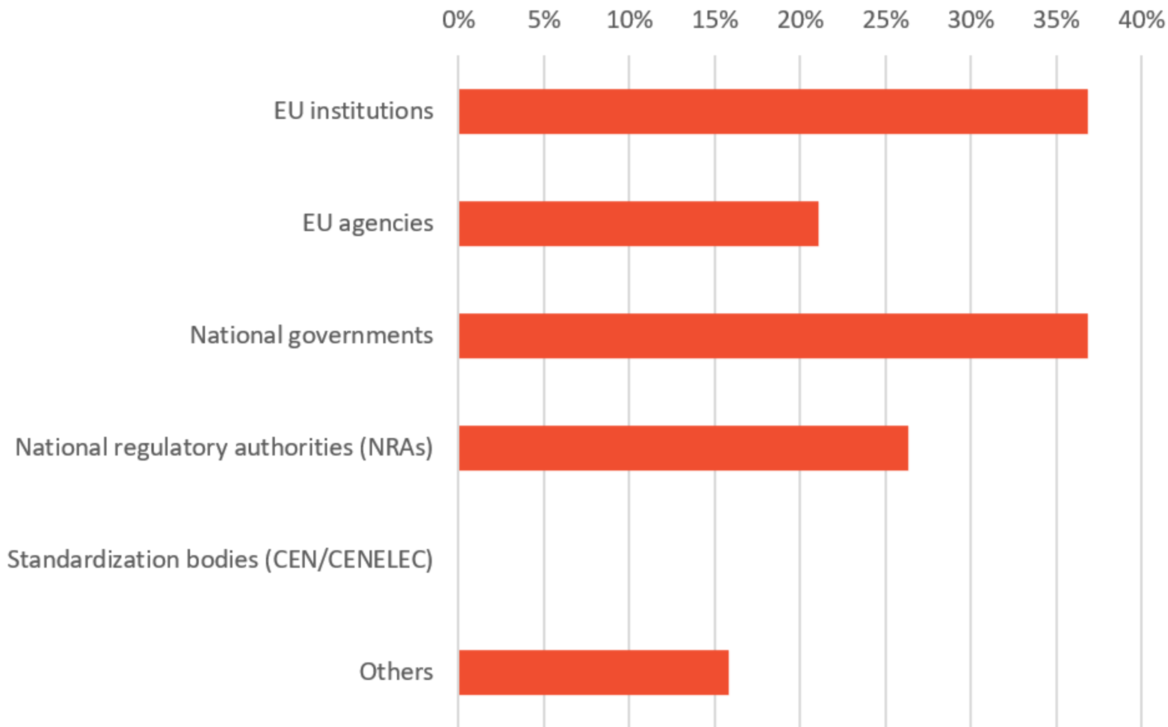
- Distortive taxation policies and network tariff structures
- Lack of contractual standardisation.

While the barriers indicated by the stakeholders largely match those identified in the literature review, we note two specific issues which were highlighted and are worth considering in the analysis:

- The possibility for utilisation of the waste heat of electrolysers in the future, whose potential should grow significantly in the future in line with the EU's ambitions regarding hydrogen and other RFNBOs (highlighted by 2 stakeholders);
- The importance of pricing signals for heat producers and consumers arbitraging flexibility between different sources and technologies, which highlights that waste heat utilisation will involve not only planning and investment decisions but increasingly smart operation of heating and cooling systems (highlighted by 7 stakeholders).

Figure 6-10 presents the responses on who should take action to overcome the barriers regarding the waste heat aspect. It can be seen that stakeholders consider actions at the EU and national levels (including by NRAs) to be the most appropriate. Other stakeholders, such as local authorities, are also mentioned frequently, reflecting the need to involve authorities in all levels for waste heat utilisation.

Figure 6-10 Responses on whom should take action to overcome the barriers in the waste heat aspect



6.2.4.1. Stakeholder recommendations to advance waste heat utilisation

Stakeholders have proposed in their survey responses the following policies and measures to advance waste heat and cold utilisation, as shown in the table below. It can be seen that while some recommendations are specific, others are more general and refer to the need for policy makers at the EU, national or local level to address the barriers that have been raised by the stakeholders. While generally only one or two stakeholders provided a certain recommendation, these have been compared to the other stakeholder inputs (in interviews and workshops) as well as the literature before being critically considered for the present report. The study recommendations are presented in section 4.4.2, while the stakeholder recommendations presented here are not necessarily endorsed.

Table 6-7 Recommendations to advance waste heat utilisation proposed in the survey responses

Recommendation	Level	Stakeholders
Improve energy taxation to promote WHU, such as in the form of tax benefits to specific operators, conditional on meeting certain energy efficiency requirements (including waste heat utilisation requirements)	National	2
Improve the role of heating strategies at the EU, national and local levels	National	1
Integrate DHC networks into national building renovation strategies	National	1
Facilitate hybrid heating solutions combining DHC with individual heating solutions	EU	1
Harmonise regulations for buildings and DHC networks using WH, such as regarding the calculation of final energy consumption and PEFs	National	1
Support lower temperature systems for buildings	National	1
Promote thermal energy storage systems	National	1
Create a global public funding framework to: - Qualify stakeholders with limited DHC/WHU knowledge such as public authorities - Improve communication, knowledge and trust between waste heat stakeholders - Involve the general public and increase acceptance of WHU solutions	National	1
Create incentives for waste heat providers to collect WH data and contract with WH users	National	1
Support risk management mechanisms for WHU projects, including risk assessment, credit/insurance mechanism pilots, identification of best practices, and training of financial sector actors	National	1
Consider unavoidable waste heat at the same level as renewable energy	EU	2
Implement a broader definition of waste heat, covering all applications	EU	1
Create framework for securing investments	EU	1
Create incentive framework for waste heat providers	EU	1
Promote long-term urban planning, with DHC integral to NECPs and national renovation strategies	EU	1
Require operators to develop WHU plans	EU	1
Require cities to develop heat plans, including assessment of future sources	EU	2

Remove entry barriers to energy markets and internalise all positive/negative externalities	EU	1
Develop appropriate network tariffs	EU	1
Remove barriers for users connecting to DHC networks	EU	1
Promote partnerships between local authorities, WH providers and energy suppliers	EU/national	1
Make mandatory the recommendations of the comprehensive heating and cooling assessment for municipalities above 45 000 citizens	EU	1

6.2.5. Stakeholder views on transversal aspects of energy system integration

This section presents the stakeholder views on transversal aspects of energy system integration based on the responses to the survey implemented in May-July 2023. The figure below presents the number of responses received for the aspect, according to the stakeholder category. 56 Responses were received in total for this aspect, 72% of it coming from business associations and industry:

Figure 6-11 Number of responses per user category for the energy infrastructure aspect

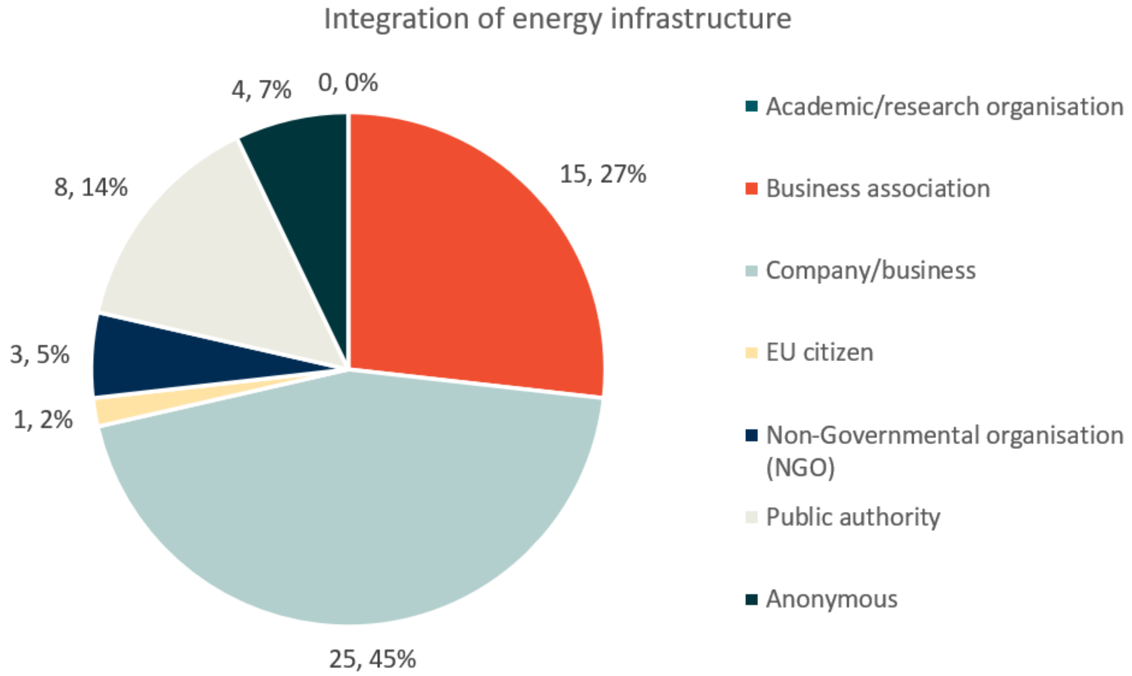


Figure 6-12 presents that both EU institutions and national governments are identified as the main actors to overcome the barriers for four key aspects, although National Regulatory Authorities seem to have an import role here as well. It is noticeable that the differences between the actors to take action are small. This is most likely due to the fact that respondents could select multiple actors to take action. When a respondent selects multiple actors to take action, the differences between the groups attenuates.

Figure 6-12 Responses on who should take action to overcome the barriers on integration of energy infrastructure

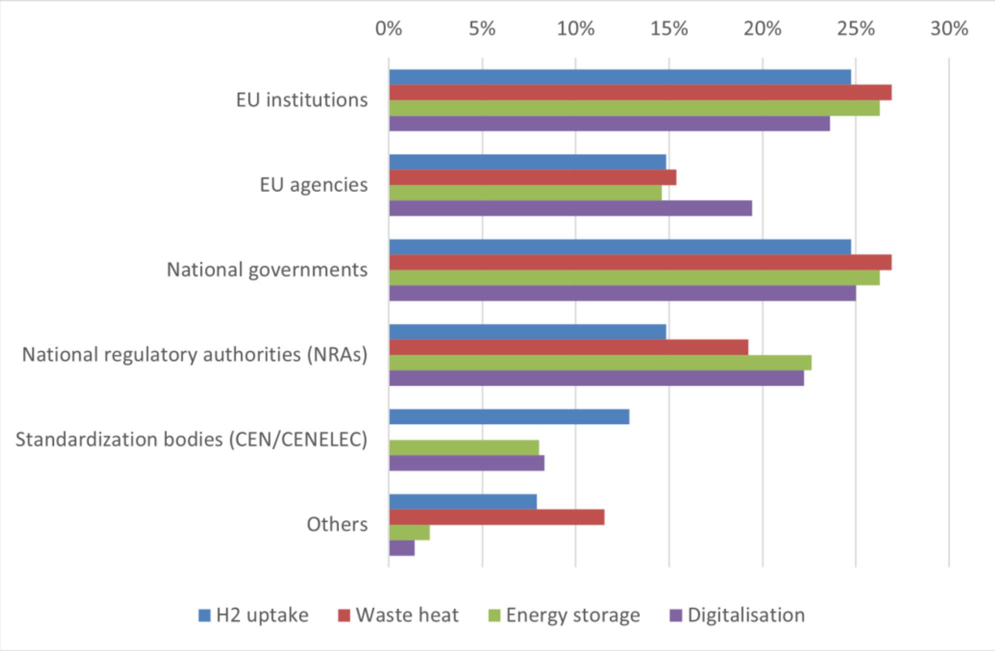


Figure 6-13 presents the survey replies on qualifying the barriers for developing energy storage projects.

Figure 6-13 Number of responses on qualifying the barriers for developing energy storage projects

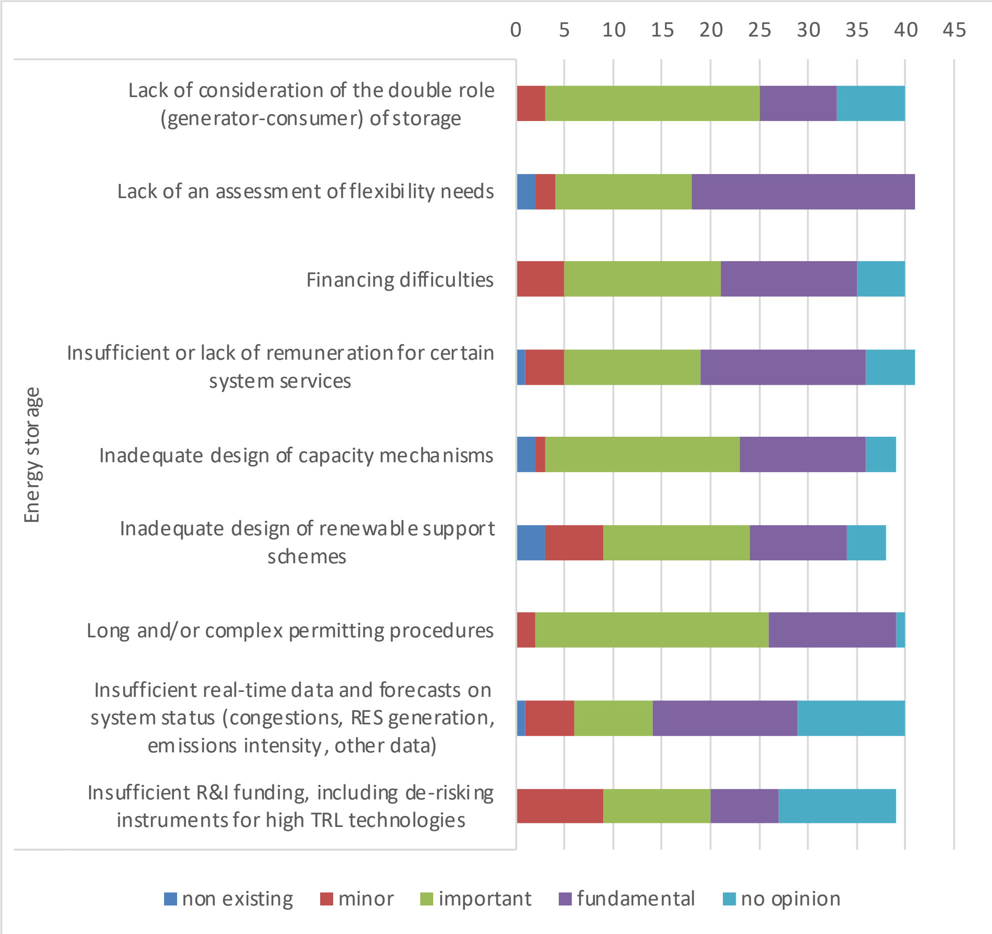


Figure 6-14 presents the number of responses received for the aspect of digitalisation and innovation in the energy sector, according to the stakeholder category. In total 41 responses were received.

Figure 6-14 Number of responses per user category for the digitalisation and innovation aspect

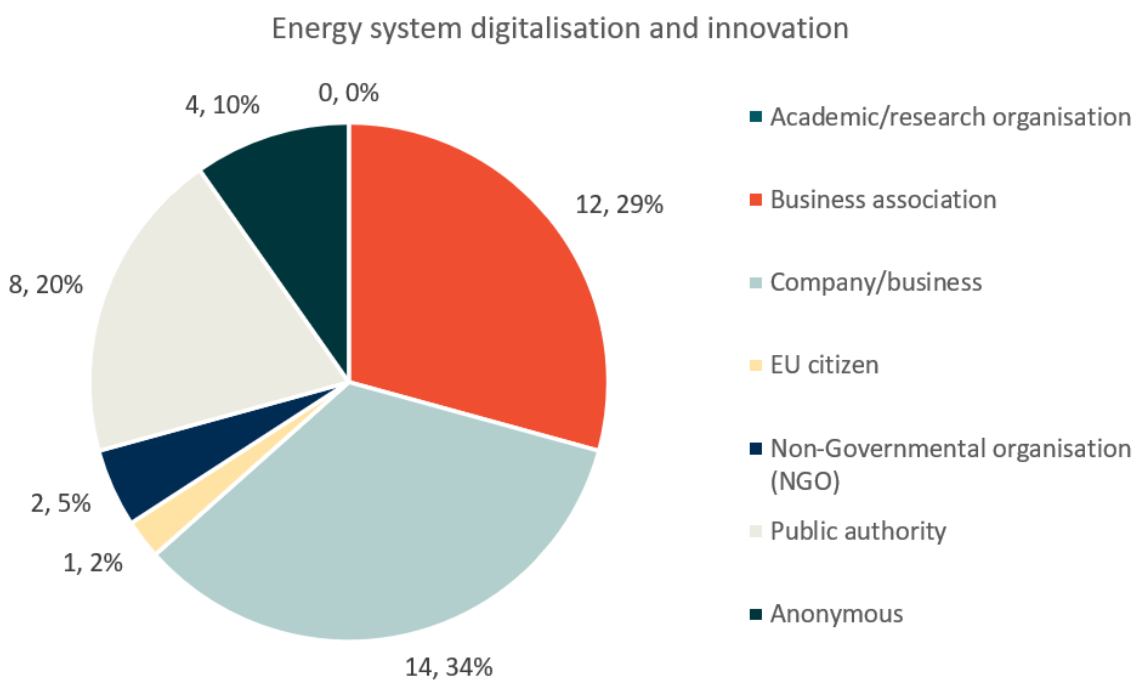
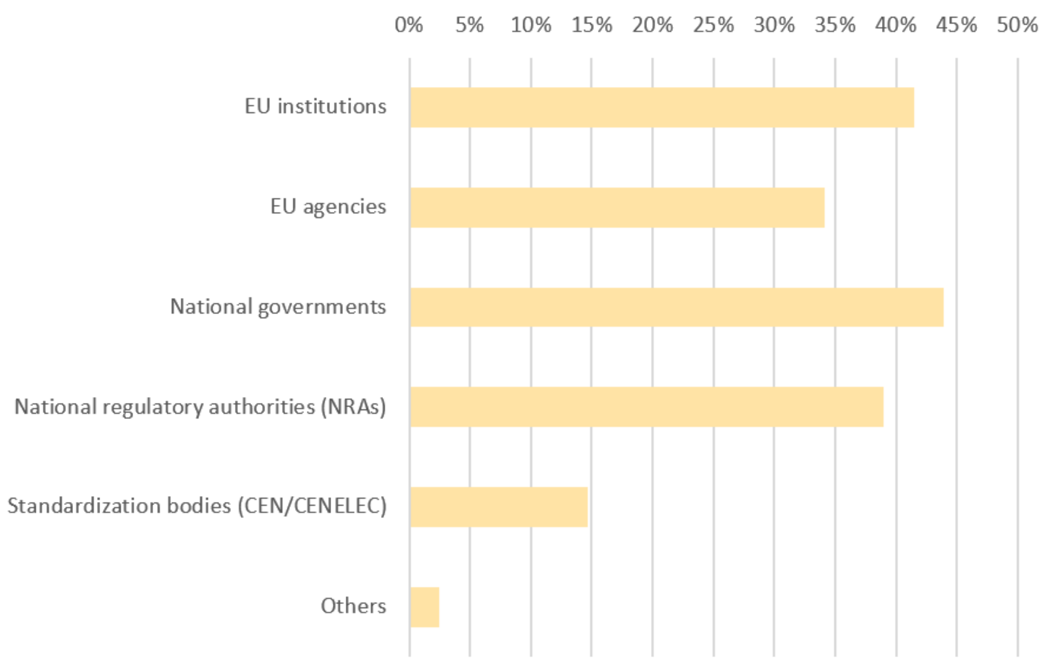


Figure 6-15 presents the survey replies on who should take action to overcome the barriers on digitalisation and innovation.

Figure 6-15 Responses on who should take action to overcome the barriers on digitalisation and innovation



6.3. Stakeholders interviewed

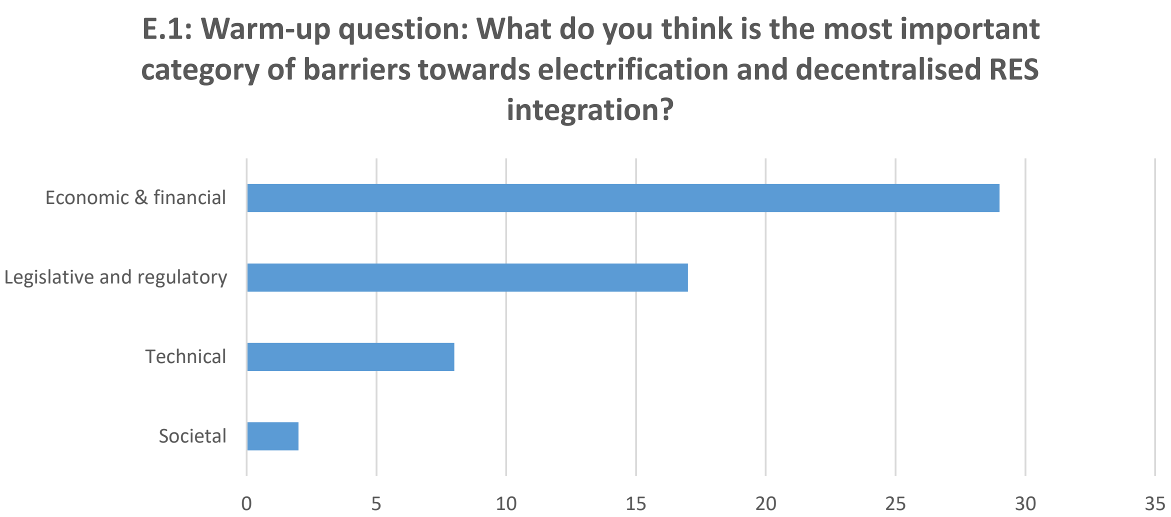
The following organisations were interviewed for the analysis of this study:

- Cross-topic
  - ENTSOG
  - CEER (Regulatory Gas Strategy, Future Policy, Infrastructure and Distribution Systems Working Groups/Work Streams)
- Hydrogen Uptake
  - Transport & Environment
  - Hydrogen Europe
  - Reiner Lemoine Institute
  - Fluxys
  - Air Liquide
- Waste Heat Utilisation
  - Amsterdam Metropolitan Studies Institute
  - CO2OLHEAT project coordinator
  - EMB3Rs project members
  - European Data Centre Association
  - Euroheat & Power
  - European Heat Pump Association
  - StEB Koeln

6.4. Stakeholder workshop poll results

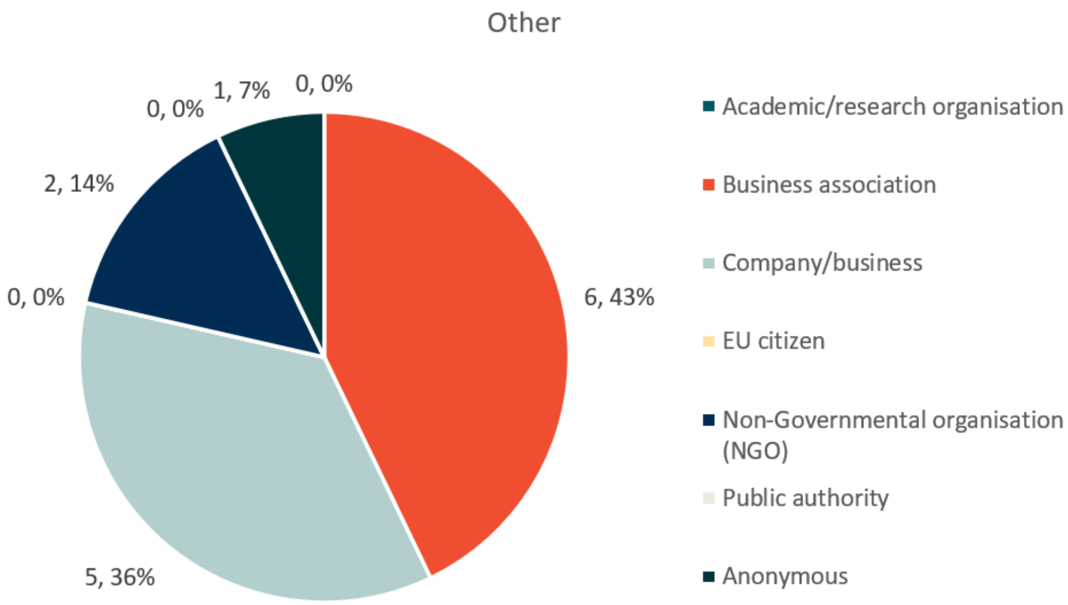
6.4.1. Electrification and decentralised RES polls

6.4.1.1. E.1 – 56 responses

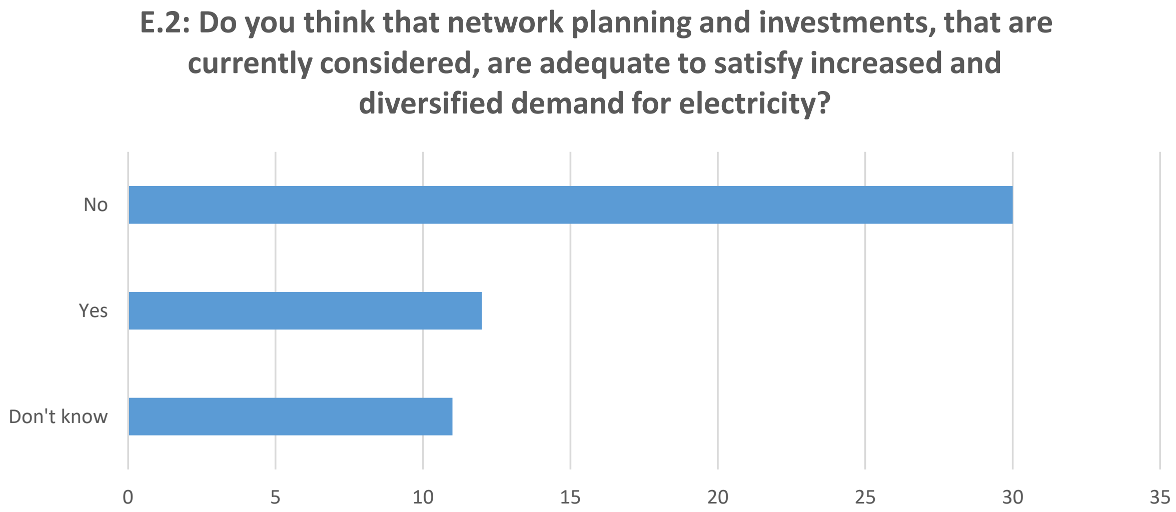


	Societal	Technical	Legislative and regulatory	Economic & financial
Total	2	8	17	29

Figure 5-5 Number of responses per user category for the 'other' aspect



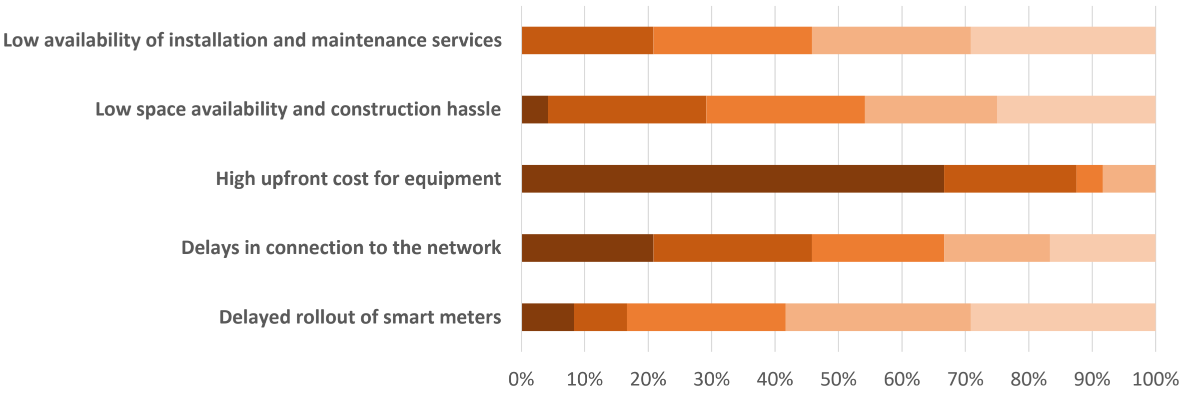
6.4.1.2. E.2 – 53 responses



	Don't know	Yes	No
Total	11	12	30

6.4.1.3. E.3 – 47 responses

E.3: What do you consider the biggest barriers towards electrification in the buildings sector (rank)?

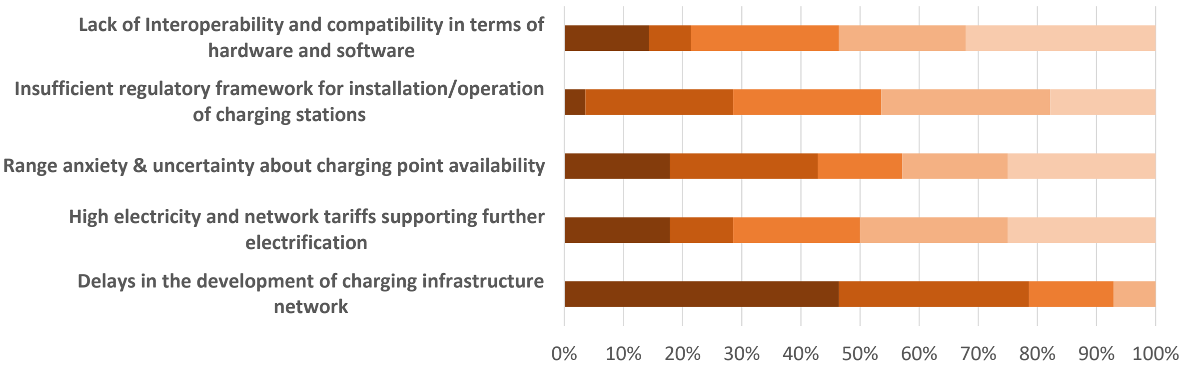


	Delayed rollout of smart meters	Delays in connection to the network	High upfront cost for equipment	Low space availability and construction hassle	Low availability of installation and maintenance services
1st	2	5	16	1	0
2nd	2	6	5	6	5
3rd	6	5	1	6	6
4th	7	4	2	5	6
5th	7	4	0	6	7

1st 2nd 3rd 4th 5th

6.4.1.4. E.4 – 44 responses

E.4: What do you consider the biggest barriers towards electrification in the transport sector?

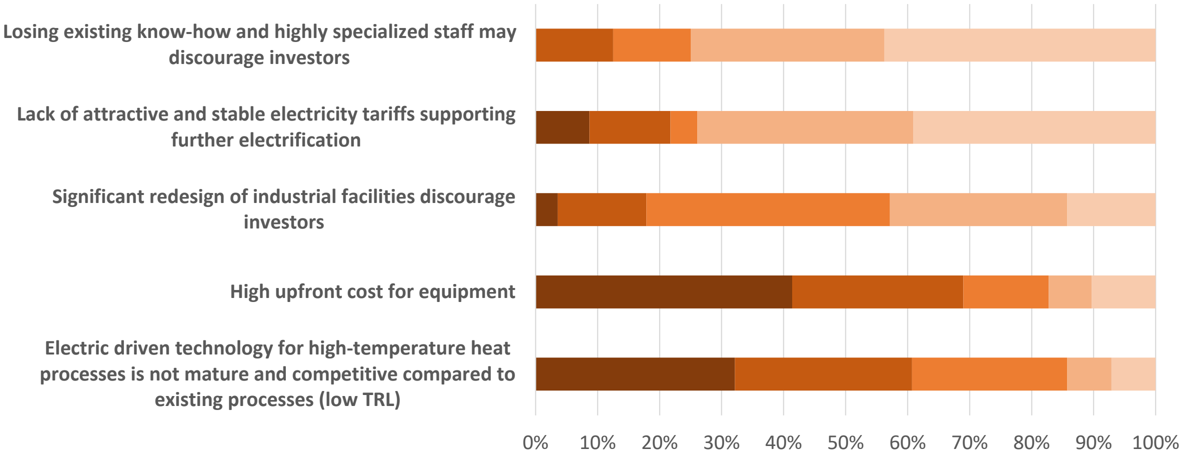


	Delays in the development of charging infrastructure network	High electricity and network tariffs supporting further electrification	Range anxiety & uncertainty about charging point availability	Insufficient regulatory framework for installation/operation of charging stations	Lack of Interoperability and compatibility in terms of hardware and software
1st	13	5	5	1	4
2nd	9	3	7	7	2
3rd	4	6	4	7	7
4th	2	7	5	8	6
5th	0	7	7	5	9

1st 2nd 3rd 4th 5th

6.4.1.5. E.5 – 40 responses

E.5: What do you consider the biggest barriers towards electrification in the industrial sector?

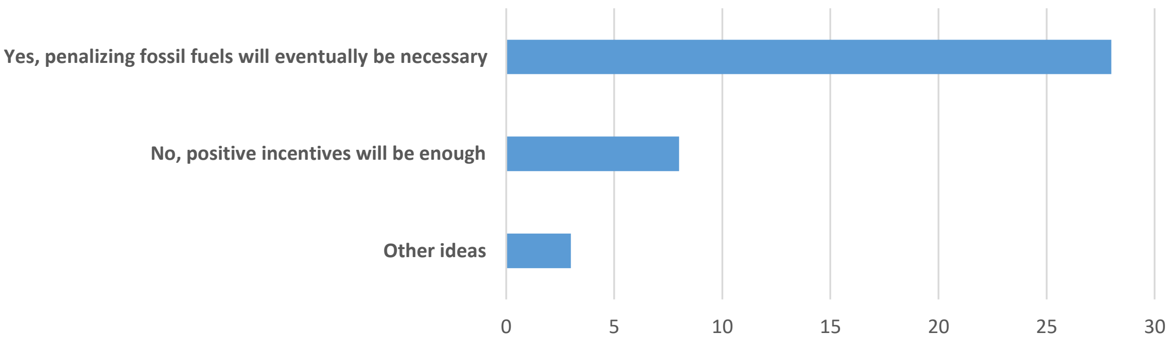


	Electric driven technology for high-temperature heat processes is not mature and competitive compared to existing processes (low TRL)	High upfront cost for equipment	Significant redesign of industrial facilities discourage investors	Lack of attractive and stable electricity tariffs supporting further electrification	Losing existing know-how and highly specialized staff may discourage investors
1st	9	12	1	2	0
2nd	8	8	4	3	2
3rd	7	4	11	1	2
4th	2	2	8	8	5
5th	2	3	4	9	7

1st 2nd 3rd 4th 5th

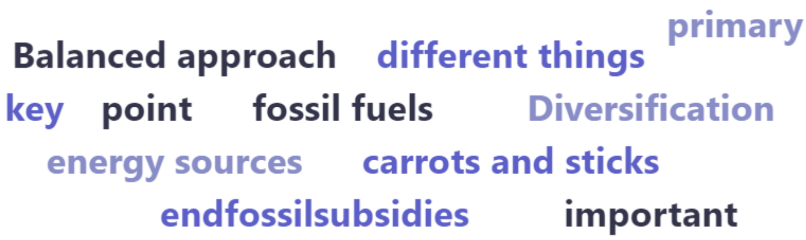
6.4.1.6. E.6 – 39 responses

E.6: Do you think result-oriented measures, like obligations to ban fossil fuels will be eventually needed to promote electrification in the long run?



	Other ideas	No, positive incentives will be enough	Yes, penalizing fossil fuels will eventually be necessary
Total	3	8	28

2. If 'other ideas', which?

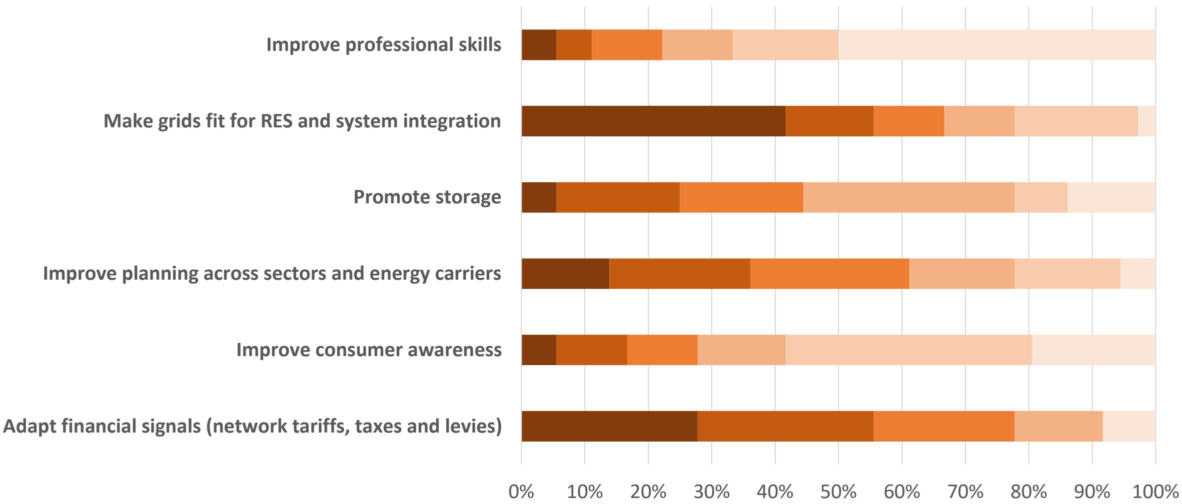


Full answers list:

1. "banning" and "penalising" are very different things.
2. Balanced approach is required, while banning fossil fuels may be required at some point it is important to ensure that no one is left behind
3. both carrots and sticks are needed
4. Diversification in all primary energy sources is key.
5. Endfossilsubsidies

6.4.1.7. E.7 – 46 responses

E.7 What are the most relevant actions to incentivize electrification and flexibility?

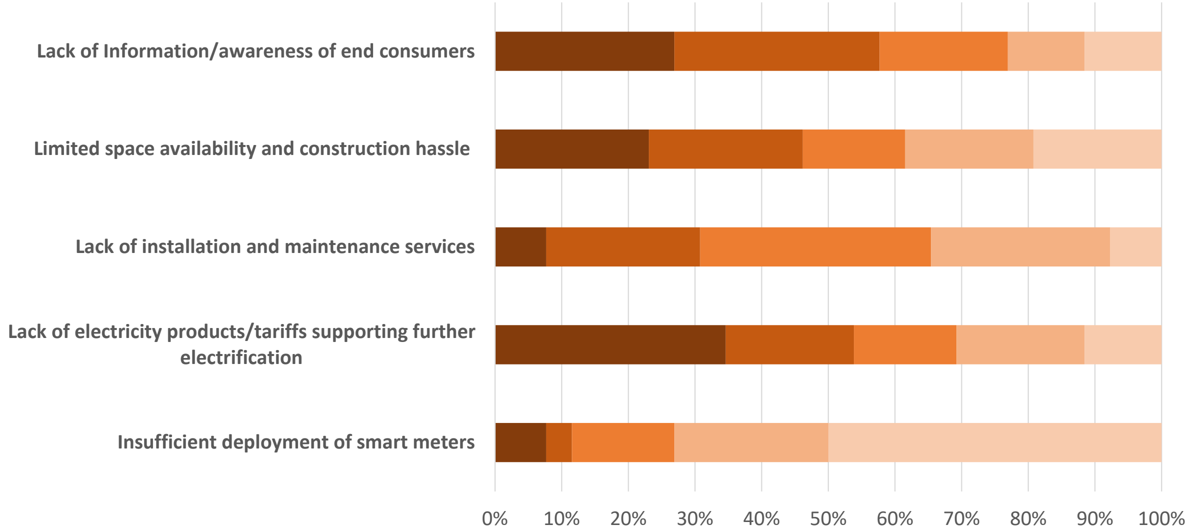


	Adapt financial signals (network tariffs, taxes and levies)	Improve consumer awareness	Improve planning across sectors and energy carriers	Promote storage	Make grids fit for RES and system integration	Improve professional skills
1st	10	2	5	2	15	2
2nd	10	4	8	7	5	2
3rd	8	4	9	7	4	4
4th	5	5	6	12	4	4
5th	0	14	6	3	7	6
6th	3	7	2	5	1	18

1st 2nd 3rd 4th 5th 6th

6.4.1.8. E.8 – 39 responses

E.8: Buildings: Which aspect you think of is the most important barrier and may need more policy guidance?



	Insufficient deployment of smart meters	Lack of electricity products/tariffs supporting further electrification	Lack of installation and maintenance services	Limited space availability and construction hassle	Lack of Information/awareness of end consumers
1st	2	9	2	6	7
2nd	1	5	6	6	8
3rd	4	4	9	4	5
4th	6	5	7	5	3
5th	13	3	2	5	3

1st 2nd 3rd 4th 5th

6.4.1.9. E.9 – 46 responses

E.9: Which other (EU) measures are still necessary to address barriers?

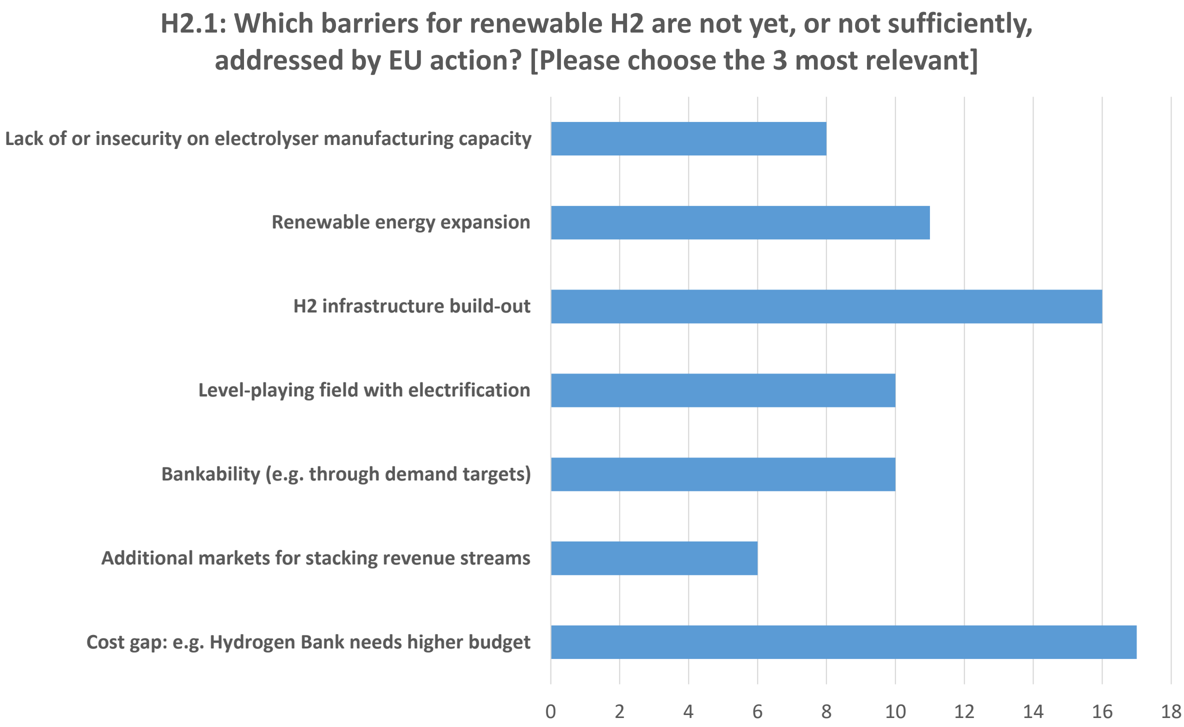
Full answers list:

1. Bi-directional charging capability e.g. via AFIR/EPBD
2. demand target
3. electricity demand

4. Electrification
5. electrification by sectors
6. electrification uptake
7. emission reductions
8. EU Strategy
9. EU Strategy on Electrification needed
10. excess heat
11. harmonisation of purchase process of vehicle chargers
12. heat
13. heat pump roll-out (all HPs)
14. heat strategy
15. infrastructure of networks
16. Low prices
17. mandatory plan to use excess heat
18. more financing
19. observatory of the electrification
20. Quick support
21. Quick support EU industry
22. set a final electricity demand target for 2030/40
23. speed in the regulation
24. speed in the regulation and implementations
25. Strategy on Electrification
26. support network as enablers
27. Technology neutrality
28. Technology neutrality (focus on emission reductions not technologies)
29. the decarbonisation of heat plan
30. the decarbonisation of heat strategy
31. Use NECPs to monitor electrification uptake
32. We need an observatory of the electrification by sectors to see progress, official Eurostat data show that electrification has been decreasing since 2014 about.

6.4.2. Hydrogen uptake polls

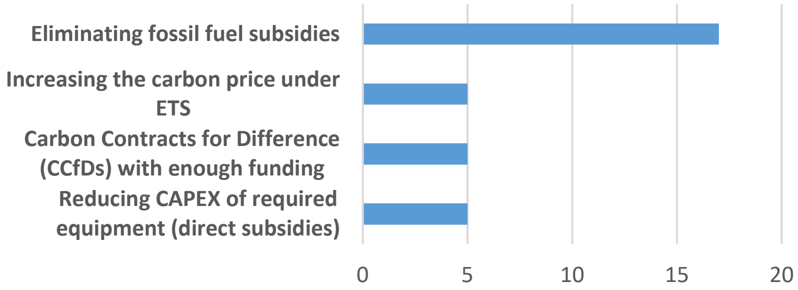
6.4.2.1. H2.1 – 33 responses



	Cost gap: e.g. Hydrogen Bank needs higher budget	Additional markets for stacking revenue streams	Bankability (e.g. through demand targets)	Level-playing field with electrification	H2 infrastructure build-out	Renewable energy expansion	Lack of or insecurity on electrolyser manufacturing capacity
1st	17	6	10	10	16	11	8

6.4.2.2. H2.2 – 32 responses

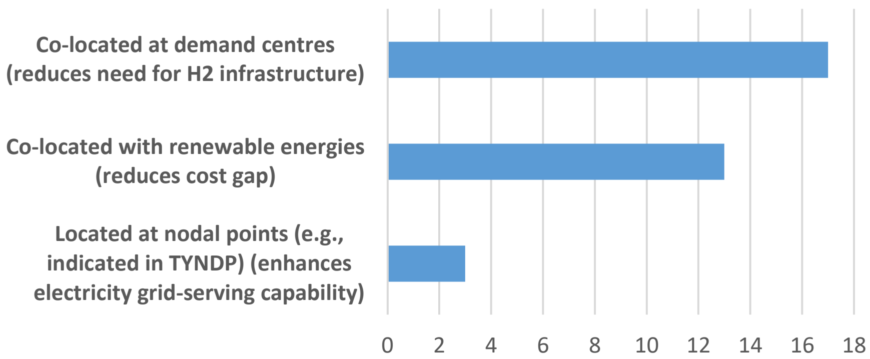
H2.2: The cost gap is a complex interplay of many factors, what is the measure of highest impact?



	Reducing CAPEX of required equipment (direct subsidies)	Carbon Contracts for Difference (CCfDs) with enough funding	Increasing the carbon price under ETS	Eliminating fossil fuel subsidies
Total	5	5	5	17

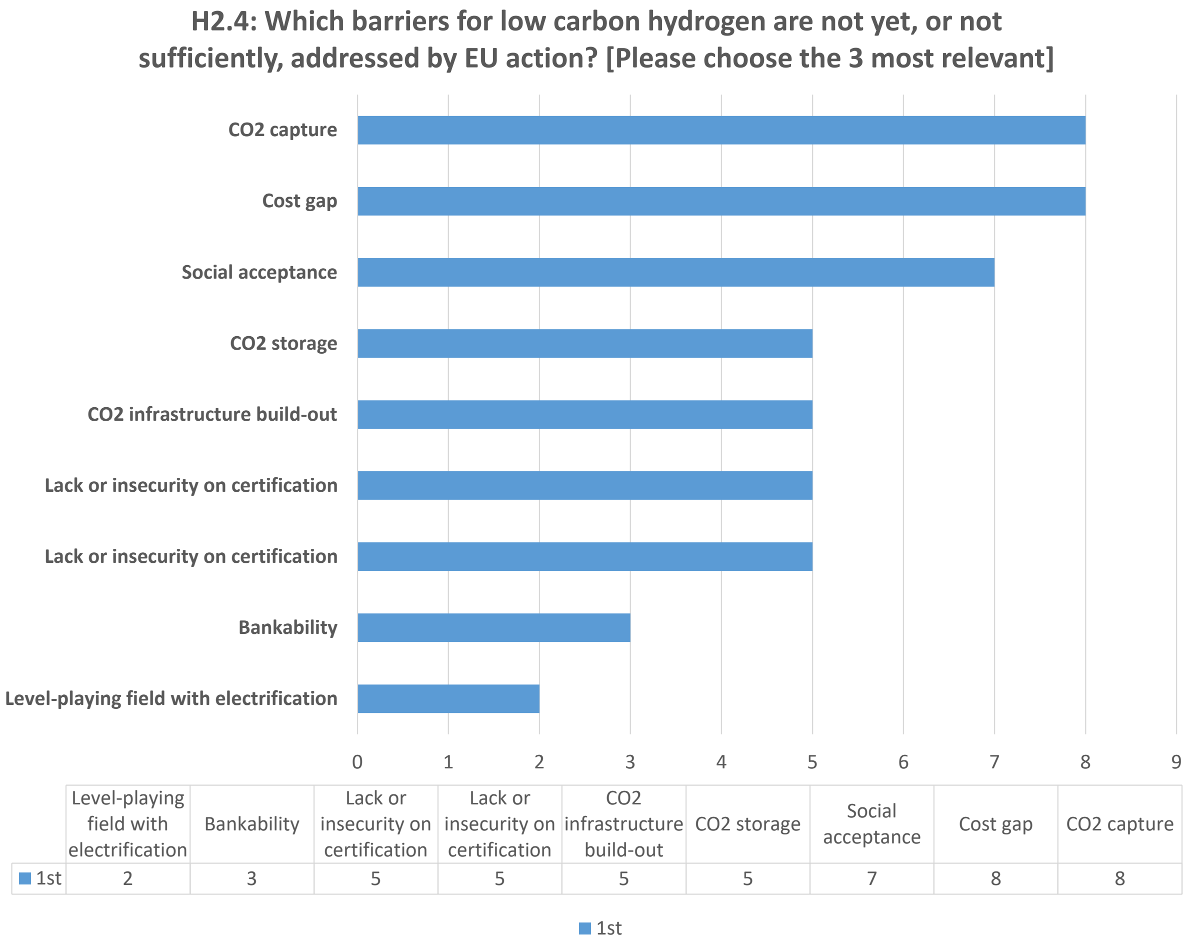
6.4.2.3. H2.3 – 33 responses

H2.3: Infrastructure planning priorities: Where should electrolysers be located preferably?



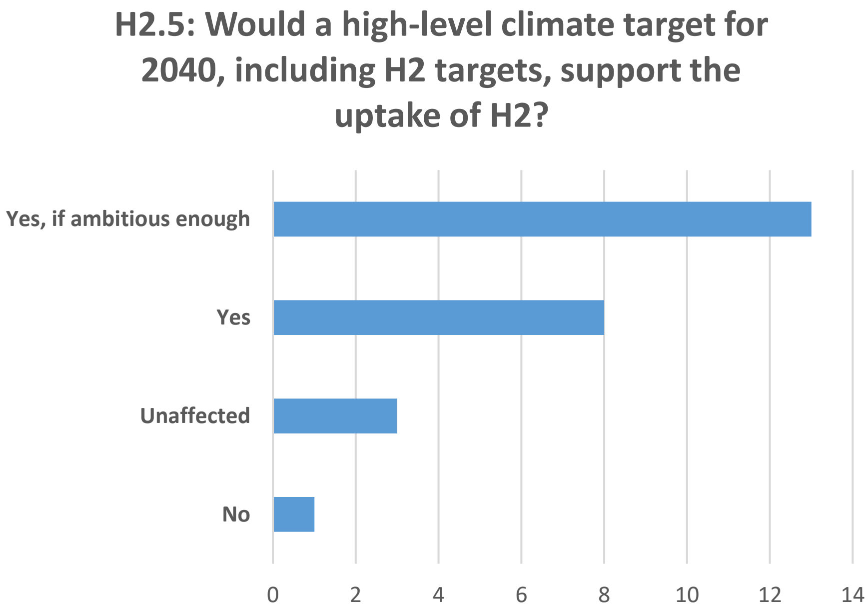
	Located at nodal points (e.g., indicated in TYNDP) (enhances electricity grid-serving capability)	Co-located with renewable energies (reduces cost gap)	Co-located at demand centres (reduces need for H2 infrastructure)
Total	3	13	17

6.4.2.4. H2.4 – 19 responses



	Level-playing field with electrification	Bankability	Lack or insecurity on certification	Lack or insecurity on certification	CO2 infrastructure build-out	CO2 storage	Social acceptance	Cost gap	CO2 capture
1st	2	3	5	5	5	5	7	8	8

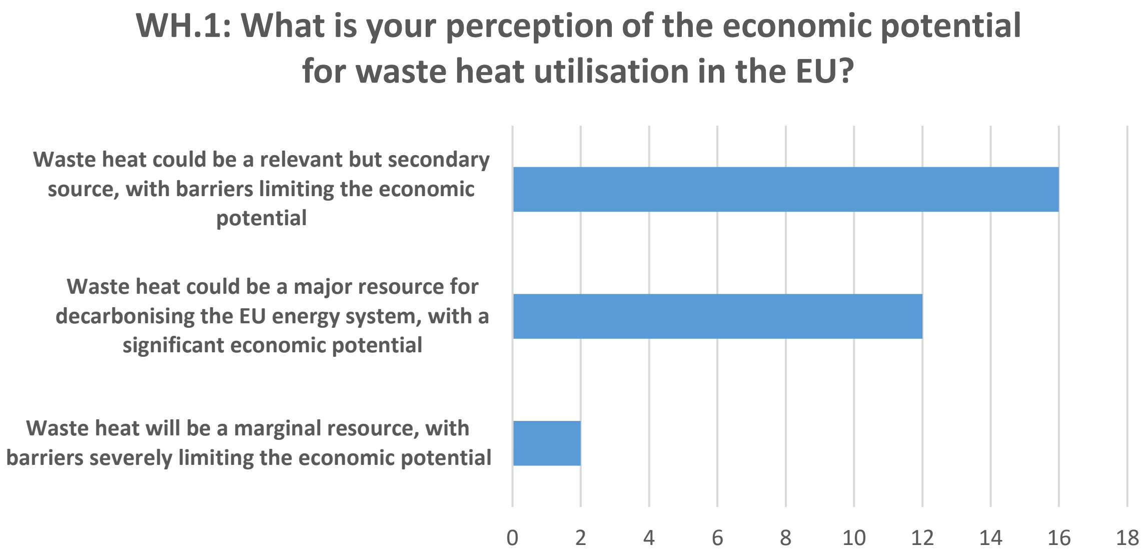
6.4.2.5. H2.5 – 25 responses



	No	Unaffected	Yes	Yes, if ambitious enough
Total	1	3	8	13

6.4.3. Waste heat utilisation polls

6.4.3.1. WH.1 – 30 responses



	Waste heat will be a marginal resource, with barriers severely limiting the economic potential	Waste heat could be a major resource for decarbonising the EU energy system, with a significant economic potential	Waste heat could be a relevant but secondary source, with barriers limiting the economic potential
Total	2	12	16

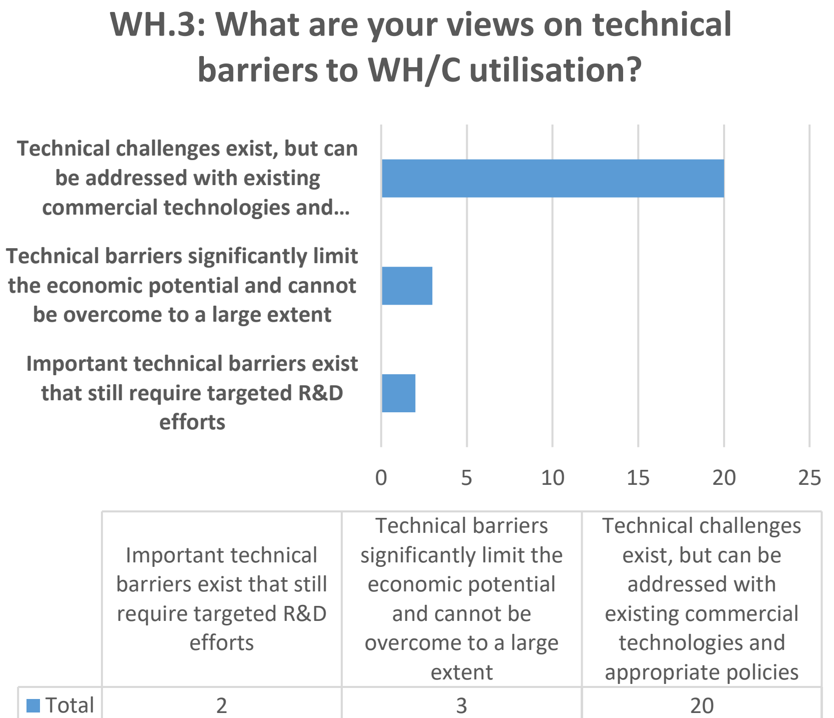
6.4.3.2. WH.2 – 22 responses

WH.2: What other important developments should be considered in the 2040 horizon?

Full answer list:

1. back-up capacities or funds for industrial waste heat
2. cooling
3. data center growth
4. Developing more the concept of positive energy district
5. district heating
6. fuel cells
7. heat recovery in industry
8. Heat waste high-temperature fuel cells
9. HT storage
10. Incentives for DH network operators to offtake WH
11. more cooling required
12. Movable high-temperature solid thermal storage
13. on-site
14. sector integration
15. storage
16. thermal storage
17. Utilisation of waste heat from waste water treatment plants can be very important source for district heating systems in 2040.
18. waste incineration

6.4.3.3. WH.3 – 25 responses



	Important technical barriers exist that still require targeted R&D efforts	Technical barriers significantly limit the economic potential and cannot be overcome to a large extent	Technical challenges exist, but can be addressed with existing commercial technologies and appropriate policies
Total	2	3	20

6.4.3.4. WH.4 – 7 responses

Full answer list:

1. Awareness
2. incentives to industrial processes
3. long term thermal storage
4. policy forbidding heat dumping
5. public ownership of heat infra
6. Seasonal Thermal Storage
7. Social Awareness

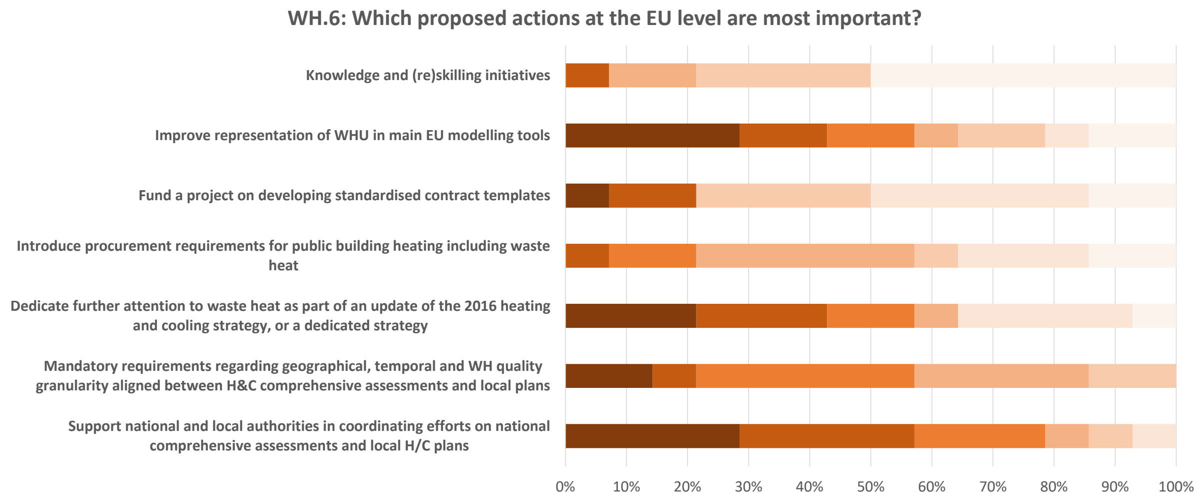
6.4.3.5. WH.5 – 10 responses

WH.5: Which other (EU) measures are still necessary to address economic and financial barriers? Please indicate the relevant WH source(s) if applicable

Full answer list:

1. As A Service prevented from subsidies design (asset ownership)
2. GHG accounting
3. heat from waste incineration plus mandatory CCS
4. mandatory policies
5. Proper risk mitigation framework is needed. This will enable utilisation of waste heat sources for instance further away from the network
6. risk mitigation schemes are central. However, for DH we need additional physical back-up capacities due to uncertainty of industrial waste heat. What happens if a company/ data centre moves abroad? DHC providers still must cover their contracts and deliver heat to customers. Risk schemes + physical back-up are needed. Who covers the costs for that?
7. Valleys of heat
8. volumetric valuation of energy

6.4.3.6. WH.6 – 14 responses



	Support national and local authorities in coordinating efforts on national comprehensive assessments and local H/C plans	Mandatory requirements regarding geographical, temporal and WH quality granularity aligned between H&C comprehensive assessments and local plans	Dedicate further attention to waste heat as part of an update of the 2016 heating and cooling strategy, or a dedicated strategy	Introduce procurement requirements for public building heating including waste heat	Fund a project on developing standardised contract templates	Improve representation of WHU in main EU modelling tools	Knowledge and (re)skilling initiatives
1st	4	2	3	0	1	4	0
2nd	4	1	3	1	2	2	1
3rd	3	5	2	2	0	2	0
4th	1	4	1	5	0	1	2
5th	1	2	0	1	4	2	4
6th	1	0	4	3	5	1	0
7th	0	0	1	2	2	2	7

1st 2nd 3rd 4th 5th 6th 7th

6.5. Status of actions in the EU Energy System Integration Strategy

Measure	Deadline in ESI Strategy	Status
3.1 A more circular energy system, with 'energy-efficiency-first' at its core		
1. Issue guidance to Member States on how to make the energy-efficiency-first principle operational.	2021	Implemented
2. Further promote the energy-efficiency-first principle in all upcoming relevant methodologies (e.g. in the context of the European resource adequacy assessment) and legislative revisions (e.g. of the TEN-E Regulation).	n/a	Implemented
3. Review the Primary Energy Factor, in order to fully recognise energy efficiency savings via renewable electricity and heat, as part of the review of the Energy Efficiency Directive.	June 2021	Implemented

Measure	Deadline in ESI Strategy	Status
4. Facilitate the reuse of waste heat from industrial sites and data centres, through strengthened requirements for connection to district heating networks, energy performance accounting and contractual frameworks, as part of the revision of the Renewable Energy Directive and of the Energy Efficiency Directive.	June 2021	Implemented
5. Incentivise the mobilisation of biological waste and residues from agriculture, food and forestry sectors and support capacity-building for rural circular energy communities through the new Common Agriculture Policy, Structural Funds and the new LIFE programme.	From 2021 onwards	(Continuous action)
3.2 Accelerating the electrification of energy demand, building on a largely renewables-based power system		
6. Through the Offshore Renewable Strategy and follow-up regulatory and financing actions, ensure the cost-effective planning and deployment of offshore renewable electricity, taking into account the potential for on-site or nearby hydrogen production, and strengthen EU's industrial leadership in offshore technologies.	2020	Implemented
7. Explore establishing minimum mandatory green public procurement (GPP) criteria and targets in relation to renewable electricity, possibly as part of the revision of the Renewable Energy Directive …	June 2021	Dropped
8. … supported by capacity building financing under the LIFE programme.	n/a	(Continuous action)
9. Tackle remaining barriers to a high level of renewable electricity supply that matches the expected growth in demand in end-use sectors, including through the review of the Renewable Energy Directive.	June 2021	Implemented
10. As part of the Renovation Wave initiative, promote the further electrification of buildings' heating (in particular through heat pumps), the deployment of on-buildings renewable energy, and the roll-out of electric vehicle charging points, using all available EU funding, including the Cohesion Fund and InvestEU.	From 2020 onwards	Implemented
11. Support the roll-out of 1 million charging points by 2025, using available EU funding, including the Cohesion Fund, InvestEU and Connecting Europe Facility funding, and communicate regularly on the funding opportunities and regulatory environment to roll out a charging infrastructure network.	From 2020 onwards	(Continuous action)
12. Develop more specific measures for the use of renewable electricity in transport, as well as for heating and cooling in buildings and industry, in particular	June 2021	Implemented

Measure	Deadline in ESI Strategy	Status
through the revision of the Renewable Energy Directive, and building on its sectoral targets.		
13. Finance pilot projects for the electrification of low-temperature process heat in industrial sectors through Horizon Europe and the Innovation Fund.	From 2021 onwards	(Continuous action)
14. Assess options to support the further decarbonisation of industrial processes, including through electrification and energy efficiency, in the revision of the Industrial Emissions Directive.	From 2021 onwards	Implemented
15. Propose to revise CO2 emission standards for cars and vans to ensure a clear pathway from 2025 onwards towards zero-emission mobility.	June 2021	Implemented
16. Support the roll-out of 1 million charging points by 2025, using available EU funding, including the Cohesion Fund, InvestEU and Connecting Europe Facility funding, and communicate regularly on the funding opportunities and regulatory environment to roll out a charging infrastructure network.	From 2020 onwards	(Continuous action)
17. Use the upcoming revision of the Alternative Fuels Infrastructure Directive to accelerate the roll-out of the alternative fuels infrastructure, including for electric vehicles, strengthen interoperability requirements, ensure adequate customer information, cross-border usability of charging infrastructure, and the efficient integration of electric vehicles in the electricity system.	2021	Implemented
18. Take up corresponding requirements for charging and refuelling infrastructure in the revision of the Regulation for the Trans-European Transport network (TEN-T).	2021	Implemented
19. Explore greater synergies through the revision of the TEN-E Regulation in view of possible energy network related support for cross border high capacity recharging as well as possibly hydrogen refuelling infrastructure.	2020	Implemented
20. Develop a Network Code on Demand Side Flexibility to unlock the potential of electric vehicles, heat pumps and other electricity consumption to contribute to the flexibility of the energy system.	Starting end-2021	On track
3.3 Promote renewable and low-carbon fuels, including hydrogen, for hard-to-decarbonise sector		
21. Propose a comprehensive terminology for all renewable and low-carbon fuels and a European system of certification of such fuels, based notably on full life cycle greenhouse gas emission savings and sustainability criteria, building on existing provisions including in the Renewable Energy Directive.	June 2021	Implemented
22. Consider additional measures to support renewable and low-carbon fuels, possibly through minimum shares or quotas in specific end-use sectors (including aviation and maritime), through the revision of the Renewable Energy Directive and building on its sectoral targets, complemented, where appropriate, by additional measures assessed under the REFUEL Aviation and FUEL Maritime initiatives (2020). The support regime for	June 2021	Partly Implemented

Measure	Deadline in ESI Strategy	Status
hydrogen will be more targeted, allowing shares or quota only for renewable hydrogen.		
23. Promote the financing of flagship projects of integrated, carbon-neutral industrial clusters producing and consuming renewable and low-carbon fuels, through Horizon Europe, InvestEU and LIFE programmes and the European Regional Development Fund.	From 2021	(Continuous action)
24. Stimulate first-of-a-kind production of fertilisers from renewable hydrogen through Horizon Europe.	From 2021	(Continuous action)
25. Demonstrate and scale-up the capture of carbon for its use in the production of synthetic fuels, possibly through the Innovation Fund.	From 2021	(Continuous action)
26. Develop a regulatory framework for the certification of carbon removals based on robust and transparent carbon accounting to monitor and verify the authenticity of carbon removals.	by 2023	On track
3.4 Making energy markets fit for decarbonisation and distributed resources		
27. Issue guidance to Member States to address the high charges and levies borne by electricity and to ensure the consistency of non-energy price components across energy carriers.	2021	Implemented
28. Align the taxation of energy products and electricity with EU environment and climate policies, and ensure a harmonised taxation of both storage and hydrogen production, avoiding double taxation, through the revision of the Energy Taxation Directive.	June 2021	On track
29. Provide more consistent carbon price signals across energy sectors and Member States, including through a possible proposal for the extension of the ETS to new sectors.	June 2021	Implemented
30. Further work towards the phasing out of direct fossil fuel subsidies, including in the context of review of the State aid framework and the revision of the Energy Taxation Directive.	From 2021 onwards	Implemented
31. Ensure that the revision of the State aid framework supports cost-effective decarbonisation of the economy where public support remains necessary.	2021	Implemented
32. Review the legislative framework to design a competitive decarbonised gas market, fit for renewable gases, including to empower gas customers with enhanced information and rights.	Q4 2021	Implemented
33. In the context of the Climate Pact, launch a consumer information campaign on energy customer rights.	2021	Implemented

Measure	Deadline in ESI Strategy	Status
34. Improve information to customers on the sustainability of industrial products (in particular steel, cement and chemicals) as part of the sustainable product policy initiative, and, as appropriate, through complementary legislative proposals (by 2022).	2022	Implemented (provisionally agreed in Dec 2023)
3.5 A more integrated energy infrastructure		
35. Ensure that the revisions of the TEN-E and TEN-T regulations fully support a more integrated energy system, including through greater synergies between the energy and transport infrastructure, as well as the need to achieve the 15% electricity interconnection target for 2030.	2020 (TEN-E Regulation) and 2021 (other relevant legislation)	Implemented
36. Review the scope and governance of the TYNDP to ensure full consistency with the EU's decarbonisation objectives and cross-sectoral infrastructure planning as part of the revision of the TEN-E Regulation (2020) and other relevant legislation (2021).	2020 (TEN-E Regulation) and 2021 (other relevant legislation)	Implemented
37. Accelerate investment in smart, highly-efficient, renewables-based district heating and cooling networks, if appropriate by proposing stronger obligations through the revision of the Renewable Energy Directive and the Energy Efficiency Directive, and the financing of flagship projects.	June 2021	Implemented
3.6 A digitalised energy system and a supportive innovation framework		
38. Adopt a Digitalisation of Energy Action plan to develop a competitive market for digital energy services that ensures data privacy and sovereignty and supports investment in digital energy infrastructure.	Q4 2021 or Q1 2022	Implemented
39. Develop a Network Code on cybersecurity in electricity with sector-specific rules to increase the resilience and cybersecurity aspects of cross-border electricity flows, common minimum requirements, planning, monitoring, reporting and crisis management.	End 2021	On track
40. Adopt the implementing acts on interoperability requirements and transparent procedures for access to data within the EU.	First one in 2021	Implemented
41. Publish a new impact-oriented clean energy research and innovation outlook for the EU to ensure research and innovation supports energy system integration.	Q3 2021	Implemented
Conclusion		
42. Organisation of a large dedicated public event on Energy System Integration.	Q2 2021	Dropped

6.6. Uptake of hydrogen - Details on environmental impacts of hydrogen imports

For the transition to a carbon-neutral economy, the greenhouse gas intensity of hydrogen production and delivery is important. In addition to implementing the local production scale-up,[487] the European Union plans on importing hydrogen and its derivatives from other countries to minimise overall costs.[488] The environmental impacts of these imports need to be considered in order to also achieve the environmental goals that the Union has set for itself. This part of the report analyses the factors that determine the environmental aspects of hydrogen import and the different import pathways, focusing on greenhouse gas emissions measured in CO_2 equivalents.

In this section, different hydrogen production pathways are analysed with a focus on renewable and low-carbon hydrogen as well as different transport methods, including pipeline transport and marine transport in the form of different hydrogen derivatives such as liquid hydrogen (LH_2), ammonia (NH_3) and Liquid Organic Hydrogen Carriers (LOHC). The emissions of these pathways are in the end also compared to the alternative of emissions from a fossil fuel-based energy supply (based on the fossil fuel comparator in REDII and the Delegated Acts related to it).

In order to understand the GHG footprint of hydrogen, it is crucial to take a closer look at its production chain. The production method of the hydrogen and the electricity mix that is used in the production steps are two of the most important drivers of GHG emissions and major factors in the overall lifecycle emissions of hydrogen and its derivatives.[489,490] In the following, the factors which have an impact on the footprint during the production process are examined.

To produce renewable hydrogen, renewable electricity is needed for electrolysis. Renewable hydrogen is considered to be the production pathway with the lowest emissions, together with hydrogen from nuclear sources, as analysed in case studies comparing the emissions of different hydrogen production pathways.[491,492,493] The GHG emissions per kg of renewable hydrogen (world average, best practice assumed), including emissions related to the manufacturing of installations (so-called CAPEX emissions) are calculated to be around 0.3 kg of CO_2-equivalent emission for hydrogen from hydro power, 0.6 kg from onshore wind power, and 1 kg from solar power in 2030, according to a study from the Hydrogen Council.[494]

For hydrogen from nuclear energy, greenhouse gas emissions are projected to be very low in 2030 compared to other technologies, contributing only around 0.6 kg GHG emissions per kg hydrogen.[495] However, other risks associated with nuclear power generation should not be neglected, including safety and security aspects and radioactive waste.

Low-carbon hydrogen can also be produced from natural gas using steam methane reforming processes and carbon capture and storage (CCS) technologies. The footprint is highly dependent on three aspects: the methane emission rate of the natural gas supply, the global warming potential (GWP) metric used in the analysis, and the carbon capture

[487] European Commission (2020) A hydrogen strategy for a climate-neutral Europe
[488] Nunez-Jimenez, A., & De Blasio, N. (2022) Competitive and secure renewable hydrogen markets: Three strategic scenarios for the European Union - ScienceDirect
[489] Hydrogen Council (2021), by LBST Hydrogen Council Report Decarbonization Pathways Part-1 Lifecycle-Assessment
[490] Delpierre, M., Quist, J., Mertens, J., Prieur-Vernat, A., & Cucurachi, S. (2021) Assessing the environmental impacts of wind-based hydrogen production in the Netherlands using ex-ante LCA and scenarios analysis - ScienceDirect
[491] World Economic Forum (WEF) (2023) How to understand the carbon footprint of green hydrogen | World Economic Forum (weforum.org)
[492] Timmerberg, S. (2020) Hydrogen supply from North Africa to the EU – Potentials, costs and GHG emissions
[493] IPCC (2014) AR5 Climate Change 2014: Mitigation of Climate Change, Page 1335
[494] Hydrogen Council (2021), by LBST Hydrogen Council Report Decarbonization Pathways Part-1 Lifecycle-Assessment
[495] Hydrogen Council (2021), by LBST Hydrogen Council Report Decarbonization Pathways Part-1 Lifecycle-Assessment

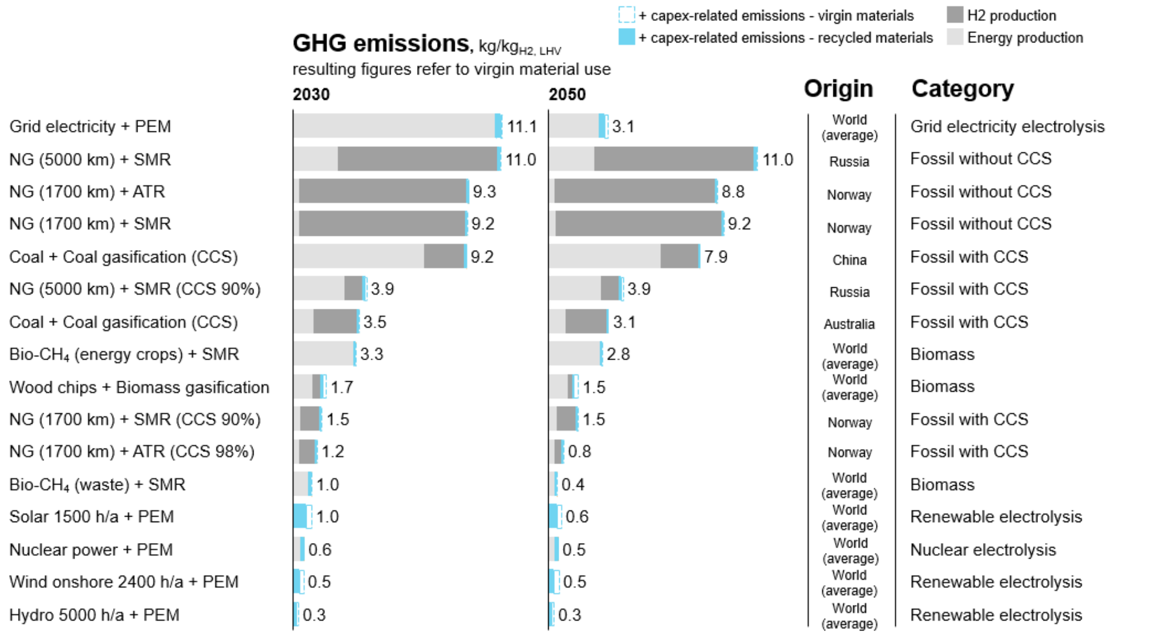
rate.[496] Additionally, it is important to recognise that a stated 90% carbon capture rate does not result in a reduction of GHG emissions per kgH_2 of 90%, as further greenhouse gas emissions are generated earlier in the natural gas supply chain and additional energy (with according emissions) is required to operate the capture and sequestration process.[497]

Due to these differences, the GHG emissions for the production of hydrogen from natural gas with CCS can vary strongly between the producing countries, with the production of low-carbon hydrogen using CCS from Norway creating far lower emissions than the same type of hydrogen based on natural gas from Russia, China, and Australia.[498] With a high carbon capture rate, hydrogen production using natural gas can be among the production methods with the lowest GHG emissions in some cases, but in other cases with lower capture rates and less strict regulations of the emissions in the fossil fuel production chain, imports of such hydrogen can be related to high GHG emissions.[499,500]

According to CertifHy hydrogen certification, hydrogen production via steam methane reforming (SMR) of natural gas without CCS produces 10.9 $kgCO_2eq/kgH_2$, and a review paper by Bhandari et al. gives a range of 8.9-12.9 $kgCO_2\text{-}eq/kgH_2$ for the same production method.[501,502] The Hydrogen Council projects for 2030 GHG emissions of about 9 kg CO_2eq per kg H_2 for hydrogen production using SMR or autothermal reforming (ATR), both without CCS, while no significant reduction of the footprint is expected by 2050. Therefore, literature shows that production of renewable (0.3-1.0 $kgCO_2eq/kgH_2$) or low-carbon hydrogen can have by far lower environmental impacts than for example hydrogen from Russian natural gas (transported over 5,000 km) that is produced via SMR (11 $kgCO_2eq/kgH_2$).

Figure 6-16: GHG emissions of various H2 production pathways Source: LBST, based on Hydrogen Council (2021), by LBST Hydrogen Council Report Decarbonisation Pathways Part-1 Lifecycle-Assessment

[496] Bauer, C., Treyer, K., Antonini, C., Bergerson, J., Gazzani, M., Gencer, E., ... & Van der Spek, M. (2022) On the climate impacts of blue hydrogen production - Sustainable Energy & Fuels (RSC Publishing)
[497] Hydrogen Council (2021), by LBST Hydrogen Council Report Decarbonization Pathways Part-1 Lifecycle-Assessment
[498] Hydrogen Council (2021), by LBST Hydrogen Council Report Decarbonization Pathways Part-1 Lifecycle-Assessment
[499] Richard Taylor, Ellie Raphael, Chester Lewis, Ross Berridge, Jo Howes (2022). Expansion of hydrogen production pathways analysis – import chains (publishing.service.gov.uk)
[500] Hydrogen Council (2021), by LBST Hydrogen Council Report Decarbonization Pathways Part-1 Lifecycle-Assessment
[501] Kanz, O., Brüggemann, F., Ding, K., Bittkau, K., Rau, U., & Reinders, A. (2023 Life-cycle global warming impact of hydrogen transport through pipelines from Africa to Germany - Sustainable Energy & Fuels (RSC Publishing)
[502] R. Bhandari, C. A. Trudewind and P. Zapp (2014). Life cycle assessment of hydrogen production via electrolysis – a review - ScienceDirect



Source: Hydrogen Council, LBST

Another component of the GHG emissions of imports of hydrogen and its derivatives are the emissions from transportation. Hydrogen can be transported by pipeline or by ship.

Using modified existing pipelines is generally preferable from a carbon and resource point of view, if possible, rather than building new pipelines, because higher greenhouse gas emissions are generated, and environmental impacts are caused during the manufacturing and construction process. To transport hydrogen via pipelines, the gas must be compressed. Electricity is needed for this compression step, and therefore, again, the local electricity used is the main source of emissions. Pipeline transport of compressed hydrogen is, however, the most energy efficient transportation method at distances up to 10,000 km, due to higher conversion energies needed in the pathways “LNG + SMR”, “LH_2”, “NH_3 + cracking” and “LOHC”.[503] During pipeline transport, the emission factor of the grid electricity is a factor for GHG emissions. Under the assumptions of the study by Taylor et al. (2022), the emissions for pipeline transport from Spain to the UK are higher than for pipeline transport from Norway to the UK, which is due to the grid emissions being higher in Spain.[504] However, due to the expected decarbonisation of the Spanish grid, the transport emissions are expected to fall over time. Also, in a study by Wulf et al. (2018) that calculated emissions for a transporting distance of 100 km, the pipeline solution has far lower emissions (0.16 kg CO_2eq per kg H_2) compared to transportation of LOHC via truck (3.39 kg CO_2eq per kg H_2) and the transportation of gaseous hydrogen via truck (1.23 kg CO_2eq per kg H_2).[505]

There are several options for transporting hydrogen by ship, all of which have different environmental impacts.

One option is to use liquid hydrogen (LH_2) as a hydrogen carrier. According to Zhou et al. (2021), all other parameters being equal, liquid hydrogen generally has a higher GHG intensity than gaseous hydrogen due to the higher electricity consumption during liquefaction compared to compression.[506] Again, the energy mix used to generate the electricity for liquefaction is the main factor influencing GHG intensity.

[503] DVGW (2023) Kurzstudie zu Transportoptionen von Wasserstoff
[504] Richard Taylor, Ellie Raphael, Chester Lewis, Ross Berridge, Jo Howes (2022) Expansion of hydrogen production pathways analysis – import chains (publishing.service.gov.uk)
[505] Wulf, C., Reuß, M., Grube, T., Zapp, P., Robinius, M., Hake, J. F., & Stolten, D. (2018) Life Cycle Assessment of hydrogen transport and distribution options - JuSER (fz-juelich.de)
[506] Zhou, Y., Swidler, D., Searle, S., & Baldino, C. (2021) LCA-gas-EU-white-paper-A4-v5.pdf (theicct.org)

In a study by Kim et al. (2021), a carbon footprint analysis of overall hydrogen supply from overseas for several hydrogen carriers, including liquid hydrogen, were conducted.[507] The results indicate that the footprint for hydrogen transported as LH_2 is lower than for LOHC and NH_3 as hydrogen carriers. These results are consistent with a study by Wulf & Zapp (2018) where they come to similar conclusions of a lower footprint of LH_2 compared to LOHC.[508] When using grid electricity for conversion steps, the footprint of LH_2 amounts to 2.5 $kgCO_2eq$ per kg H_2, when using only wind energy for liquefaction, this amount decreases to 2 $kgCO_2eq$ per kg H_2. In contrast, LOHC has a higher footprint (3.5 $kgCO_2eq$ per kg H_2) even when the natural gas for the heat production for dehydrogenation is substituted by hydrogen. The main reason they cite for the lower emissions from LH_2 is that LH_2 transports have a higher transport capacity and therefore emit fewer greenhouse gases during transport per unit of hydrogen, compared to LOHC.

For a case study for hydrogen imports of the United Kingdom (UK), Taylor et al. (2022) calculates the emissions of overseas hydrogen production and import via different realistic pathways consisting of the hydrogen production pathway, the export country, and the hydrogen or hydrogen derivative used.[509]

The emissions from shipping in the values below are based on the baseline trajectory of the average shipping fuel GHG intensities until 2050, given in the IEA Net Zero 2050 report, which predicts an 85% drop by 2050 (compared to 2008 levels; resulting from the increased use of renewable H_2 and ammonia).[510] The following pathways and emissions (in $gCO_2eq/MJ\ H_2$) were calculated for 2030 and 2050:

- Renewable hydrogen, Australia, in the form of ammonia (2030: 25g; 2050: 9 g)
- NG + CCS hydrogen, UAE, in the form of LOHC (2030: 70g; 2050: 50 g)
- NG + CCS hydrogen, USA, in the form of LH_2 (2030: 80g; 2050: 40 g)
- NG + CCS hydrogen, Norway, compressed hydrogen via pipeline (2030: 18g; 2050: 17 g)
- Renewable hydrogen, Spain, compressed hydrogen via pipeline (2030: 3g; 2050: 1 g)

In the above shown results, ammonia (NH_3), in terms of GHG emissions and under the applied assumptions, would become a low-emission transportation pathway for hydrogen (the direct use of ammonia was not considered) by ship, even for long distance transportation like from Australia by 2050. It is assumed that the ammonia conversion process is fuelled by renewable electricity only. Consequently, the transportation emissions emerge as the primary contributor in the short-term within the ammonia supply chain, closely followed by the emissions from ammonia cracking. The above-mentioned gradual decarbonisation of shipping (toward an average reduction of GHG intensity in shipping of 88% by 2050) and trucking leads to a consistent reduction in GHG emissions for the ammonia production chain over time (decreasing the emissions from 25g CO_2eq per MJ H_2 in 2020 to 9g CO_2eq per MJ H_2 in 2050). In the short term, import chains that include shipping (LH_2, ammonia, LOHC) have much greater GHG impacts compared to pipeline-

[507] Kim, A., Lee, H., Brigljević, B., Yoo, Y., Kim, S., & Lim, H. (2021). Thorough economic and carbon footprint analysis of overall hydrogen supply for different hydrogen carriers from overseas production to inland distribution - ScienceDirect
[508] Wulf, C., & Zapp, P. (2018). Assessment of system variations for hydrogen transport by liquid organic hydrogen carriers | Request PDF (researchgate.net)
[509] Richard Taylor, Ellie Raphael, Chester Lewis, Ross Berridge, Jo Howes (2022) Expansion of hydrogen production pathways analysis – import chains (publishing.service.gov.uk)
[510] IEA (2021) Net Zero by 2050. Figure 03.25

based supply chains.[511] By 2050, with decarbonised shipping, transportation emissions will be almost negligible. The remaining emissions mainly stem from the gas grid inputs utilised for ammonia cracking in the UK. For a complete picture of the environmental impacts that large-scale imports of ammonia can have, the toxicity of ammonia should be mentioned. While it is a commonly traded commodity, ammonia spills could have strong negative effects on local population and wildlife.[512] Chinese regulations, for example, are heavily concerned with the impact that ammonia can have in bodies of water. This is regulated by the GB 13458-2013 standard issued by the China's Ministry of Ecology and Environment (MEE).[513]

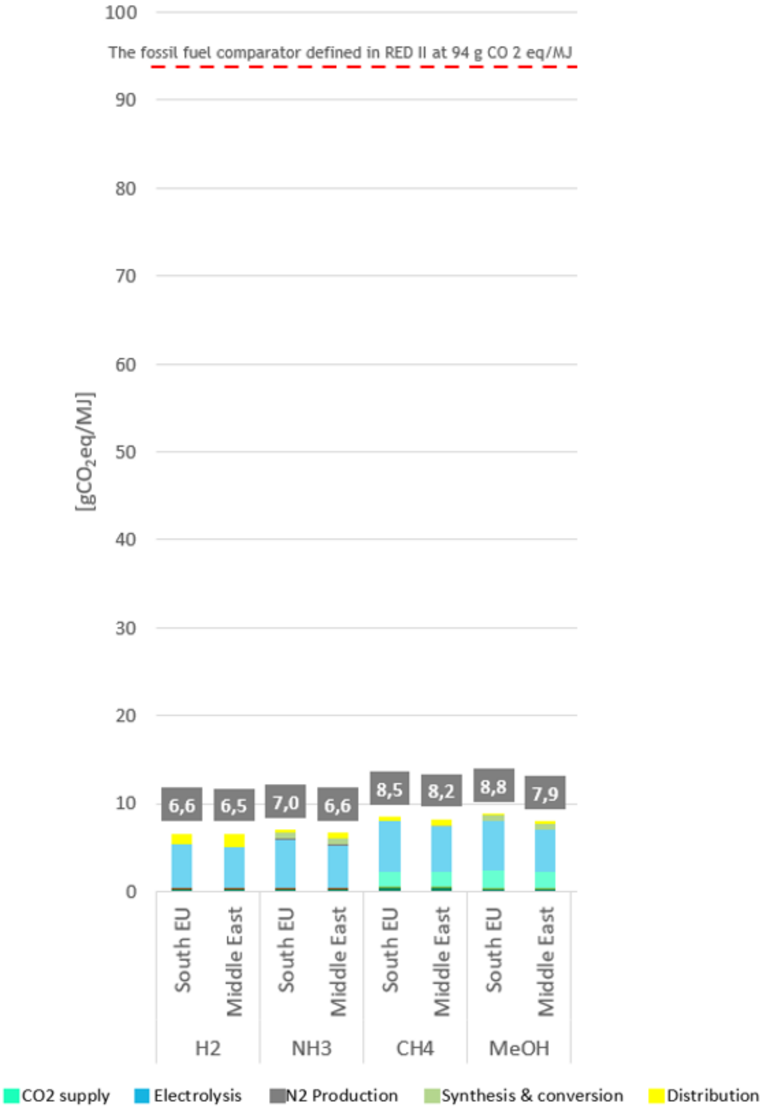
The above listed results of the study by Taylor et al. further show that especially imports of low-carbon hydrogen from SMR using CCS from countries such as the United States of America (USA) and United Arab Emirates (UAE) are connected to high GHG emissions. In these countries, regulations concerning low-carbon hydrogen production are not as strict. For the case of the USA, the high emission level is also attributed to the significant electricity consumption during liquefaction and the carbon intensity of the grid electricity in Texas, USA. Because of this, emissions are expected to decrease over time to about 40 g CO_2eq per MJ H_2 in 2050 due to enhanced liquefaction efficiency, decarbonisation of the USA electricity grid mix, and assumed decarbonisation measures for shipping and trucking. However, the carbon intensity of imports of low-emission hydrogen (in the forms of LOHC from the UAE or LH_2 from the USA) is not expected to decrease the emission level of imports of renewable hydrogen or even decrease below the UK production threshold of 20g CO_2eq/MJ H_2.

The study by LBST for Concawe on decarbonisation pathways[514] analyses the GHG emissions of the import of hydrogen and its derivatives in 2050 (Figure 6-17). It compares hydrogen with the derivatives, and for each of the products the emissions of importing it to the rest of the EU from Southern Europe (Spain) or the Middle East. The reforming/cracking steps of the hydrogen carriers in order to reconvert them into hydrogen and their according emissions are included in this study. In this analysis, only production using renewable electricity (which we have seen is the environmentally preferred import option) is considered. The breakdown of emissions differs slightly between pathways, with higher emissions during distribution needed for pipeline transportation of pressurised hydrogen, some synthesis and conversion emissions for ammonia and methanol and the sourcing of CO_2 (which is required to come from Direct Air Capture from 2041 onwards) playing a role for synthetic methane and methanol.

Sourcing the energy carriers from the Middle East instead of the South of Europe adds additional steps to the supply chain (shipping over a distance of 5.000 km and unloading). However, due to ships assumed to be fuelled in 2050 by e-diesel, their GHG impact is marginal and contributes only a maximum of 0.2 gCO_2eq/MJ. These emissions will be overcompensated by the lower carbon intensity of the renewable electricity used, making the electricity mix for the synthesis process the dominant factor, even when long distance transportation is involved.

[511] Richard Taylor, Ellie Raphael, Chester Lewis, Ross Berridge, Jo Howes (2022) Expansion of hydrogen production pathways analysis – import chains (publishing.service.gov.uk)
[512] Duong, P.A.; Ryu, B.R.; Song, M.K.; Nguyen, H.V.; Nam, D.; Kang, H. (2023) Safety Assessment of the Ammonia Bunkering Process in the Maritime Sector: A Review.
[513] China's Ministry of Ecology and Environment (2013) Discharge standard of water pollutants for ammonia industry
[514] *Concawe (2022), by LBST E-Fuels: A techno-economic assessment of European domestic production and imports towards 2050 (Concawe Report 17/22)*

Figure 6-17 Comparison of GHG emissions of hydrogen and derivatives' imports produced in Southern Europe and Middle East in 2050



Source: LBST, based on Concawe (2022) [515]

The overall size of emissions of imports of renewable hydrogen and its derivatives do not drastically change in 2050 between hydrogen carriers (between 6.5 and 8.8 $gCO_2eq/MJ\ H_2$) or between import countries,[516] making neither the choice of hydrogen carrier nor the choice of the exporting country a crucial decision for reducing the GHG emissions of renewable hydrogen imports.

This is made especially clear, when comparing the emissions of the above pathways to the emissions of a continued use of fossil fuels. The emissions of the pathways can be compared to the red line at the top of the graph. This red line shows the fossil fuel comparator defined in the REDII (and the related Delegated Acts). This represents the GHG intensity of the average liquid and gaseous fossil fuel mix in the EU for the purposes of calculating compliance towards the GHG target and represents gasoline, diesel and natural

[515] *Concawe (2022), by LBST [E-Fuels: A techno-economic assessment of European domestic production and imports towards 2050 (Concawe Report 17/22)]*
[516] *Concawe (2022), by LBST [E-Fuels: A techno-economic assessment of European domestic production and imports towards 2050 (Concawe Report 17/22)]*

gas.[517] The emissions value of this comparator is 94 g $gCO_2eq/MJ\ H_2$, which would be 10.7 to 14.5 times the amount of emissions of the renewable hydrogen products via these import pathways. This demonstrates the improvement by using renewable hydrogen instead of fossil fuels.

Much more important in terms of environmental impacts are therefore the decisions to quickly replace current fossil fuels and to do so by preferably importing renewable hydrogen-based products rather than those based on natural gas and CCS. Transport distance is a factor in the short- to medium-term, while in the long-term it is anticipated that ship transport is decarbonised reducing transport emissions to very low levels. Nonetheless, renewable hydrogen transported by pipeline has the lowest emissions. Europe has a number of options for imports or transports within Europe by pipeline including the Norther Africa-Italy corridor, the North Sea corridor (off-shore wind and Norway), the Nordic & Baltic corridor, as well as the Eastern and South-eastern European routes.

Instead of the limited differences in GHG emissions between different renewable energy carriers and between exporting countries of renewable hydrogen, other factors will play a more crucial role in determining the future of European energy imports, such as production and import costs as well as safety considerations related to ammonia.

6.7. Waste heat utilisation case studies

6.7.1. EMB3Rs project

6.7.1.1. Description

The EMB3Rs project (User-driven Energy-Matching & Business Prospection Tool for Industrial Excess Heat/Cold Reduction, Recovery and Redistribution) aims to advance waste heat utilisation by developing an open-source matching platform between waste heat and cold providers and end users, and demonstrating this platform in 7 case studies in different European countries, as listed below. EMBERs is composed of 16 project partners from across Europe.

Table 6-8 EMB3Rs case studies

Case study	Country
Process resource and energy intensive industries (REII) – Cement production	PT
Process REII – Metal casting	UK
Heat-exchange within an industrial park	GR
REII Waste heat supply to residential and commercial DHC network	PT
Analysing excess heat potentials in different DHC network expansion scenarios	SE
Innovative Business Models: DH network with P2P market structure	DK
Overall Platform Functionalities in Super-User Mode	PT

[517] *ICCT (2021) Alternative transport fuels elements of the European Union's "Fit for 55" package*

The EMB3Rs matching platform went live in June 2023 and is available at https://platform.emb3rs.eu. The platform allows users to input details about potential waste heat sources and well as heat demand, including in a collaborative manner. The platform calculates the most cost-efficient solution to match waste heat supply and demand, by considering detailed generation and demand schedules, prices as well as calculate the NPV and return on investment of the business case.

6.7.1.2. Technical characteristics and benefits

The EMB3Rs platform comprises a knowledge base providing default data for the modules (where case-specific information is not available), and 5 modules (Core functionalities, GIS, Techno-economic, Markets and Business models modules) .[518] The platform code for installation is available on https://github.com/Emb3rs-Project.

The EMB3Rs platform for matching waste heat and cold providers and end-users should allow for the high-level planning of district heating and cooling systems and conduct a preliminary viability assessment for utilisation of waste heat and cold sources.[519] As such, the main expected project benefits are not only those arising from the waste heat utilisation in the case studies, but rather the larger deployment of waste heat utilisation in Europe, by considering not only sources and sinks from mature technologies and existing processes but also allowing future users to investigate potential process integration opportunities from emerging technologies aiming at decarbonising our industries (e.g., H2, CCU/S chain, etc.) that could have a match in a certain region, create synergies and improve the feasibility of some future investments

One of the industrial case study participants highlighted that the waste heat utilisation project was pursued due to the reduced reliance on an external energy supply, but that the profitability of the project would on itself do not justify the investment. Project partners have also highlighted that waste heat utilisation could reduce the need for electricity network expansion, in context where electricity networks in several Member States are already facing significant congestion.

6.7.1.3. Barriers, lessons learned and recommendations

The final report of the Work Package 5 “Platform Scalability and Deployment”[520] identifies a number of challenges for waste heat and cold utilisation rated as medium or high:

- Competition with other heating energy sources, particularly natural gas, which can have cost-related and operational advantages;
- Risk of heat capacity production or connection outage;
- Data availability on RHC potentials;
- Large capital expenditure associated with waste heat utilisation projects;
- Capital markets risk;
- Long payback periods;
- Counterparty risk;
- Absence of effective emissions prices for large parts of the heating sector (before EU ETS 2 implementation);
- Misaligned incentives between stakeholders (e.g. district heating system operator, municipality and/or waste heat provider).

[518] https://www.emb3rs.eu/platform/
[519] Cardoso and Remédios (2023) D 4.7 Overall Platform Functionalities in Super-User Mode. EMB3Rs (User-driven Energy-Matching & Business Prospection Tool for Industrial Excess Heat / Cold Reduction, Recovery and Redistribution)
[520] Jensterle and Montella (2023) D5.1 – WP5 Final Report. EMB3Rs (User-driven Energy-Matching & Business Prospection Tool for Industrial Excess Heat / Cold Reduction, Recovery and Redistribution)

Moreover, the report highlights two challenges for the utilisation of the EMB3Rs platform in particular, which can be summarised as follows:

- **Complexity of district heating and cold systems employing waste heat**: larger district heating systems can have complex topologies, multiple heat sources, a high number of end-users and can combined centralised with individual (back-up) heating solutions. As such, different tools are necessary for developing waste heat and cold utilisation projects – from simpler ones able to identify synergies for matching waste heat and cold sources with potential demand, with more advanced modelling tools to design and operate the system;
- **Data requirements for users employing the EMB3Rs platform**, which will have to apply a systematic approach to collect the necessary input data – although the tool was designed with this challenge in mind, providing users with guidance on data needs, some flexibility for data inputs as well as default values for various parameters.

The report also conducts an analysis of financing mechanisms for 5 EU Member States, identifying a significant difference in funding opportunities between Northern and Southern Member States. Southern Member States typically lack funding mechanisms specifically for district heat or waste heat utilisation (which have a long payback period), meaning these project have to compete with others with a shorter payback.

While the challenges are multiple, EMB3Rs partners have highlighted that the main barriers for waste heat utilisation comprise availability of data on waste heat and cold potentials and needs (including confidentiality issues and data owners not necessarily trusting other project actors), the costs of the projects, and the associated risks. This areas are aligned with the policy recommendations of the Work Package 5 “Platform Scalability and Deployment”[521] final report. Particular recommendations which could have an involvement of EU actors include:

- **Establish a comprehensive and reliable data basis specifically for RHC use** with actions at the EU and national level, with systematic bottom-up data collection, sharing through trusted actors and aligning the bottom-up data collection with planning processes at the national and local level;
- **Implement de-risking measures in support mechanisms** either through increased support or provision of insurances, addressing various risk types (of outages of heat sources or connections, counterparty, excessive opportunity costs or capital market risks).

Furthermore, discussions with the project partners have highlighted the following additional recommendations:

- Further consideration could be given to binding legislation on companies to identify synergies and where waste heat can be shared and on implementation of the actions listed in local heating and cooling plans;

[521] Jensterle and Montella (2023) D5.1 – WP5 Final Report. EMB3Rs (User-driven Energy-Matching & Business Prospection Tool for Industrial Excess Heat / Cold Reduction, Recovery and Redistribution)

- EU legislation could be implemented ensuring municipalities have the right to make connection to district heating and cooling networks mandatory for newly built buildings, as currently this is not the case for all municipalities in e.g. Germany;
- Need for greater involvement of authorities, businesses and citizens at the local level.

6.7.2. StEB Köln / Celsius project

6.7.2.1. Description

The CELSIUS project was implemented between 2013 and 2017, aiming to help cities across Europe to advance low-carbon heating and cooling solutions, particularly waste heat solutions.[522] The project has led to the on-going Celsius initiative.[523]

The Cologne site was one of the demonstrators of the original CELSIUS project, with three sites providing waste heat to schools in the districts of Wahn, Mulheim and Nippes. The demonstrated sites were operational between 2013 and 2015.[524] Regarding applications, the demonstrator focused on 1) the recovery of sewage heat and 2) the provision of hot water to certain household appliances.[525] The focus of this case study is on the first application, given the overall Energy System Integration study focus on off-site waste heat utilisation.

The demonstrator counted with several stakeholders, including the municipal wastewater company StEB Köln, the city of Cologne, the utility Rheinenergie AG, technology suppliers, technology providers, and the administration of the schools utilising the waste heat. The financial modelled for the project was called energy supply contracting, with Rheinenergie contracting external technology and service providers, and charging the schools for supply of the (waste) heat,[526] with StEB Köln receiving a small financial compensation for the waste heat extracted.

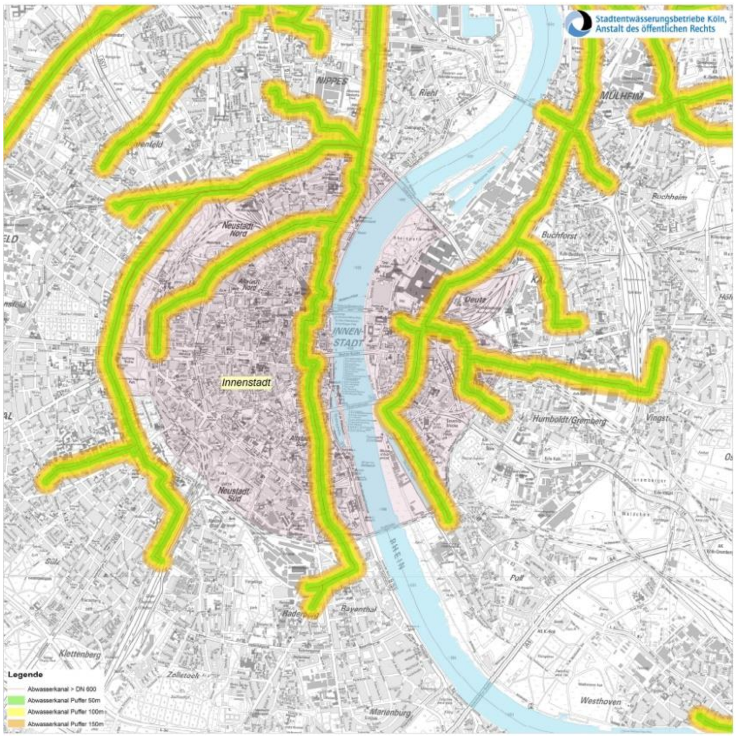
Figure 6-18 CELSIUS City Cologne demonstrator sites[527]

Furthermore, StEB Köln has published detailed wastewater heat potential maps, with the map for the city centre shown below. The company is in discussion with a number of clients

[522] https://smart-cities-marketplace.ec.europa.eu/projects-and-sites/projects/celsius
[523] https://celsiuscity.eu/about-us/celsius-project/
[524] https://celsiuscity.eu/waste-heat-recovery-from-sewage-water-in-cologne-germany/
[525] https://smart-cities-marketplace.ec.europa.eu/projects-and-sites/projects/celsius/celsius-site-cologne
[526] https://celsiuscity.eu/waste-heat-recovery-from-sewage-water-in-cologne-germany/
[527] https://celsiuscity.eu/waste-heat-recovery-from-sewage-water-in-cologne-germany/

for implementing further wastewater heat utilisation projects – with a number of different user categories (commercial, residential, public) although most use cases consist of newly built buildings which are better insulated and can employ low-temperature heating.

Figure 6-19 StEB Köln wastewater heat potential map for the Cologne city centre[528]



6.7.2.2. Technical characteristics and benefits

The table below summarises the technical characteristics of the two main sites of the Cologne demonstrator sites. The project demonstrated two technologies for extracting waste heat (temperature of at least 12 ºC): direct heat extraction, where the sewage water is bypassed to a heat pump evaporator in the Nippes site, and the novel indirect heat extraction, where a heat exchanger is installed in the sewage pipes and then the heat is upgraded through heat pumps and transmitted to the Wahn and Mulheim sites.

Table 6-9 Technical characteristics of the CELSIUS City Cologne demonstrator[529,530]

	Wahn	Mulheim
Area served	20 650 m2	11 199 m2
Baseline technology	Gas boilers	Gas Boilers
Capacity	200 kW	158 kW
Baseline gas boiler power	1370 kW	940 kW
Yearly production	1000 MWh	700 MWh
District heating set temperature	60 ºC	60 ºC
Investment	€ 530 000	€ 530 000
Payback period	19 years	35 years

[528] https://steb-koeln.de/Redaktionell/ABLAGE/Downloads/Brosch%C3%BCren-Ver%C3%B6ffentlichungen/Abwasser/Abwasserw%C3%A4rmepotentiale/waermekarte_internet_innenstadt.pdf
[529] https://smart-cities-marketplace.ec.europa.eu/sites/default/files/2021-04/the_making_of_a_smart_city_-_best_practices_across_europe.pdf
[530] https://celsiuscity.eu/waste-heat-recovery-from-sewage-water-in-cologne-germany/

The project brings a number of benefits, as illustrated in the figure below for the Wahn and Mulheim sites. In addition, the project has an impact on reducing the wastewater temperature levels. As the wastewater heat is recovered in the sewers, this could potentially be negative as a minimum temperature is necessary for biological processes at the wastewater treatment plant. Hence, too much waste heat recovery could contradictorily lead to the need to heat the wastewater at the treatment plant. However, the scale of waste heat recovery in Cologne at the moment is not significant enough to have negative impacts. StEB Koeln is also developing a project for waste heat recovery at the plant after treatment, where the reduction of the water temperature before discharging in water bodies would actually be a positive impact.

Table 6-10 Benefits of the CELSIUS City Cologne demonstrator in the 2014/2016 period[531,532]

Benefit	Wahn	Mulheim
Energy savings	120-410 MWh/y	166-216 MWh/y
Cost savings	10 – 35 c€/kWh	16 – 21 c€/kWh
Reduced air pollution (compared to baseline)	SO2: -5 to -10% NOx: -65 to -147% PM: -3 to -6%	SO2: -6% NOx: -85.5 to -87% PM: -3 to -4%
GHG emission reduction	214 tCO_2/y	150 t CO_2/y

6.7.2.3. Barriers, lessons learned and recommendations

Overall, the project was considered successful, with the Wahn and Mulheim sites still operating as of October 2023 – 8 years after commissioning. Nonetheless, the project faced a number of difficulties:

- **Technical difficulties**: The Nippes site has faced difficulties related to the direct transmission of wastewater and has been discontinued. For example, the wastewater grinder used broke down and the manufacturing company went bankrupt, impeding the servicing of the machine, while the other sites faced corrosion of the heat exchanger;
- **High cost** of the waste heat recovery and upgrade system compared to the standard solution (gas boiler), which is complicated further by the electricity cost for operation of the heat pump. Financing mechanisms can exist for larger-scale wastewater heat recovery projects e.g. servicing a whole district, but there are no funding mechanisms for projects servicing individual buildings;
- **Resource assessment and project siting:** the wastewater availability and other factors must be considered for siting the project, such as accessibility to the sewer system, distance to the end-user and ability to lay pipes, and end-user acceptance for low-temperature heat (i.e. energy efficiency level of the building stock). One site faced challenges with wastewater availability, which is subject to changes and difficult to predict. There was also no previous

[531] https://smart-cities-marketplace.ec.europa.eu/sites/default/files/2021-04/the_making_of_a_smart_city_-_best_practices_across_europe.pdf
[532] https://celsiuscity.eu/waste-heat-recovery-from-sewage-water-in-cologne-germany/

measurement of the wastewater flows. Since then, StEB Köln has developed the wastewater heat potential map indicated above, and flow measurements are conducted but which can cost up to 3-5 k€;

- **Governance challenges:** wastewater heat utilisation requires the definition of clear governance rules regarding the ownership of the heat exchangers and pipes, maintenance of the equipment and conduction of heat supply activities. While ideally the heat supplier would own the assets and service them (possibly through a third-party), this is complicated by sewers constituting a hazardous environment requiring qualified technicians and by city regulations limiting who can lay pipes (now the city of Cologne is planning to allow private operators to lay renewable energy infrastructure).
- **Project planning complexity:** the barriers above make the planning of such a project a complex endeavour, which can result in a long lead time for assessing the resource, parties reaching an agreement, designing the installations and the project commissioning. Moreover, solutions cannot be fully replicated with each project being tailored to some extent and requiring significant human resources, although subsequent experience of StEB Köln means it is already able to reap some replicability benefits regarding e.g. the set-up of contracts.

Based on these barriers, A number of recommendations could be considered to advance wastewater heat utilisation:

- **Financial support** for the assessment of wastewater heat potentials and for the development of projects, including those supplying waste heat to a limited number of buildings;
- **Awareness raising and advertising** of wastewater heat utilisation solutions;
- **Addressing ownership problems with private pipes/networks in public property/ground,** with municipalities allowing it in certain cases (e.g. when to transmit exclusively waste or renewable energy) and providing sufficient human resources for permitting;
- **Addressing competitiveness issues vis-à-vis competing heating alternatives**, for example by addressing the high electricity costs for operating heat pumps (driven by high taxes and levies) and comparatively low taxation of natural gas.

6.7.3. CO2OLHEAT

6.7.3.1. Description

The project CO2OLHEAT aimed to advance the use of supercritical CO_2 in order to employ recovered industrial waste heat to produce electricity (waste heat-to-power, WH2P). It should do so by addressing several current barriers, including the small size of installations, limited competitiveness and flammability of the fluids utilised.[533] More specifically, the stated key goals of the project were:[534]

[533] CO_2OLHEAT webpage
[534] CO_2OLHEAT leaflet

- "**Untapping industrial waste heat potential**: Design of a novel waste-heat-to-power (WH2P) plant layout for WH valorisation at temperatures above 400°C
- **Innovations, economic viability and easy replicability**: Development of the state-of-the-art CO_2 power block offering numerous financial benefits and a vast replicability potential, which will be tested already during the project
- **Increase of energy efficiency**: CO2OLHEAT will enable industries to improve their resource utilisation and will contribute towards a reduction of energy costs"

The project had a demonstration site in the CEMEX cement plant Prachovice (Czechia), aiming to apply the technology in a real operating environment for at least 2 500 hours, reaching a technology readiness level of 7. It also comprised 6 replications sites (in Turkey, Greece, Spain, Belgium, France and Spain), for analysing through simulations the potential to replicate the technology. The project was a cooperation between the lead ETN global and 20 other organisations, starting in June 2021. [535] The project was suspended in 2022 due to a number of challenges detailed below.

6.7.3.2. Technical characteristics and benefits

The Czechia demonstration site has two mills for grinding the material for cement production. Total waste heat availability depends on how many are in operation (with most often one single mill operating)[536]. The maximum waste heat potential of around 16 MW, concentrated in three hot spots: [537]

- Kiln/preheater, with a temperature range of 300-500˚C
- Bypass, with a temperature range of over 1 100˚C
- Cooling towers, with a temperature range of 100-400˚C

The supercritical CO_2 power plant would have a calculated efficiency of 11-17% depending on the waste heat availability in the flue gas, meaning 1.26 to 2.17 MW_e could be generated.[538] The consortium partners estimated that the solution would be quite attractive – the avoided costs of electricity purchase could lead to a payback of 4.3 to 7.8 years. A number of benefits were estimated from the project, including:[539]

- Energy savings of >40.000 MWh/year;
- Avoided costs of electricity purchases of 750 k€/year;
- Reduced greenhouse gas emissions of 6.5 tCO_2/year;
- Reduction of water consumption by 100%;
- Reduction of raw materials in equipment by 30-40%.

[535] CO_2OLHEAT webpage
[536] Alfani et al. (2023) Part Load Analysis of a Constant Inventory Supercritical Co2 Power Plant for Waste Heat Recovery in Cement Industry. 5th European sCO2 Conference for Energy Systems. DOI: 10.17185/duepublico/77288
[537] Ibid.
[538] Alfani et al. (2023) Part Load Analysis of a Constant Inventory Supercritical Co2 Power Plant for Waste Heat Recovery in Cement Industry. 5th European sCO2 Conference for Energy Systems. DOI: 10.17185/duepublico/77288
[539] https://co2olheat-h2020.eu/wp-content/uploads/2022/02/CO2OLHEAT-public-presentation_Feb-2022.pdf

6.7.3.3. Barriers, lessons learned and recommendations

The project has encountered several hurdles, including:

- ✓ **High initial ambition**: the project involves implementing a new technology in the challenging environment of a cement plant. This environment is known for operational difficulties, including issues such as dust in the exhaust systems;
- ✓ **High upfront costs**: a feasibility study was conducted at the start of the project, which indicated the initial investment of the demo would be higher than anticipated;
- ✓ **Benefit uncertainty**: identifying end-users who could benefit from the system was a challenge. Financial viability of the investment is critical given the main customers would be industries, and there is still uncertainty regarding the overall financial viability of the technology.

A number of measures are recommended by the project coordinator to address the challenges faced in the project:

- **Consider a two-step approach for future European Framework Programme calls**: The experience has highlighted the need for a comprehensive feasibility study before issuing calls for the deployment of similar projects under Horizon Europe, which, it is argued, does not allow for extensive upfront analysis;
- **System integration knowledge**: recognise that system integration issues go beyond policy and require specialised knowledge and expertise that is not taught currently. Cover the skills gap in waste heat recovery, particularly in industries like cement production. Larger companies have built knowledge over time, but smaller ones have not; **Companies should be made more aware of the costs and complexities** involved in waste heat recovery projects. Such endeavours may appear simple at first but often require substantial expertise and investments;
- **Emphasise the importance of realising commercial benefits from waste heat recovery projects**. Address barriers to commercialisation, including return on investment, lengthy payback periods, and competition with alternative investments like renewable energy. If necessary, explore subsidies to shorten payback periods but do so with well-structured arguments to drive cost reduction. More demonstration projects within the EU could also help address this issue;
- **Regulation and labelling**: Consider regulating waste heat power generation as a clean energy source to incentivise its adoption;
- **Explore the technology in targeted applications:** supercritical CO_2 power plants could have important benefits in certain applications, such as in offshore oil & gas platforms, saving space and reduce overall emissions.[540]

[540] Persico et al. (2023) Supercritical Carbon Dioxide Bottoming Cycle for Off-Shore Applications – an Optimization Study.

6.7.4. Digital Heat in the Amsterdam Metropolitan Area

6.7.4.1. Description

The project Digital Heat in the Amsterdam Metropolitan Area aimed to study the development of a 5th generation low-temperature heat-cold network employing waste heat from data centres in the Amstel III district of the Amsterdam Metropolitan Area (AMA). The project was a collaboration of the district heating operator Firan, the Amsterdam Institute for Advanced Metropolitan Solutions (AMS), the Amsterdam municipality and TU Delft. The project looked at technical, governance, financial and other barriers to enable the acceleration of the decarbonisation of heat networks in the broader AMA.

6.7.4.2. Technical characteristics and benefits

The project studies the potential utilisation of the data centre AM5 of Equinix. This waste heat would be delivered by Fira through a low-temperature heat-cold network (5C°– 15C°) to mixed use and residential areas, where the heat could be upgraded and used in combination with renewable sources or heat provided by the current supplier. A significant part of the building blocks to be supplied with the waste heat should be disconnected from the gas grid in the future, in line with Dutch energy & climate policies.[541] Currently, another heat network is in place in the area, with a different operator managing the network and supplying the heat.

Figure 6-20 Design for the connection and transport of data centre waste heat in the Digital Heat in AMA project[542]

Utilisation of waste heat from the data centre should lead to a 70% CO_2 saving compared to if natural gas was employed, totalling 39 kton CO_2 in savings. This would be sufficient to heat 50 000 new-build homes, or 25 000 existing ones. The project would equate but not exceed the climate performance (i.e. equivalent GHG emission) of individual heat pump solutions. The project would create jobs for companies supplying and transporting the heat, as well as companies installing and operating end-use heating equipment. The project

541 Van Berkel (2022) Energy Justice in Holendrecht
542 https://openresearch.amsterdam/nl/page/71800/lab-3-lage-temperatuur-warmtenetten

should also contribute to reducing electricity network congestion compared to all-electric heating solutions.[543] Moreover, the extensive use of aquifer thermal energy storage in the Netherlands would represent a feasible solution to address the temporal mismatch of the heat supply and demand.

6.7.4.3. Barriers, lessons learned and recommendations

Despite the significant benefits of waste heat utilisation from the data centre, the project faced a number of uncertainties. Hence, in 2023 the district heating operator participating in the project decided not to proceed with the investment for the moment. The main difficulties affecting the project were:

- **There was insufficient firm heat demand for the project**. The main potential heat offtakers, real estate project developers, were unable to sign a firm commitment to purchase the waste heat in line with the timeline of the project (the heat network would be operational sooner than when the offtakers would require the heat). Only two real estate developers were more commitment as offtakers.
- **The low-temperature heat provided would be unsuitable for the existing building stock in the absence of significant renovation efforts**. Housing corporations responsible for such renovation for their properties were not ready to commit to any offtake. The data centre was built before regulations where in place requiring it to anticipate the technical space and capabilities to recover the waste heat, increasing costs for the project and impeding liquid cooling solutions (which would increase the recovered heat temperature);
- **The subsidies for the project had a strict execution time**, meaning the project could not be postponed to better fit the timeline of the heat offtakers as this would lead to the loss of the awarded subsidies;
- **The Amsterdam municipality heating transition plan[544] was perceived as providing insufficient guidance**. Several parties were critical of the assumptions and modelling of the plan, which indicated that the most cost-efficient options for decarbonising heating in the Holendrecht Oost and Zuid neighbourhoods was district heating. They also argued the plan defined district heating as the best source without creating a mandate for an operator to develop the network. Currently, there is not yet an obligation for building owners to connect to a district heating network or other solution defined in the heat transition plan. The Amsterdam municipality is furthermore exploring several approaches for developing heating and cooling networks, for example with direct participation in projects in other neighbourhoods;
- **The proposed heat network faced competition from the existing (higher-temperature) network already servicing the area.** The capital intensity and network effects which characterise heat networks represent an entry barrier for a second network;
- **The project required an additional actor to undertake the supply activities (heat sales to the final customers).** The project network operator does not currently conduct supply activities nor is allowed according to the

[543] Kansen voor West
[544] https://overmorgen.nl/wp-content/uploads/2020/09/tvw-amsterdam.pdf

current Heat Law.[545] Although a partner was identified to take up the supply activities, this added complexity to the project governance. District heating and cooling operators are expected to be allowed to undertake supply activities in the upcoming Collective Heating Law. The possibility that the network would be required to provide third-party access for other sources also negatively affected the business case;

The Amsterdam municipality has decided that new data centres (or significant expansions of existing one) should be obliged to provide the waste heat for free for district heating networks, or to make the necessary preparations in case no nearby network exist, with the district heating company bearing the costs. Similarly, the proposed Collective Heating Law indicates that waste heat producers should make it available to district heating networks, at a compensation covering the costs for providing the waste heat (including ensuring the security of supply).[546]

Considering this context, a number of lessons learned can be derived from the case study to advance waste heat utilisation in the EU:

- **Further investigate approaches to increasing community acceptance and on-boarding of offtakers.** The city of Amsterdam is currently investigating if co-ownership rules could be implemented in the future, giving some ownership to inhabitants to guarantee participation and interest from their side;
- **Ensure flexibility of funding mechanisms while incorporate monitoring mechanisms to incentivise project completion.** Waste heat and district heating/cooling projects are complex and can take several years for completion – funding mechanisms should take this into account, although a balance must be struck with avoiding delays as much as possible;
- **Ensure the policy process does not increase uncertainty for heating and cooling sector stakeholders,** which can act as an important disincentive for investments;
- **Requirements for data centre (and other) operators can strongly drive waste heat utilisation**, for example for the operators to make waste heat available when requested and/or to make anticipatory investments. This must be balanced however with an appropriate distribution of risks and compensating the operators for the incurred additional costs.

[545] https://wetten.overheid.nl/BWBR0033729
[546] Article 6.1 of the legislative proposal. https://www.internetconsultatie.nl/warmtewet2

6.8. Selected energy system integration studies considered

The following (non-exhaustive) list presents recent energy system integration-related studies considered in the analysis:

- ACER (2023) Report on monitoring the barriers to electricity demand response
- ACER (2023) Demand response and other distributed energy resources: what barriers are holding them back?
- Austrian Institute of Technology and Euroheat & Power (2020) Discussion Paper - The barriers to waste heat recovery and how to overcome them?
- Consentec et al (2023) Potentials and Levels for the Electrification of Space Heating in Buildings"
- Clean Hydrogen Observatory (2023) The European hydrogen market landscape
- CRE (2023) Recommandations pour accompagner le déploiement de la mobilité électrique
- DNV (2023) Bidirectional charging of Electric Vehicles: enablers & barriers in Europe
- DNV (2023) Demand-side flexibility: Quantification of benefits in the EU
- EEA (2022) Decarbonising road transport — the role of vehicles, fuels and transport demand
- EEA and ACER (2023) Flexibility solutions to support a decarbonised and secure EU electricity system
- Energy Cities (2023) EU Tracker - Local Heating and Cooling Planning in EU Member States
- ENTSO-E (2023) Study on Power and Heat Sectors: Interactions and Synergies
- Eurelectric (2021) Connecting the dots: Distribution grid investment to power the energy transition
- Eurelectric (2023) Power System of the Future: Keys to delivering capacity on the distribution grid
- European Clean Hydrogen Alliance (2021) Alliance Roundtables on Barriers and Mitigation Measures
- Green Hydrogen Hub (2023) Accelerate the integration of renewables
- Heatleap (2023) Waste Heat Recovery - Potentials, applications and recommendations for better policies
- IEA (2021) Distributed energy resources for net zero: An asset or a hassle to the electricity grid?
- IEA (2021) Distributed energy resources for net zero: An asset or a hassle to the electricity grid?
- IEA (2022) Global Hydrogen Review
- IEA (2022) The Future of Heat Pumps
- IEA (2023) Electricity Grids and Secure Energy Transitions
- IISD (2022) Industrial Electrification
- IRENA (2023) Innovation Landscape for Smart Electrification
- JRC (2021) Assessment of heating and cooling related chapters of the national energy and climate plans (NECPs)
- JRC (2021) Defining and accounting for waste heat and cold
- JRC (2023) The Heat Pump Wave: Opportunities and Challenges

- Lygnerud (2023) Urban waste heat recovery as an enabler of the energy transition policy implications and barriers
- Milieu, Trinomics and Panteia (2022) Promotion of e-mobility through buildings policy
- smartEn (2022) The smartEn Map 2022 – Ancillary Services
- smartEn (2022) The implementation of the Electricity Market Design to drive demand-side flexibility
- Tilia (2021) Integrating renewable and waste heat and cold sources into district heating and cooling systems - Case studies analysis, replicable key success factors and potential policy implications
- TNO et al. (2021) Best practices for planning and construction of thermal networks identified in the EU
- University of Aberdeen et al. (2023) Overview of Heating and Cooling: Perceptions, Markets and Regulatory Frameworks for Decarbonisation

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