European Commission

Coordinated Energy Infrastructure (CEI) Planning for a decarbonised system

ETIP SNET

European Technology and Innovation Platform Smart Networks for Energy Transition

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CONTENTS

INDEX OF FIGURES

INDEX OF TABLES

EXECUTIVE SUMMARY

This paper examines the need and scope of a coordinated energy infrastructure planning (CEI) approach that will fulfil the policy objectives and legislative requirements for Europe. It considers the requirements, attributes, and challenges to the development of a CEI planning approach and suggests possible ways to address these challenges with new policy/legislation, research and development.

Central to this is a consolidated vision (in Figure 2. Of chapter 3.) and related scenarios of what is expected, when it needs to occur and what the building blocks are to make this happen.

This vision initially focuses on the electricity, natural gas and hydrogen energy sectors. Their integration is of more intense industry focus, with immediate policy goals, and considered to form the backbone of the integration of the wider energy sectors in this report. As a result, the consolidated vision also focuses on the coordination and integration of these sectors. The vision sets out the development risk level of each building block. This risk level is based on either previously development work of mainstream solutions that are/will be applied nationally or Europe wide, or research and development towards solutions. It was determined that of the building blocks in the near term, many have either not commenced or are going to fall short of their intended scope of work or delivery date.

The report considers the reasons and potential solutions to address this in order to provide a series of recommended actions as to how the building blocks and the vision as a whole could be completed in a timely manner.

These recommended actions include:

Setting direction (vision and scenarios)

CEI planning vision and scenarios should be used to build a more detailed and comprehensive plan. The vision in this paper would require and benefit from assignment of empowered owners of the building blocks, and review with alignment of projects that will deliver these building blocks in the **transport, water and IT sectors.** The transport and IT sectors need a new central body to align nationally and at a European level to develop the capability for CEI planning of the sector, which are independently developed with no central organisation.

Disruptive technologies

Create a single source of recognised and reliable information and a supervisory body to develop a list of disruptive technologies. Develop a centralised live list of potentially disruptive technologies for each sector covered by CEI planning.

Disruptive technologies shall be included in all CEI planning and scenarios with a what-if analysis method. The timing and impact of these technologies are acute and requires energy sectors and investments to be prepared for their arrival and be adaptive to this.

Research and development for CEI planning models, tools, procedures for disruptive technologies shall be initiated as soon as a disruptive technology is identified. Disruptive technologies can develop in a fraction of the lifetime of a new large-scale infrastructure investment and therefore CEI planning research and development for these must come first.

Adapt R&D pathways

Review existing research & development for greater advanced CEI planning. This review should examine whether new models, tools and procedures (e.g. scenario development) including cross sectors are fit for purpose or require more development. The review should also consider whether, data transfer formats, network models, market and network system analysis software, cost benefit analysis, are or can be made inclusive of other sectors.

Implement a fully staged (live) programme of CEI planning research & development needs to fully 2050 decarbonised system. This should include the context for each piece of research & development, how it will integrate with early and later research & development and monitoring of progress.

Accelerate the calls, approvals and longevity of research & development funding. This should consider processes with immediate application and decisions, rather than annual calls. Funding mechanisms would benefit from applying more intense timelines with 'go/no-go' milestones by fund owners (to halt projects that are not timely or become stranded).

Models and Methodologies

Immediate timely development of new CEI planning energy integration system modelling, tools and procedures, scenario building and sensitivities with a common modular structure. At present, software modelling tools, methodologies and processes are restricted at best to single sector-wide analysis. The project for the development of pan-European models for electricity and gas is the most advanced for assessing all interrelated projects at a European level. However, the project as devised[1] currently falls short of a complete transition from present practices to prepare for future sector integrations. The project does not consider a common modular structure, distribution networks (and their projects of common interest), range of commercially ready innovative technologies needed in future, or dynamic modelling. A common modular structure is required to be able to onboard each new sector integration.

The interlinking of the IT sector, water sector and heating and cooling sectors. Identifying how to select appropriate opportunities (i.e. a use case) and provide models, tools and the procedures to test them across the pan-European sector is required. At present this is only conceptual.

New principal[2] bodies to be involved in model and methodical development of coordinated energy infrastructure planning. Cross-sector modelling requires markedly different skills sets which will require new actors from technology developers, research and development bodies, academia and policy makers (regulators, government, public) in tandem with system operators and asset owners.

Legislative requirements

Recommendation to apply in scenario building exercises a least-worst-regrets approach to ensure that solutions consider the full spectrum on network needs. Selection from candidate solutions must consider growing future uncertainty to ensure they are the most robust to these changes.

Develop cost benefit analysis (CBA) method for all sectors. When assessing cross-sector projects, the CBA will need to include the needs/benefits in each sector that the project will provide to, and alternatives from, different sectors. Existing CBA methods are developed independently.

Issuance of guidelines by the European Commission on the application of CEI planning. To accelerate adoption of new CEI planning methods and manage timely change in practices. Changes to CEI planning methods often require direction before action will occur due to their complexity, with many vested interests of stakeholders and users both nationally and Europe wide. Prioritising effort, time and management or expert resources is also a problem.

Oversight of compliance with legislation for energy infrastructure planning. To ensure the timely adoption of CEI planning to keep track with legislative requirements and to fill sector gaps where CEI planning does not exist.

Recommendation of a bi-yearly report issued with gap analysis from an oversight body. The report will examine the linkage of CEI planning with the stated objectives of the energy sector national and European wide in NECPs.

Fast R&D Knowledge Sharing

Implement widespread adoption of successful research and development tools and processes. Utilise existing European Commission structures like ETIP SNET and monitored by BRIDGE to create a new research and development WG with a focus on CEI planning using the learning from a number of H2020 and Horizon projects.

Create a dedicated cross sector platform on CEI planning best practice tools, models and procedures. Created to drive all relevant stakeholders to be aware and apply existing and future R&D learning to close gaps.

[1] See: file:///C:/Users/mark.norton/OneDrive%20-%20Smart%20Wires%20Inc/Documents/currENT/currENT/ETIP%20SNET/entsos_ILM_progress_report_240430.pdf

[2] A principal body would be an overarching impartial body deciding on what will be adequate and effective for cross sectors

1. Context and introduction

Towards integration: Major changes in the energy system, like volatile renewables, hydrogen-based energy carriers, electrification of transport, and residential and industrial uses, drive the demand for European coordinated energy infrastructure (CEI) planning. Energy infrastructure planning is separated into sectoral areas such as electricity and gas networks, heating and cooling, water, and transport, in conjunction with the interrelated telecommunication sector. This separation is, to a growing extent, a problem now that sectors are getting intertwined and interdependent. At the same time innovative technologies and digitalisation are making coordinated energy infrastructure planning possible by providing the industry with more advanced methods and tools.

Full energy decarbonisation will be extremely challenging for many energy users that do not have a mainstream alternative means of decarbonised energy delivery e.g. shipping and aircraft. Conversion to an alternative fuel source is unavoidable, with perhaps the most likely solution being either a renewable gas, or electricity. This in turn would add to the growing number of new large user sites of these energy sources e.g. airports, ports, datacentres, industrial and residential centres, etc. The issues with integration of these energy users are, if not explicitly, then implicitly covered in this paper. This is because the sectors that will be required to support these users will in turn require energy infrastructure to be planned to permit this. Cross-energy sector planning will become more crucial as a result.

Thus, the challenges of one disruption can be partly addressed through another. Disruptive developments in generation, load and storage in the power system can partly be responded to by using disruptive developments in innovative grid technologies, digitalisation and radically improving cooperation across sectors and borders through CEI planning.

Where we are: The European Commission has expressed its motivation towards CEI planning. To enable this the Commission has been developing a number of policies to progressively make this happen across a range of sectors. However, some areas are more difficult than others, which is an additional driver towards progressive sector integration. Today national sectoral infrastructure plans are being developed independently. For energy, these plans have been aggregated into regional and finally European-wide infrastructure development plans, like the regulatory mandated Ten-Year Network Development Plans (TYNDPs) for electricity and gas. Some progress has been made in the consideration of interacting sectors, mainly through scenarios. Still, proper integration of infrastructure planning between sectors is absent, although some provisional work is being done to determine how this might be achieved[3]. As each energy sector described above is progressing through a paradigm shift due to digitalisation and/or decarbonisation, the increasing impact each sector has on each other cannot be ignored.

What's at stake: CEI planning is key to ensuring that the changes across sectors can be understood, included, coordinated, and planned into an integrated infrastructure system. Failure to do so will result in infrastructure being late, ineffective, less secure, more costly and unable to support the decarbonisation goals of the Commission.

Purpose of the paper: This paper examines the lack of coordination and integration of energy infrastructure planning. We discuss how separate planning challenges interact and suggest possible ways to address these challenges with new policy/legislation, research and development, and to consider the use of disruptive technologies and digitalisation that emerge across the industries involved. The paper guides policymakers, stakeholders and industry on future requirements, policy directions, and gaps to be filled in research and development.

Structure of the paper: The body of this paper is divided into five chapters (see figure 1 below). First, we identify challenges to the existing regulatory framework, with timely compliance with existing legislation (Ch.2.3), Challenges for CEI planning related to further R&D (Ch.2.4), Other identified challenges from EU Funded research (Ch.2.5) and finally Disruptive Technologies (Ch.2.6). Then we suggest a roadmap (Ch.3) for how to get to CEI planning. Finally, we detail some actions. We identify actions through a GAP analysis - findings and suggested actions (Ch.4) and further specify some immediate research, development and knowledge sharing actions (Ch.5).

[3] ENTSOE, Progress Report on Interlinked Modelling The Cross-Sectorial Integration of Energy System Planning, April 2024, file:///C:/Users/mark.norton/OneDrive%20-%20Smart%20Wires%20Inc/Documents/currENT/currENT/ETIP%20SNET/entsos_ILM_progress_report_240430.pdf

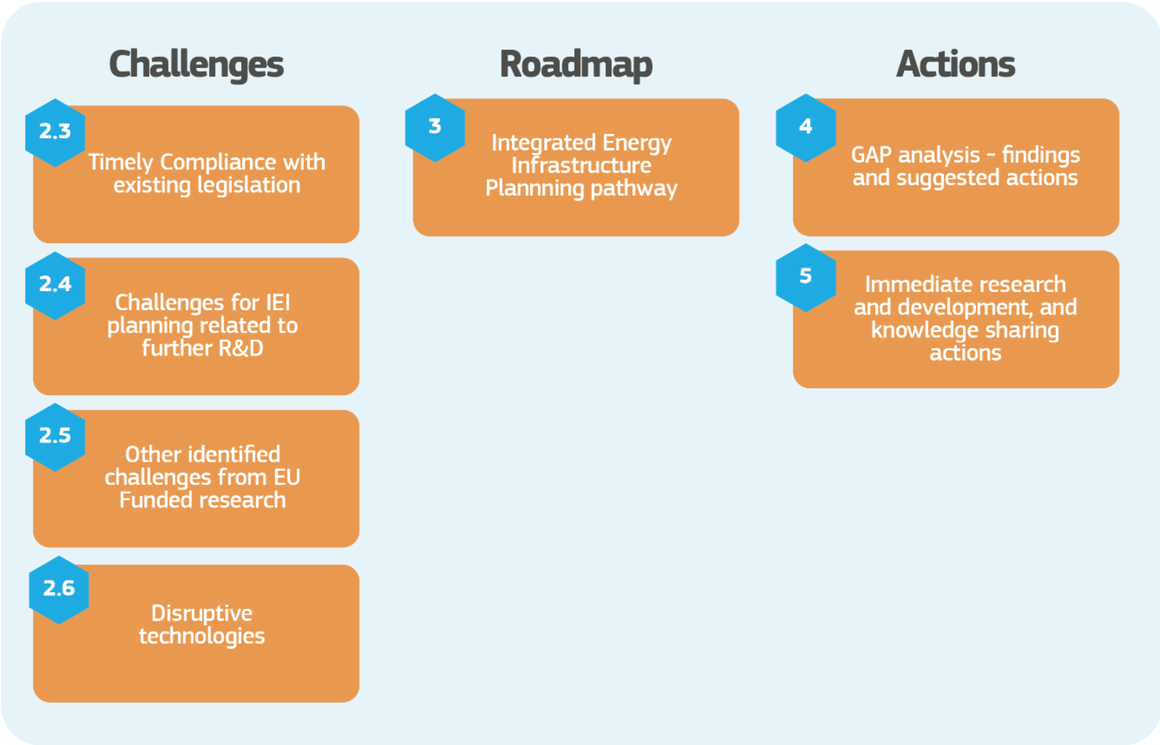


Figure 1: Breakdown of chapters in this report

2. Challenges for CEI planning related to meeting legislation

2.1 Challenges to Coordinated Energy Infrastructure planning

The European Commission, in its communication 'The European Green Deal' (December 2019), sets out a new growth strategy to transform the Union into a fair and prosperous society with a modern, resource-efficient and competitive economy where the climate neutrality objective is met by 2050 at the latest and where economic growth is decoupled from resource use. Subsequently, the Commission put forward the REPowerEU plan in May 2022, building on the implementation of the Fit for 55 proposals. These support the ambitious EU goal of cutting net greenhouse gas emissions by at least 55% by 2030 and achieving climate neutrality by 2050, which aligns with the European Green Deal. Most recently in November 2023, the European 'Action Plan for Grids' was released to make sure our electricity grids will operate more efficiently and be rolled out further and faster to contribute to the delivery of the European Green Deal.

A fully functional integrated energy system is key to achieving European policy and legislation[4]. Initially this integration and coordination will focus on the electricity, natural gas and hydrogen energy sectors. Their integration is of more intense industry focus, with immediate policy goals, and considered to form the backbone of the integration of the wider energy sectors. CEI planning is a starting point and a prerequisite for realising this objective. There are several challenges to making CEI planning an interlocked process. Infrastructure development is a continuous process, and creating such an integrated process will take steps, as discussed more fully in chapter 3 ***Coordinated Energy Infrastructure Planning pathway***. Two such challenges are: How can this coordinated process be organised; and how can applications that deliver the desired outcomes be developed?

Primary EU legislation seeks to unite public and political expectations of infrastructure planning. Chapter 2.2 ***Identified challenges for CEI planning*** to comply with primary legislation summarise key EU legislation. This legislation guides the development of national legislation. National best practice experience is also included where applicable.

Further, we seek to understand what an integrated process may require including organisation, tools, and technologies and how to incorporate this to enable CEI planning. No CEI planning mechanism exists, so we explore best practice projects that have investigated, developed and demonstrated elements of an overall planning mechanism. This is covered in the Main relevant EU Project in Appendix 1 of this report.

[4] Notably the commission communication on the 'European Green Deal' (December 2019) and 'Stepping up Europes 2030 climate ambitions – investing in a climate-neutral future for the benefit of our people' (September 2020)

2.2 Electricity – Gas cooperation as a starting point

Based on the investigations carried out in the period 2019 – 2020 and implementing recently adopted European legislation, ENTSO-E and ENTSOG have worked on the development of a consistent process for the inclusion of a dual infrastructure assessment in TYNDPs as well as of a methodology for its application.

The target of this exercise is to explore methodologies for the development of an "Interlinked Model" that shall provide consistency between single sector methodologies based on common assumptions including electricity, methane and hydrogen transmission infrastructures. The European energy sector naturally evolves as new national, regional and global targets are ratified. Over the last 3 years, these evolutions have been rapid and substantial.

An Interlinked Model can play an important role in this context by striving to ensure that the mutual influence of the natural gas, hydrogen and electricity sectors are considered during the evaluation of infrastructure projects in the context of cost-benefit analysis (CBA) in the respective TYNDPs. This approach acknowledges the interconnected nature of energy systems and underlines the importance of comprehensive planning to optimise the development and sustainability of the European Union's energy infrastructure.

2.3 Identified challenges for CEI planning to comply with primary legislation

In its communication of 17 September 2020 entitled 'Stepping up Europe's 2030 climate ambition – Investing in a climate-neutral future for the benefit of our people', the Commission proposed to increase the greenhouse gas emissions reduction target to at least 55 % by 2030. The European Council endorsed that ambition on 11 December 2020 and the impact assessment underpins the need to review and, if necessary, to revise the energy legislation. This, in turn, has led to a number of recent legislative changes that have led to the need for CEI planning.

Of the raft of primary European legislation which has been reviewed, the following key legislation, guidelines and directives have been identified as requirements for the CEI planning process.

Many of these requirements have yet to be adequately developed and pose challenges to the development of any CEI planning process. These are summarised below.

Legislation (EU) 2022/869 European Parliament and of the Council of 30 May 2022 on guidelines for trans-European energy infrastructure5

The EU Strategy Communication for Energy System Integration underlined the need for coordinated energy infrastructure planning across energy carriers, infrastructures, and consumption sectors.

Legislation 2022/869 sets out the objectives [6]to plan all sectors with a 'one energy system' view. It states that:

*'In line with the conclusions of the 2020 Energy Infrastructure Forum, it is necessary to ensure that all relevant sectors, such as **gas, electricity, and transport,** are considered in an integrated perspective in the planning processes of all onshore and offshore, transmission and distribution infrastructure.'*

The objective is set to comply with the Paris Agreement and to achieve the Union's 2030 climate objectives, the 2040 offshore energy development objectives, and the objective of climate neutrality by 2050. Reaching these combined objectives should be secured by developing a progressively integrated model that enables consistency between single-sector methodologies based on common assumptions and reflects interdependencies. Legislation 2022/869 also points this out in its introduction (Whereas 36):

*'The planning and implementation of Union projects of common interest in the areas of **energy, transport and telecommunication** infrastructure should be coordinated to generate synergies where it is feasible from an overall economic, technical, environmental, climate or spatial planning point of view and with due regard to the relevant safety aspects.'*

The legislation says that by 24 June 2025, the ENTSO for Electricity and the ENTSO for Gas shall jointly submit a consistent and progressively integrated model that will provide consistency between single sector

[5] Amending Legislations (EC) No 715/2009, (EU) 2019/942 and (EU) 2019/943 and Directives 2009/73/EC and (EU) 2019/944, and repealing Legislation (EU) No 347/2013

[6] 'Whereas' item 26, 36 and 14 of the legislation

methodologies based on common assumptions including electricity, gas and hydrogen transmission infrastructure as well as storage facilities, liquefied natural gas and electrolysers. This is required to cover at least the relevant sectors' interlinkages at all stages of infrastructure planning, specifically scenarios, technologies and spatial resolution, infrastructure gaps identification and the cost-benefit analysis methodology for project assessment. The ENTSOs are guided and required to take into account stakeholder input in this process, and this paper seeks to provide support for this process. At the time of writing, the ENTSO-E and ENTSO-G have just published for consultation their draft methodology to meet this requirement.

In addition to this key milestone, the legislation also sets enduring principles with regard to CEI planning from passing into legislation. Notably chapter 4 on 'Rules and indicators concerning criteria for projects in appendix IV, requires that smart electricity and gas projects, as well as hydrogen project consider the ability of the projects' impact, cost saving and contribution to other sectors (telecommunications, heat/cooling and transport). This is then further elaborated in appendix V, where it is required that:

*'(3) they [*the ENTSO's*] shall establish the analysis to be carried out, based* ***on the relevant multi-sectorial input dataset by determining the impact with and without each project and shall include the relevant interdependencies with other projects****.*

*(4) they [*the ENTSO's*]* ***shall give guidance for the development and use of energy network and market modelling necessary for the cost-benefit analysis. The modelling shall allow for a full assessment of economic benefits,*** *including market integration, security of supply and competition, as well as lifting energy isolation, social and environmental and climate impacts****, including cross-sectorial impacts. The methodology shall be fully transparent including details on why, what and how each of the benefits and costs are calculated;*** *…*'

Appendix II also sets out the enabling flexibility services such as demand response and storage by facilitation of smart energy sector integration through the creation of links to other energy carriers and sectors, measured by assessing the cost savings enabled in connected energy sectors and systems, such as the heat and power system, transport, and industry.

Summary of Key Relevant Challenges of Legislation (EU) 2022/869:

- Implementation of the requirement to plan for 'One Energy System' which includes energy vectors (such as natural and synthetic gas, and electricity with adequate transport and telecommunication) solutions, in time to achieve the EC climate goals from 2030-50
- Delivery of electricity, gas and hydrogen consistent and progressive CEI process by June 2025, including the modelling, gap identification and cost benefit analysis.
- Process required for cross-sector models, modelling apparatus and method, for needs and project assessment. This will be required for market, network and cost benefit analysis.

Directive (EU) 2019/944 Common rules for the internal market for electricity

With regard to CEI planning, Legislation 2019/944 in Article 32 'Incentives for the use of flexibility in distribution networks' sets the requirement for ten-year DSO development plans, with the reinforcement requirements for the 5-10 years, in paragraph 3. This plan is to be updated every 2 years. It must emphasise the main distribution infrastructure which is required to connect new generation capacity and new loads, including recharging points for electric vehicles.

In addition, in Article 51, 'Network development and powers to make investment decisions' sets the requirement for TSO ten-year development plans in Article 1 – 3. These plans are required to also show the reinforcement needs and timing of these, and to account for the use of demand response, energy storage facilities or other resources as alternatives to system expansion.

Both the DSO and TSO are required to ensure their plans and acquisition of flexibility services are consulted upon and reflective of the other's needs. The TSO must ensure that the national development plan is reflective of and in compliance with the ENTSO-E Ten-Year Network Development Plan. The national regulatory authorities are tasked with monitoring and also ensuring this consistency.

Summary of Key Relevant Challenges of Directive (EU)EU Reg. 2019/944:

- Development of DSO and TSO network plans on the same cycle every 2 years and must be aligned and modelled consistently. These plans should also include the existing and future needs of other sectors (e.g., transport).

- TSO network development plans must be consistent with and by inference also DSO plans must be consistent with the union-wide ten-year network development plan.

Legislation (EU) 2019/943 Internal market for electricity

With regard to CEI planning, Article 1 defines the fundamental principles for a well-functioning, integrated electricity market, which allow all resource providers and electricity customers non-discriminatory market access, ensure competitiveness on the global market, and enable sector integration.

Article 48 sets the requirements for a 10-year network development plan with roles and responsibilities for producing it (the ENTSO for Electricity), and for monitoring and making recommendations (ACER) to both this plan and the alignment of related national plans. Article 55 sets the requirement for the EU DSO entity and its membership to promote the operation and planning of distribution networks in coordination with the operation and planning of transmission networks, including deployment of smart grids.

In addition, Article 55 requires that the EU DSO entity shall cooperate with the ENTSO for Electricity and adopt best practices on the coordinated operation and planning of transmission and distribution systems and for the introduction of energy efficiency improvements in the distribution network.

Similarly, Article 57 requires DSOs and TSOs to cooperate with each other in planning and operating their networks, in particular, the long-term planning of network investments, with the view to ensure the cost efficient, secure and reliable development and operation of their networks.

The legislation also requires the ENTSO for Electricity to carry out the European resource adequacy assessment on an annual basis. This assessment shall be based on a transparent methodology which shall ensure that the assessment shall take account of the contribution of all resources including sectoral integration and their contribution to flexible system operation. It should apply probabilistic calculations and use a single modelling tool with real network developments, identifying the sources of possible resource adequacy concerns, in particular whether it is a network constraint, a resource constraint, or both.

Summary of Key Relevant Challenges of Legislation (EU) 2019/943:

- Suitable single model for European resource adequacy assessment that includes sector integration from present day to full decarbonisation.

Consistent tools for central and national 10-year plans for transmission and distribution networks that include sector coupling (integration) and demonstrate deployment of Smart Grids. These plans must be prepared cooperatively between TSOs and DSOs. Electricity market design, COM(2023) 148 final, 14 March 2023

The proposed changes to Legislation 2019/943 in this communication include a proposal for the requirements for assessment of flexibility needs by 1 January 2025 and every two years thereafter. It requires the regulatory authority of each Member State to assess and form a report on the need for flexibility in the electricity system for at least 5 years, including the integration of different sectors.

The ENTSO for Electricity and the EU DSO entity are required to coordinate transmission and distribution system operators and to develop a methodology for the analysis of the flexibility needs, taking into account at least all existing sources of flexibility and planned investments at interconnection, transmission and distribution level as well as the need to decarbonise the electricity system.

At the time of writing, a final text has been agreed upon by the three European institutions (Parliament, Council and Commission) and is ready to be published.

Summary of Key Relevant Challenges of COM(2023) 148:

- Single model that can assess flexibility services needs that includes sector integration from present day to full decarbonisation is a very relevant tool to achieve climate objectives.

Directive (EU) 2023/2413 amending Directive (EU) 2018/2001, Legislation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652[7]

The overall objectives of the revision are to increase the energy use from renewable sources by 2030, to foster

[7] repealing Council Directive (EU) 2015/652

better energy system integration and to contribute to climate and environmental objectives.

The revision is to ensure that district heating and cooling participate fully in energy sector integration. Sector integration requires TSOs and DSOs to widen the scope of cooperation in the areas of grid investment planning and markets to better utilise the potential of district heating and cooling for providing flexibility services in electricity markets. Further cooperation with gas network operators, including hydrogen and other energy networks, should also be made possible to ensure a wider integration across energy carriers and their most cost-effective use.

Member States are to increase the share of renewable energy in the heating and cooling sector by at least 0.8% as an annual average calculated for the period 2021 to 2025 and by at least 1.1% as an annual average calculated for the period 2026 to 2030. As 50% of industry demand is for heating and cooling, the full impact and potential of this development become significant to CEI planning.

Notably Article 15.3 replacement paragraph states:

'*Member States shall ensure that their competent authorities at national, regional and local level include provisions for the integration and deployment of renewable energy, including for renewables self-consumption and renewable energy communities, and for the use of unavoidable waste heat and cold when planning, including … energy and transport infrastructure, including electricity, district heating and cooling, natural gas and alternative fuel networks. Member States shall, in particular, encourage local and regional administrative bodies to include heating and cooling from renewable sources in the planning of city infrastructure where appropriate and to consult the network operators to reflect the impact of energy efficiency and demand-response programmes as well as specific provisions on renewables self-consumption and renewable energy communities, on the infrastructure development plans of the network operators.'*

And Article 24 replacement paragraph 8 states:

'Member States shall establish a framework under which electricity distribution system operators will assess, at least every four years, in cooperation with the operators of district heating and cooling systems in their respective areas, the potential for district heating and cooling systems to provide balancing and other system services, including demand response and thermal storage of excess electricity from renewable sources, and whether the use of the identified potential would be more resource and cost-efficient than alternative solutions.

Member States shall ensure that electricity transmission and distribution system operators consider the results of the assessment required under the first subparagraph in grid planning, grid investment and infrastructure development in their respective territories.

Member States may extend the assessment and coordination requirements under the first and third subparagraphs to gas transmission and distribution system operators, including hydrogen networks and other energy networks.'

Summary of Key Relevant Challenges of Directive (EU) 2023/2413:

- ➢ CEI planning process for all TSOs and DSOs required for heating and cooling systems benefits to be considered as an alternative option to traditional network development in sector coupling, notably electricity and gas (natural and hydrogen) with cost benefit analysis.

2.4 Challenges for CEI planning related to further R&D

The R&I Roadmap 2022 – 2031 is structured according to high-level use cases (HLUCs) and identifies challenges requiring further research and development initiatives. The roadmap acknowledged that these challenges may and should be treated as symbiotic or unified if possible. The priority project concepts (PPCs) within each HLUC that are relevant for CEI planning are the following:

Table 1: PPCs related to each High level Use Case

HLUC 1: Optimal cross sector integration and grid-scale storage	**Priority Project Concept (PPC) 1.1: Value of cross-sector integration and storage (IP 2022-2025)**

The scope of the PPC: Role and value of cross-sector integration and energy storage under different future decarbonisation pathways, assessing the impact on operation and planning of energy infrastructure costs. Assessment of cost and benefits of local versus national and international approach to cross-sector integration. Role of large-scale energy storage (electricity, thermal, synthetic liquids, hydrogen, etc.) in supporting cost effective decarbonisation.	
HLUC2 Market-driven TSO–DSO–system user interactions	**PPC 2.4: Planning tools for TSO-DSO cooperation (IP 2022-2025)**
The scope of the PPC: Optimisation of the energy system infrastructure planning and its implications on capital investments. Expand the more developed TSO-DSO cooperation at operational level and timeframe towards the network planning longer timeframe. Clarify how the planning tasks are coordinated in order to contribute to an efficient digitalisation of the entire electricity grid.	
HLUC4 Massive RES penetration into the transmission and distribution grid:	**PPC 4.4: Planning for a resilient system with massive penetration of RES (IP 2022-2025)**
The scope of the PPC: Enhance system resilience in the presence of increased RES penetration at all levels, via situational awareness, advanced forecasting methods, restoration mechanisms, adaptive network reconfiguration including microgrids and smart load shedding ensuring stability of the system and robustness to extreme events. Planning should take into consideration the integration of other energy carriers (e.g. hydrogen) and sectors (e.g. mobility).	
HLUC8 Sustainable transport integration	**PPC 8.3: Integrated planning of energy and transport sectors (IP 2022-2025)**
The scope of the PPC: Development of probabilistic system planning strategies incorporating the impact of large-scale deployment of different transport sectors and energy storage technologies. Develop common standards, protocols and digital services for full interoperability between energy and transport sectors, allowing seamless connectivity of EVs to IoT. Development of electricity system design codes to include the secure contribution of smart charging of EVs and V2G, practices, considering solutions for slow and rapid charging infrastructures. Planning for Battery efficient recycling and health preservation.	
HLUC9 Flexibility provision by building, districts and industrial processes	**PPC 9.3: Planning for reliable integration of buildings and infrastructures in an integrated energy system (IP 2022-2025)**
The scope of the PPC: Design and validate energy models connecting in a digitised electricity grid multi-vector systems supplying buildings, infrastructure and communities, through enhanced forecasting and multi-objective techniques to achieve optimal use of resources. Ensure secure and resilient integration of multiple infrastructures, forming microgrids, VPPs and VPSs, offering overall grid stability at the lowest cost.	

As well as these HLUCs, **Research Area 4: Planning – Holistic Architectures and Assets,** specifies the need for addressing the design and infrastructure planning of the integrated energy system overcoming the silos among energy vectors. It considers the necessary approaches and tools to plan and analyse the integrated energy system from all perspectives.

2.5 Other identified trends from EU policy

Hydrogen Strategy and Roadmap

The 2020 EU hydrogen strategy set a plan for a first phase deployment of 6 GW of electrolysers by 2024, which is considered too early and not sufficiently significant to require an immediate change to be part of CEI planning process. However, phase two in 2025-2030 sets a goal of 40 GW of electrolysers, and the third phase, from 2030-2050, renewable hydrogen technologies should reach maturity and be deployed at large scale to reach all hard-to-decarbonise sectors with up to 25% of renewable electricity production used for renewable hydrogen production. In May 2022, in the REPowerEU plan, this target was accelerated with 10 million tonnes of domestic renewable hydrogen production and 10 million tonnes of imports by 2030, to replace natural gas, coal and oil in hard-to-decarbonise industries and transport sectors.

During this period the combined electrolyser and renewable energy investment is envisaged to be as much as €380 bn. The European Commission's strategy sees the need for:

'Sound infrastructure planning, such as on the basis of ten-year network development plans ('TYNDP'), is needed on the basis of which decisions to invest can be taken. Such planning should also inform and be the basis for incentivising investments by private investors in electrolysers at the best locations. The Commission will thus ensure the full integration of hydrogen infrastructure in the infrastructure planning, including through the revision of the Trans-European Networks for Energy and the work on Ten-Year Network Development Plans (TYNDPs), taking into account also the planning of a network of fuelling stations.'

The European Clean Hydrogen Alliance was launched alongside the EU hydrogen strategy in 2020 bringing together industry, national and local authorities, civil society and other stakeholders. The objective is to achieve an ambitious deployment of hydrogen technologies by 2030, across renewable and low-carbon hydrogen production, demand in industry, transport and other sectors, and hydrogen transmission and distribution. Their Roadmap on Hydrogen Standardisation recognises that there is a need for cross-sector integration in chapter 6.6 and that the development of the necessary tools for doing so need to be under way by 2025 and in place by 2030 for among other things electrical power generation where conversion of up to 25-100% to hydrogen for existing gas-fired units considered possible. It concludes that many of the tasks to enable this are outside of this roadmap but are required.

Summary of Key Relevant Challenges:

- The timing of this CEI planning roadmap will be challenging, needing to be aligned with this EU Strategy and Alliance roadmap. The development of a CEI process will need to start in the second phase of the strategy in 2025 and to be timed for the first introduction on converted H2 generation and widespread electrolysers for 2030 and therefore completed by 2028 nationally and regionally.
- CEI planning at not only the TYNDP level, but at national transmission plans that must be aligned, and distribution plans (e.g. fuelling stations).

2.6 Disruptive Technologies

Disruptive technologies present a particular challenge as their unexpected appearance or failure to appear can create a pivotal change in need, or adequacy of solutions for needs, or the associated timelines for these.

With regard to CEI planning, a number of recent disruptive technologies have been identified. Depending on when these were identified, they are either incorporated into research and development work on the topic or are being mandated into the CEI planning process (e.g. through legislation). As these disruptive technologies are now well known and the extent of their potential has been quantified, they are within the process and procedure capability of CEI planning. They now present a lower risk of disruption. Some examples are the introduction of hydrogen gas into the planned energy mix, commercial and utility batteries. Datacentre development for the first phase of implementation of the IoT is also similarly categorised.

Beyond this, some further disruptive technologies have been identified, but are not included, and any CEI planning process development should have the flexibility to manage their impact. This means the CEI planning process should consider them and, if possible, it should model these technologies and their impact. It should also automatically calculate and avoid risk of regret in the solution selection process.

Disruptive technologies under development and deemed relevant for consideration:

Optical computing or photonic computing (either for conventions or quantum computing): These reduce the energy consumption growth from IoT. The expected growth by a factor of the existing power usage for data processing will become a real network challenge. Optical computing offers power consumption of a third of traditional silicon and consequentially a major reduction in demand growth.

High Energy Storage Battery (for transport or electricity networks): Conversion to electric vehicles would accelerate with high energy storage batteries, reducing the time for transition of the fleet by 10 years or more. This would create a rapid growth in demand to be catered for by networks.

Grid Enhancing Technologies[8] (for better use of electricity grids): These technologies maximise the transmission electricity across the existing system by applying a family of technologies that include sensors, power flow control devices, and analytical tools.

Energy Communities and adequate technical solutions and technologies[9] for better use of electricity grids and the integrated operation of electricity/gas/H2 networks at the end-user level: These technologies, on the one hand, maximise the transmission and distribution of electricity across the existing system by applying a family of technologies that include sensors, power flow control devices, and analytical tools. On the other hand, it increases the hosting capacity of renewable distributed resources by coupling with gas/H_2 and heating and cooling systems.

[8] Many European projects listed in Appendix 1 consider Grid Enhancing Technologies The Project of Common Interest GreenSwitch will consider the combination effect of many of these and cross-sector integration impacts.

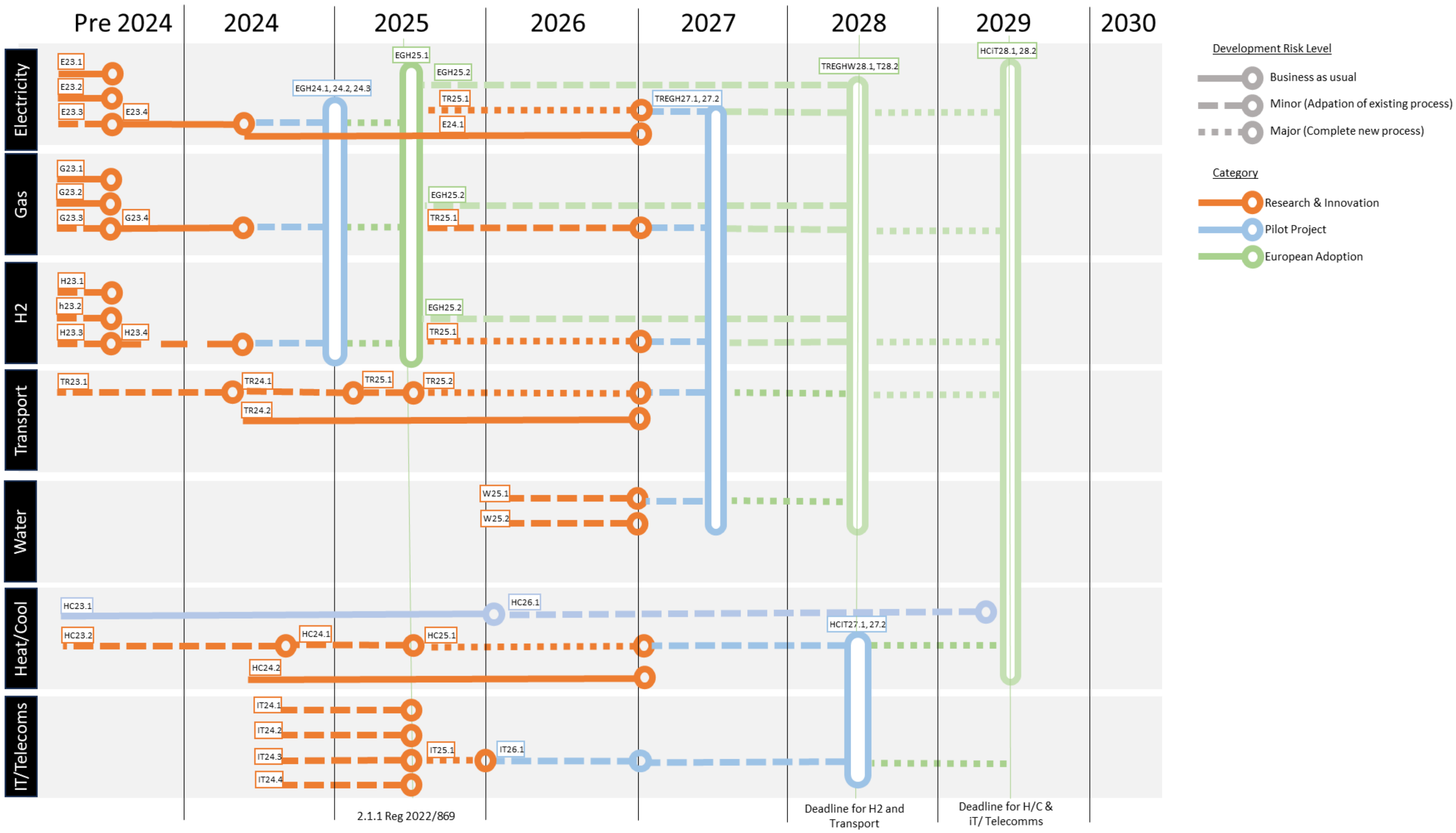
[9] European Commission, Directorate-General for Energy, Ilo, A., Rossi, J., Gallego Amores, S. et al., Energy communities' impact on grids – Energy community embedment increasing grid flexibility and flourishing electricity markets, Ilo, A.(editor), Publications Office of the European Union, 2024, https://data.europa.eu/doi/10.2833/299800

3. Coordinated Energy Infrastructure Planning pathway

In order to create a CEI planning process, the modelling, testing and selection of developments in energy systems have to be seamlessly integrated, breaking down the traditional silos between electricity, gas, heating, cooling, transportation, water networks and telecoms/IT. This integrated approach fosters synergy between different energy sources and enables efficient sharing of resources, leading to a more sustainable, flexible, and cost-effective energy ecosystem. Furthermore, when looking ahead, the development of innovative technologies should be accounted for as a means of improving and integrating sectors. Failure to do so could mean inefficient resource allocation and, more importantly, jeopardising future energy goals, which could in turn result in costly stranded assets. Many of the key challenges to this segregation have been identified in the preceding chapter, and they all mean that the introduction of an CEI planning process will progress step by step. Some of these steps are required in the near term both practically and through legislative requirements, with the aim of designing effective governance, through structural and joint planning by public authorities in cooperation with the private sector.

The roadmap in Figure 2, shows both the timing driven by working forward driven by legislative requirements and from tracking back based on the lead time to have CEI planning steps ready to prepare network projects to meet decarbonisation targets.

Figure 2: Coordinated Energy Infrastructure Planning Roadmap Vision



Programme 2030 end date: Electricity grid projects typically[10] take 10 years to build, but sometimes with lead times of up to 20 years or even more. Gas pipeline projects, railway projects, and programmes for transport electrification have similar lead times. TYNDP also has a ten-year rolling basis, providing the links that support and complement national grid development plans. TYNDP is essential to the timely and effective development of transmission infrastructure (gas and electricity) to deliver long-term European policy and aspirations while keeping the system secure. Therefore, it is a cornerstone of European-wide infrastructure planning to be prepared in coordination with the related vectors and sectors. Each TYNDP provides a European-wide vision of the future power system and investigates how power grids and storage can be used to make the energy transition happen in a cost-effective and secure way. The consideration of the other fundamental portion of the grid, the distribution system, is subject to obligations regarding the elaboration of development and operation plans on a similar timescale[11], providing transparency to the planned investments for the next five-to-ten years together with information on the medium and long-term flexibility services needed (as recognised in the European legislation analysed in Chapter 2).

All the above means that for CEI planning to be effective in developing any of the energy infrastructure for a decarbonised network by 2050, the CEI process would need to be in place by 2030. This can be seen as a latest date as the process is, in essence, required to be more economically and resource efficient, and therefore early development is likewise of Europe-wide benefit.

H_2 in roadmap: This timeline has been recognised as the need for the development of a CEI planning process. For hydrogen the CEI process is taken to start in 2025 and for first introduction on converted H2 generation by 2030 its completion by 2028 in line with section 2.1.

Transport in roadmap: The “Fitfor55 package” released by the EU on July 2021 states that all new cars on the European market must be zero-emission vehicles from 2035. “Fitfor55” also modifies the Renewable Energy Directive (RED) and introduces renewable hydrogen quotas for transport by 2030. Electric batteries and green hydrogen are the two main technologies to decarbonise transport. The impact of zero-emission transport as it grows is being considered in existing planning approaches using scenarios. However, this is only based on sizing the energy consumption placed on electricity, gas and in future hydrogen. What is required for cross-sector planning is, where there is a need for investment of a sector and infrastructure that could be resolved by investment[s] not in that sector but in one or more of these sectors (including transport), that new CEI planning methods will be developed. These will not only actively consider the needs arising from transport but should also consider the use of different transport energy types as a possible part of the solution. For example, is the use of inherent battery or gas storage in vehicles (cars, buses, lorries, trains or shipping) to provide prosumer energy and ancillary services an effective whole or part solution to needs? CEI planning will need to encapsulate the potential of transport as it becomes effective as a solution. Given that the DSOs expect that EVs are expected to only represent 8%[12] of their total investment by 2030, it is unlikely that this will become relevant to investment built before this date. Given the lead time of planning to commissioning of investments, and the development of CEI planning for both hydrogen and electricity, the timing of integrating transport into CEI planning is aligned with that of hydrogen.

IT and telecoms in roadmap: The Digitising the EU action plan of 2022, concludes that digitalisation of the energy system is a policy priority and one where the European Green Deal and the Digital Decade Policy Programme 2030 for Europe go hand-in-hand as a twin transition. It recognises that around €170 bn of the envisaged €400 bn from 2020-30 in distribution network spend in Europe will be for digitalisation of the grid. The first steps are considered to be a digital twin of the transmission and distribution networks, developed by ENTSO-E and EU DSO entity, which will not be created in one go but will be a continuous investment and innovation effort for years to come, enabling joint network planning. In chapter 6, the scale of global power use of 7% of total system power is expected to nearly double by 2030, with nearly 60% of this growth due to increased datacentres' demand and digital network operation. The action plan conclude that this issue ‘requires comprehensive planning given the demand it puts on our electricity grid’.

Water – energy nexus

The water-energy nexus is a complex and critical concept in the sustainable management of resources. Both are primary needs for a modern society, sometimes in competition for the use of scarce resources; both are characterised by heavy, capital-intensive infrastructures. The nexus refers to the multifaceted interdependence between water and energy systems: energy is required to extract, treat and deliver water, while water is essential

[10] IEA Energy Technology Prospectives 2023
[11] Directive (EU) 2019/944
[12] Eurelectric ‘Debunking the myth of the grid as a barrier to e-mobility’ April 2021

for producing nearly all forms of energy. This nexus highlights the need to consider both resources together rather than in isolation, as decisions in one area can significantly impact the other. For instance, the generation of hydroelectric power is directly dependent on water availability, while the production of energy through fossil fuels or nuclear power requires significant water for cooling processes. Conversely, the treatment and distribution of water are energy-intensive tasks, making the relationship between these two resources a balancing act of efficiency and sustainability.

In Europe, the interdependencies between water and energy have garnered attention from both scientific and policy communities. The European Commission's Joint Research Centre[13] has reported on the specific challenges and opportunities presented by the water-energy nexus in Europe. The report discusses how changes in water availability due to climate change could significantly affect the energy system, especially given the EU's ambitious decarbonisation goals which rely on water-demanding energy technologies.

The United Nations Economic Commission for Europe (UNECE) has explored the broader implications of the water-food-energy-ecosystem nexus, emphasising that actions in one policy area often have impacts on others, as well as on the ecosystems that natural resources and human activities depend upon. This integrated approach is crucial for addressing the multiple challenges of resource management and ensuring the resilience of both water and energy systems.

The nexus approach also opens up opportunities for energy savings and increased efficiency within the water sector. For example, wastewater contains significant amounts of embedded energy that could be harnessed to meet the electricity needs of municipal wastewater utilities. Additionally, reducing water losses in the supply chain through improved infrastructure and management can save both water and energy. Circular economy concepts apply not only to energy and material goods/wastes, but also to water, through wastewater treatment and reuse, introducing a hierarchical scale in water value: drinking, domestic use, industrial use, cleaning use, irrigation, power generation. Indeed, water is a renewable resource, but not unlimited as wind or solar, where the only limit is the human capability and convenience to harness them, while the underlying source in practically infinite.

Therefore, the water-energy nexus is a key consideration in the pursuit of sustainable development. It requires a holistic understanding of the interplay between water and energy systems and a coordinated approach to policy and management that recognises the intricate connections between these vital resources. By addressing the nexus, we can work towards solutions that ensure the security and sustainability of water and energy for future generations. Collaboration between different sectors and stakeholders is essential to address the water-energy nexus effectively. Partnerships between water and energy utilities can lead to joint efficiency programmes that benefit both sectors. Sharing best practices and knowledge across industries and regions can also accelerate progress.

It is expected in Annexe 1 chapter, Synergies between the EU’s energy and digital agenda that:

‘*These synergies include the use of data and tools for energy system integration and planning. They also concern the optimal integration of digital infrastructure such as datacentres and cloud infrastructure into the overall energy and heating systems, in coexistence with competing uses of that system, for example through energy-efficient datacentres and the reuse of their waste heat for businesses and households, as well as allocating spectrum in telecommunications networks to smart energy grid solutions.’*

In addition, it is the intent of the strategy that promoting investment into digital infrastructure will use the TYNDP’s and PCI process, supported by the use of European cyber secure digital twin to develop the process and tools to provide digital technologies and connectivity for retrofitting the existing energy and transport infrastructures with the required cross-border digital infrastructure.

Different actors are involved in the development of infrastructures in their respective sectors and are not necessarily coordinated among them. They often use information from different sources. The integration and cooperation between those actors require adequate platforms that consider the available data, respect the defined governance and allow for seamless, transparent, non-discriminatory and cost-effective interactions[14].

For CEI planning to be truly cross sectorial, there must be modelling tools that allow each energy sector to see its influence on the other sectors. Integration of each sector's modelling techniques of its needs and network limitations are required to ensure any action by a sector is informed, not only of the acceptability of the impact to its own sector, but also whether the actions impact of interlinked sectors are also acceptable. Layered on top of this, there needs to be consolidated rules for cross sectors, for example legislative requirements, regulatory rules, grid codes, market rules, cost benefit analysis, etc. that would drive decisions by sector network operators in

[13] Found at: file:///C:/Users/mark.norton/Downloads/online_ecj095x_policy_report_interactive_4.pdf
[14] ETIP SNET, R&I Roadmap 2022 – 2031

their investment and operational decisions. In conjunction with these integrated models and consolidated rules for the sectors, a transparent understanding of the solution options that might be used to address issues in any one sector must be developed. **This understanding must be at least deep enough to identify the capability of a solution in an adjacent sector to address another sector's needs, so that a more in-depth collaborative discussion and appraisal can be made as part of solutioning**. It should be noted that cross-sectorial solutions might need and use a solution whose scope comprises multi-sector elements working together (e.g. a H2 network investment, coupled with an electricity network investment, and a district heating scheme) to resolve a need.

In conjunction with the identification of the challenges in the preceding section, a gap analysis was performed to identify the building blocks and present state-of-the-art demonstration of these building blocks from research and development projects. These building blocks are detailed in table 1, and existing research and development work to address these are discussed in the next chapter of this report.

The building blocks have been assigned an alphanumerical code, which uses the following criteria. The first letter defines the applicable sector the building block is for using Electricity (E), Natural Gas (G), Hydrogen (H), Transport (TR) Heating & Cooling (HC), water (W) Telecommunication and IT (IT). Where a building block is for more than one sector then the letter is combined e.g. Electricity (E) and Natural Gas (G) building blocks would start with (EG).

The commencement year for the works follows the sector letter[s] e.g. for an Electricity (E) building block commencing in 2024 (24), the building block would start with E.24. Any building blocks commenced before 2024 are given the year as 2023 (23). Finally, the last number provides a unique identifier for that year, e.g. the first two building blocks for a sector in 2024 (24) would be 24.1, and then 24.2.

Table 2: Building blocks required to deliver the CEI planning vision

Building Blocks[15]	Title/Topic/Brief synopsis
E23.1	<u>High Fidelity European Integrated Electrical Network Model suitable for steady state and dynamic analysis.</u> This work considers the possible models enabling the transfer of the necessary electrical network data into a format and structure that will allow conjoining of the electricity and natural/H2 gas networks into one network model and not just consistent forecast scenarios the reflect each sector's ongoing development.
E23.2	<u>Network modelling tool (software) and methodology for European wide steady state and dynamic analysis.</u> This work considers the possible methods and tools should extend or replace existing modelling tools such that electricity and natural/H2 gas networks can be modelled and studied simultaneously, and not iteratively. The tools and methodology for electricity should be able to identify needs on the electricity/natural gas/H2 gas systems, and also be able to test both electrical, gas or hybrid-based reinforcement solutions at a concept level (to confirm viability and high level CBA of cross-sector solutions) and for electricity detailed analysis of existing and innovative technological solutions.
E23.3	<u>Cost Benefit Analysis methodology for investment decisions and approval</u> of electrical reinforcement or hybrid electricity and gas investments, which should value the benefits and costs to both electricity and gas consumers, which in line with legislation shall be a TOTEX methodology.
E23.4	<u>Develop scope of electricity and gas cross sector integration model, tools and methodologies</u> which will consider the ranges of modelling, tools, methodologies for model building, network modelling and CBA options developed (in E23.1-E23.3). The scope will select and/or modify these to provide an approach that will enable national, regional and European conjoined electricity natural and H2 gas models to be developed that may be used for market, network and operational electrical network planning.
E24.1	<u>Production of a Common European Energy Space for Energy</u>[16] will be closely linked to other sector-specific data spaces (e.g. mobility and smart communities) and will thus enable actors from various sectors such as building automation and electro-mobility to actively participate in the energy market, deliver energy services, and promote sector integration (the linking of the various energy carriers - electricity, heat, cold, gas, solid and liquid fuels - with each other and with the end-use sectors, such as buildings, transport or industry).
G23.1	<u>High Fidelity European Integrated Gas Network Model suitable for steady state and dynamic analysis.</u> This work considers the possible models enabling the transfer of the necessary natural gas network data into a format and structure that will allow conjoining of the electricity and natural/H2 gas networks into one network model and not just consistent forecast scenarios the reflect each sectors ongoing development.
G23.2	<u>Network modelling tool (software) and methodology for European-wide steady-state and dynamic analysis.</u> This work considers the possible methods and tools should extend or replace existing modelling tools such that electricity and natural/H2 gas networks can be modelled and studied simultaneously, and not iteratively. The tools and methodology for natural gas should be able to identify needs on the natural gas/H2 gas/electrical systems, and also be able to test both gas, electrical or hybrid based reinforcement

[15] The convention of building block number is sector (Electricity[E], Gas[G], Transport[TR], Heating/Cooling[HC], Telecoms[T]), then Year (23, 24, etc.) then a numerical identifier starting from one
[16] DIGITAL-2024-CLOUD-AI-06-ENERSPACE

Building Blocks[15]	Title/Topic/Brief synopsis
	solutions at a concept level (to confirm viability and high level CBA of cross-sector solutions) and for natural gas detailed analysis of existing and innovative technological solutions.
G23.3	Cost Benefit Analysis methodology for investment decisions and approval of natural gas reinforcement or hybrid electricity and gas investments, which should value the benefits and costs to both electricity and gas consumers, which in line with legislation shall be a TOTEX methodology.
G24.4	Develop scope of electricity and gas cross sector integration model, tools and methodologies. This work will consider the ranges of modelling, tools, methodologies for model building, network modelling and CBA options developed (in G23.1-G23.3). The scope will select and/or modify these to provide an approach that will enable national, regional and European conjoined electricity natural and H2 gas models to be developed that may be used for market, network and operational natural gas network planning.
H23.1	High Fidelity European Integrated H2 gas Network Model suitable for steady state and dynamic analysis. This work considers the possible models enabling the introduction of H2 gas network data, either through new build, of conversion (both storage and transmission) into a format and structure that will allow conjoining of the electricity and natural/H2 gas networks into one network model and not just consistent forecast scenarios the reflect each sector's ongoing development.
H23.2	Network modelling tool (software) and methodology for European wide steady state and dynamic analysis. This work considers the possible new methods and tools for H2 that allow electricity and natural/H2 gas networks to be modelled and studied simultaneously, and not iteratively. The tools and methodology for H2 should be able to identify needs on the natural gas/H2 gas/electrical systems, and also be able to test both gas, electrical or hybrid based reinforcement solutions at a concept level (to confirm viability and high level CBA of cross sector solutions) and for H2 detailed analysis of new solutions and/or conversion options of existing infrastructure.
H23.3	Cost Benefit Analysis methodology for investment decisions and approval of H2 gas reinforcement, natural gas conversion or hybrid electricity and gas investments, which should value the benefits and costs to both electricity and gas consumers, which in line with legislation shall be a TOTEX methodology. Notably it must be suitable for the continued evaluation of the TENE Hydrogen priority corridors, and the project initiatives.
H24.4	Develop scope of H2 model, tools and methodologies for electricity and gas cross sector integration which will consider the ranges of modelling, tools, methodologies for model building, network modelling and CBA options developed (in H23.1-G23.3). Due to the lack of maturity, the scope will select and/or modify these, or consider completely new approaches that will enable national, regional and European conjoined electricity, natural and H2 gas models to be developed that may be used for market, network and operational gas network planning.
EGH24.1	Develop electricity and gas cross sector integration model to produce the first truly integrated single gas and electricity model for use by the electricity and gas sectors for market, network and operational planning.
EGH24.2	Produce first (pilot) network model and methodology[17] for electricity and gas cross sector European and national use will need to build upon the methods and options consider (in E23.4, G23.4 and H23.4) and apply the conjoined network model (EGH24.1) to produce the first European (and ideally national) development plans to comply with the deadlines for their integration.
EGH24.3	Produce first (pilot) CBA methodology for electricity and gas cross sector European and national use will need to apply the methodologies (in E23.4, G23.4 and H23.4) results of EGH24.2 to produce the first European integrated CBA to comply with the deadlines for their integration.
EGH25.1	European adoption of piloted model and methodology in Europe will include the move from existing practices of data collection, analysis and experience in both TYNDPs for Gas and Electricity to the newly piloted models, methods and tools.
EGH25.2	Achieve national adoption of piloted model and methodology in member states (aligning with EGH25.1). By extension, adoption and production of national development plans should follow to maintain the required legal consistency between both.
TR23.1	Improved transport models into network planning models. New models and algorithms are required that can model the movement of mobile renewably (electricity and H2) fuelled transport to perform robust simulations of network needs and cross-sector optimisations scenarios. Models capable of assessing the impact of progressive massive EV and hydrogen penetration on the electricity system, including modifications of hourly/weekly/seasonal load profiles, conditions for energy adequacy (primary energy supply) and power adequacy (grid congestion/reinforcements). These models need to be adequate for steady state and dynamic conditions, include all network/ancillary services, to be used in market, operational and investment network planning at Transmission and Distribution levels.
TR24.1	Development and adoption of network planning criteria rules (for electricity and gas networks) to account for new probabilistic risks (e.g. maximum correlation of charging) as part of the conversion of transport fleets to renewable sources. Due to the legislative requirements of equitability treatment in the EU, these need to be harmonised Europe-wide.
TR24.2	Production of a Common European Energy Space for Mobility[18] will be closely linked to other sector-specific data spaces (e.g. Energy and smart communities) and support the creation of the common European mobility data space (EMDS), which will facilitate the access, sharing and reuse of data in the mobility and logistics sectors.

[17] Suitable to enact all legislative requirements

[18] DIGITAL-2024-CLOUD-AI-06-MOBSPACE

Building Blocks[15]	Title/Topic/Brief synopsis
TR25.1	Network modelling tool (software) and methodology for European wide steady state and dynamic analysis. This work considers the supplemental methods and tools that allow electricity and gas networks to be modelled and studied simultaneously, and not iteratively with transport. The tools and methodology should be able to identify needs on the natural gas/H2 gas/electrical systems arising from transport developments systemically and project by project. Also, these tools and methodologies should be able to test both transport-based reinforcement and/or services solutions at a conceptual level (to confirm viability and high level CBA of cross sector solutions) and detailed analysis of new solutions and/or conversion options of existing infrastructure for transport.
TR26.1	Adapt CBA methodology for electricity and gas cross sector to include transport for European and national use which will need to apply the methodologies (in TR25.1).
W25.1	Develop relationship modelling of future water usage. This work considers the development of hourly to annualised water utilisation models to provide source data for cross sector network modelling.
W25.2	Network modelling tool (software) and methodology for water in adequacy in cross sectors development. This work considers the possible new methods and tools that can apply the variations in water availability impact to existing availability models for electrical generation, including conventional generation and renewable generation reliant on sufficient supply of water (notably nuclear and hydro).
TREGHW27.1	Develop electricity, gas cross sector and transport integration model to produce the first truly integrated single gas and electricity model with renewable transport (EV and H2) for use by the electricity gas sectors and transport for market, network and operational planning.
TREGHW27.2	Produce first (pilot) network model and methodology[19] for electricity and gas cross sector European and national use will need to build upon the methods and options consider (in TR23.1, TR24.1 and TR25.1) and apply the conjoined network model and CBA (TREGH27.1 and TR26.1) to produce the first European (and ideally national) development plans to comply with the deadlines for their integration.
TREGHW28.1	European adoption of piloted model and methodology in Europe will include the move to expand existing practices of data collection, analysis and experience in both TYNDPs for Gas and Electricity to include the newly piloted models, methods and tools for transport projects to be considered and also offer solutions to electricity and gas network needs.
TREGHW28.2	Achieve national adoption of piloted model and methodology in member states (aligning with TREGH28.1). By extension, adoption and production of national development plans should follow to maintain the required legal consistency between both.
HC23.1	Development of first national report on the potential for district heating and cooling systems to provide balancing and other system services (EU Directive 2018/2001 with RED 3. 2021/0218 amendments). This first four yearly report is likely to be more passive as tools and models will be unavailable, but can outline the developed models, tools and methodologies to provide a robust 2nd report to align approaches across Europe.
HC23.2	Heating and cooling technologies models suitable for integrated Electricity, Gas and Transport network analysis. This work considers the diversity of technologies in the heating and cooling sector many of which do not currently have models that represent the energy utilisation and service capability of these technologies for a single integrated electricity, gas and transport network model. Given the array of sizes of heating and cooling technologies (e.g. domestic heat pumps, centralised district heating schemes), both individual and grouped models will be required.
HC24.1	Network modelling tool (software) and methodology for European wide integration. This work considers the possible new methods and tools that can apply the models from HC23.1 to be able to test heating and cooling technologies impact on and solutions for gas, electrical or hybrid-based network reinforcements.
HC24.2	Common European data spaces for Heating and Cooling as set out in the European Data Strategy (COM (2020) 66 final) that announced the creation of Common European data spaces in nine sectors[20]. This may require an acceleration of the existing plans that target 2024-2027 to fully complete this sectors data space.
HC25.1	Development and adoption of network planning criteria rules (for electricity and gas networks) to account for new probabilistic risks[21] as part of the widening and scale of renewable energy (electricity and H2) heating and cooling technologies. Due to the legislative requirements of equitability treatment in the EU, these need to be harmonised Europe-wide.
HC26.1	Development of second national report on the potential for district heating and cooling systems to provide balancing and other system services. This second four yearly report can apply the developed models, tools and methodologies to provide a robust 2nd report to align approaches across Europe and encapsulate the impact of piloting integrated of heating and cooling and planning.
IT24.1	Telecom/IT technologies models suitable for integrated electricity, gas and transport network analysis. This work considers the diversity of technologies in the IT sector (e.g. datacentres) and telecoms (e.g. fibre and mobile networks) many of which do not current have models that represent the energy utilisation and service capability of these technologies for a single integrated electricity, gas and transport network model. Given the array of sizes of IT facilities (e.g. datacentres which may be localised for IoT, or very large scale), their energy needs both individual and grouped models will be required. Similarly, the telecom network not only allows for data traffic but permits the movement of the tasks associated with the data,

19 suitable to enact all legislative requirements

20 https://digital-strategy.ec.europa.eu/en/policies/data-spaces

21 e.g. simultaneous loss of H2 network elements, heating CHP/Storage, and/or power generation

Building Blocks[15]	Title/Topic/Brief synopsis
	notably data storage and computation that require energy. Models must be able to recognise this capability to determine network needs and solutions
IT24.2	Network modelling tools (software) and methodology for European-wide steady-state and dynamic analysis. This work considers the possible methods and tools to extend or replace existing modelling tools such that the unified electricity and natural/H2 gas networks can be modelled and studied simultaneously, with the telecoms networks and IT sector facilities. The tools and methodology for electricity should be able to identify needs on the electricity/natural gas/H2 gas systems, and also be able to test both electrical, gas or hybrid based reinforcement solutions at a concept level (to confirm viability and high level CBA of cross sector solutions) and for electricity/H2 detailed analysis of existing and innovative technological solutions.
IT24.3	Cost Benefit Analysis methodology for investment decisions and approval of telecom/IT reinforcement or hybrid investments, which should value the benefits and costs to all consumers, which is in line with legislation shall be a TOTEX methodology. This CBA methodology must first be able to look at telecoms/IT and heating and cooling integration to look at hybrid solutions of these two sectors, but can be easily expanded to the other sectors
IT24.4	Development and adoption of network planning criteria rules for telecoms networks (for electricity and gas networks) to account for new probabilistic risks as part of the widening and scale of renewable energy (electricity and H2) telecom/IT technologies. Due to the legislative requirements of equitability treatment in the EU, these need to be harmonised Europe-wide.
IT26.1	Develop Telecom and IT integration model to produce the first truly integrated telecom and IT integration national model for use in the ICT sector to develop private and public assets into one, that has the ability to show how data processing can be moved geographically, and how telecom/IT firms use apply and use their assets latency. For example, datacentres typically operate with other datacentres within relatively local area to back up each ones processing capabilities.
HCIT27.1	Develop Heating and Cooling, and IT integration model to produce the first truly integrated Heating and Cooling and IT national models for use by the Heating and Cooling sector and ICT sector to develop integration of two sectors e.g. producers of waste heat/cooling (datacentres/industry HC/domestic HC and users district heating/datacentres /industry/thermal storage). The interrelationship with impacts on other sectors should be included, electricity/gas network energy production or demand in preparation for greater cross sector integration.
HCIT27.2	Produce first (pilot) of model and methodology[22] for integration of Heating and Cooling and IT integration will need to build upon the methods and options consider (in HC23.2, HC24.1, HC24.2 and HC25.1) and apply the conjoined network model to produce the national development plans to comply and develop NECP's. Base this on 2024 NECPs.
HCIT28.1	European adoption of piloted model and methodology integrated Heating and Cooling and IT with Electricity/Gas/ transport in Europe will include the move to expand existing practices of data collection, analysis and experience in both TYNDPs for Gas and Electricity to include the newly piloted models, methods and tools for transport projects to be considered and also offer solutions for all energy sectors.
HCIT28.2	Achieve national adoption of piloted model and methodology integrated Heating and Cooling and IT with Electricity/Gas/ transport in member states (aligning with HCIT28.1). By extension, adoption and production of national development plans should follow to maintain the required legal consistency between both.

[22] suitable to enact all legislative requirements

4. GAP analysis - findings and suggested actions

We have identified gaps in five distinct key areas, namely gaps related to vision and direction, exploitation of disruptive technologies, stranded R&D pathways, models and methods, and legal requirements. These gaps need attention in order to deliver robust and advanced cross sector CEI planning. This chapter summarises key actions from the GAP analysis. The complete GAP analysis can be found in appendix 2.

4.1 Setting Direction (Vision and scenarios)

- A clear vision is lacking for integrated energy planning beyond the high-level overarching goals from legislation and EU strategies. The vision should be detailed into steps; it should be supported by stakeholders and be further detailed into timelines and objectives.
- The preceding chapter in this report sets out a high-level roadmap of the legislative and a number of building blocks that will be required to achieve legislative objectives, providing a starting point for setting a vision.
- Responsibilities for the steps should be allocated and adopted in legislation. Legislation should include requirements for having new holistic planning and analysis tools and new collaborative ways of working across sectors. For example, the integration of transport, heating and cooling and the IT sectors into the electricity and gas (H2/Natural) sectors into CEI planning is envisioned and required. However, there are no equivalent organisations to ENTSO-E, ENTSO-G, or EU DSO entity to work with these bodies to achieve this.

4.2 Disruptive technologies

- Disruptive technologies create challenges and solutions. The most known and visible disruptions are the challenging ones and relate to connecting large amounts of wind and solar power to the electricity grids. These new renewable generation have had a major impact on system operations and system developments. A second disruption relates to technologies that can help manage the first disruption, and includes batteries, demand flexibility, grid enhancing technologies and digitalisation.
- The full range of disruptive technologies is not identified and is, to a limited degree, included in energy system planning. Disruptive technologies occur across all sectors and infrastructures, and the new technologies are typically not included in energy system planning before they have been implemented in the system and adopted at scale.
- Disruptive technologies should be included in network planning many years in advance by asset owners and system operators. New principal bodies should be established and made responsible for developing a coordinated energy planning roadmap that is cross-sectorial and accounts for both existing and new disruptive technologies.

4.3 Adapt R&D pathways

- Existing research and development for more advanced CEI planning can quickly become defunct, with the resulting loss of time and resources as the needs of networks and cross sector interaction. The principal risk of stranding of research and development pathways is the use of a series of incremental step changes in CEI planning being introduced into single adjacent energy sectors. These incremental steps do not create an overall framework for CEI planning that each step fits into and consequently models, tools and data are at a high risk of having to be redeveloped. This is compounded by sectors working independently of their research and development and only being considered in conjunction with each other when European policy sets the requirement to do so and/or a deadline.
- A fully phased research and development programme for developing CEI planning to achieve a fully 2050 decarbonised network would be an invaluable for policy makers and industry. This would provide context for each piece of R&D, what it is for, what it must achieve and how it fits into the overall programme. It would allow monitoring in earlier years of progress towards to overall long-term deadlines. From this, the

importance, expectations, and timeline for any piece of R&D into the longer-term programme, and the necessary key deliverables to achieve the next step, would be easily shown. The programme would be ‘live’, regularly updated based on outcome of earlier stage R&D and/or disruptive technologies.

- R&D funding needs to be allocated faster. Changes to the topics that require research and development are outpacing funding mechanisms so that R&D is late, or outdated. R&D projects administration must account for the risk of disruptive technologies and validity of final results at the outset and be monitored as projects progress. R&D funding go/no-go payment releases should be tied into updates of the CEI plans to provide balance and checks.
- CEI planning research and development should account for great volatility in future predictions and be developed for the less probable future outcomes/contingencies in case they become commonplace. By default, solutions to allow for progress of cross-sector CEI planning should manage new risks introduced by considering new energy sectors in cross sector analysis.

4.4 Models and Methodologies

- CEI planning energy integration system modelling, tools and operation are not available to assess all sectors (Natural Gas, Hydrogen, electric, telecom/IT and transport). A unified transport and telecommunication assessment tool is not available. The assessment tool should allow the responses of these sectors to long-term and short-term operational impacts e.g. daily commute or data use, loss of regional infrastructure and new development to be assessed. What is required is the identification of cross-sector latent capabilities/responses that can be supportive of other sectors and development of methodologies for assessment in each sector.
- Technology developers, R&D bodies, academia and policy makers (regulators, government, public) in conjunction with system operators and asset owners will be the principal responsible bodies for the network and system. Developers will continue to determine and build individual facilities for customers.
- Given the radical and widespread changes in sectors as decarbonisation, electrification and H2 adoption is occurring on the energy infrastructure in all sectors, network system operators and asset owners will need to prepare for these changes much more in advance (many years)[23]. This will be necessary to ensure the right solutions are adopted, that they are flexible and comprehensive and to minimise any new unforeseen issues. The need to make much more forward-facing decisions on solutions and supplementing this with additional reinforcements will make the planning process more intensive and complex.
- Observability of other sectors´ needs, developments and solution choices will be crucial for efficient and cost-effective solutions in any sector. Models and methodologies will be key to doing this. Moves from traditional planning standards to more probabilistic approaches will become necessary as simpler standards (like N-1) become insufficient to manage complex needs.
- EMT and dynamic studies will become commonplace and methods/models to enable this.

4.5 Legislative requirements

- The full requirements within the existing legislation, notably EU Legislation 2022/869, EU Legislation 2019/944 and EU Legislation 2019/943 have requirements for a revised Energy Infrastructure planning methodology and are not currently met.
- At present, a full implementation of the legislative requirements to ensure the timely, efficient, effective and optimised cross-sectorial development of the energy, transport and telecommunication infrastructure as required and desired by the European Member States is not possible.
- The existing CEI planning processes and tools do not have:
    - An ability to assess all sectors simultaneously
    - A process for proposing evaluating or accepting cross sectorial candidate projects or solutions, or multitasking technologies

[23] Identified as part of ETIP SNET WG4 Energy Data Space Policy Paper

    - Capability to provide solutions that rely on cross-sectorial elements of a project to offer a solution
    - Cost benefit analysis limited to only one sector at a time
- Lack of homogeneity and criteria in different jurisdictions and sectors.
- CEI planning requirements are needed for the implementation as part of the two-yearly updates of the ten-year network development plans and the DNDP (DSO Network Development Plans) and in coordination with NECPs, but current there is limited connection and circular feedback with NECPs across all sectors.
- With regard to central sectors, electricity and gas, that form the interface in CEI planning for all other sectors, there is strong oversight from ACER and national regulators, developmental bodies with ENTSO-E, ENTSO-G EU DSO entity, national TSOs and DSOs, and policy direction from EC/EU and Member States. However, there is limited oversight in adjacent sectors to gas and electricity, and a mandated separate oversight of compliance.
- Development plans do not account for a full range of possible future scenarios for each sector, or for the effects of disruptive technologies in candidate developments. Solutions are currently restricted to being from the sector that has the identified problem. Therefore, they do not assume a less-than-perfect prediction of the future. They also do not apply the range of possible variations in future predictions to work out from the range of solutions, which one will be best suited for all possible futures and needs and is the least worst regret development.
- Legislative requirements need little recognition of alternatives when considering the deliverability of projects to address needs. For example, the requirement to have a development plan does not mean such a plan has to offer alternative supplemental or replacement solutions to account for later than expected delivery of a solution. Hence there is automatic acceptance of a project as a solution, even though it fails to deliver on time, and does not call for a more efficient solution to be found or developed. In light of the more severe impact that project delays will have when projects support multiple sectors, the risk and impact can be expected to grow exponentially.

5. Immediate research & development and knowledge sharing actions

5.1 Setting direction (vision and scenarios)

CEI Planning vision and the identified building blocks should be used to build a more detailed and comprehensive plan. The entities who own the delivery of these building blocks should also be identified. Existing ongoing projects that will deliver these building blocks should be reviewed to ensure they support the next steps in the plan and the ultimate inclusion of all sectors into CEI planning. This may include the physical projects, tools, methods, services and procedures delivered.

Requirement for new principal bodies for the transport and telecom/IT sectors. The transport sector (road, rail, metro, shipping), needs a new central body to align nationally and at a European level to develop the capability for CEI planning of the sector, which is independently developed with no central organisation. Similarly, the telecom/IT sector's datacentres, ICT and telecommunications are independently developed generally through competing commercial businesses. To enable CEI planning tools a new central body to enable development in this sector to be considered in conjunction with other sectors.

ETIP SNET, being by its founding nature a platform for multistakeholder coordination, can be supportive to set and update such vision; indeed, it's very first deliverable was "Vision 2050"[24], which in large part is still valid and well representative of this holistic need.

5.2 Disruptive technologies

Create a single source of truth with official information &datasets and a responsible body to develop a list of disruptive technologies. Develop a centralised list of potentially disruptive technologies for each sector for which CEI planning will cover. This list should be live, updated with new disruptive technologies, as they are identified and accepted. An independent body should be appointed to host and manage this list, with predicted timelines on the best estimated date the technology would be mature and become disruptive the status quo of the existing CEI planning.

Disruptive technologies shall be included in all CEI planning going forward. Given the nature of being a disruptive technology, the timing and impact of these technologies is acute and requires planned investments in all energy sectors to be prepared for their arrival and be adaptive to this. As their inherent risks and opportunities to CEI plans are unlimited, this must be done many years prior to their physical deployment. Therefore, plans such as the TYNDP should include disruptive technologies in their assessments and confirm those investments that are resilient to disruptive technologies and those that are not, alternate investments. A good step in this direction has been carried out in the ENTSO-E document "Vision for a future energy system" in the section "Game Changers"[25], where 8 disruptive trends have been selected after a brainstorming stage, analysed with risk analysis methodology, and assessed/ranked for taking appropriate early actions (either to counter risks or to foster opportunities). Also, flexible quick delivery technology projects that can manage a change to the predicted arrival date or scale of the disruption should be investigated and made ready. Flexible technology projects will be highly important to avoid long lead time project from the risk of becoming stranded or underutilised assets.

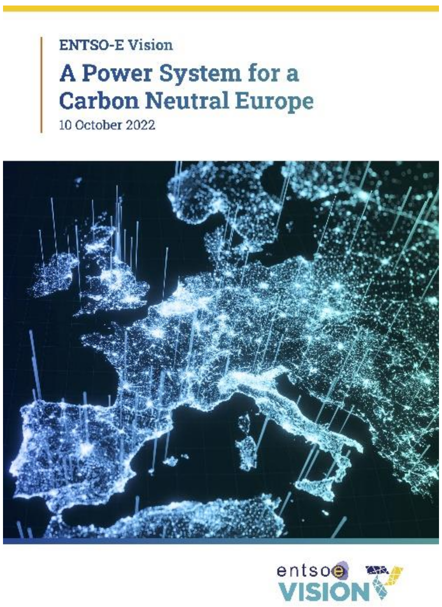


Figure 3: ENTSO-E Vision for a future energy system

Research and Development for CEI planning models, tools, procedures for disruptive technologies shall be initiated as soon as a disruptive technology is identified. The existing time to develop new large scale

[24] Found at: https://smart-networks-energy-transition.ec.europa.eu/etip-snet-vision-2050
[25] Found at: https://vision.entsoe.eu/chapters/potential-game-changers

(e.g. linear) infrastructure across the sectors is typically greater than 10 years, and for disruptive technologies to develop is only a fraction of this time. Inclusion in CEI planning must be as rapid as possible and therefore so must research and development that comes first.

5.3 Adapt R&D pathways

Review existing research and development for greater advanced CEI planning. This review will consider whether new models, tools and processes, such as scenario development methods including cross sectors, data transfer formats, network models, market and network system analysis software, cost-benefit analysis, are or can be made inclusive of other sectors. In this context, inclusive is not purely related to whether sectors networks/users' impact can be represented, but also if all the factors of these sectors are included[26]. The principal biggest risk of this is the incremental step changes in CEI planning introducing single adjacent energy sectors. The Interlink Model[27] by ENTSO-E and ENTSO-G is an example of a first step to harmonise scenarios and coordinate different energy sectors.

Implement a fully staged program of CEI planning research and development needs to fully 2050 decarbonized network. This should include the context for each piece of research and development, how it will integrate with early and later research and development and monitoring of progress. The necessary key deliverables for each research and development project to achieve the next step should be included. The program should be 'live', and regularly updated based on outcomes of earlier stage R&D and/or disruptive technologies.

Accelerate the calls, approvals and longevity of research and development funding. This accelerated program with a complete plan for decarbonization can eliminate annual calls with a series of calls immediately. Also, a more intense timeline for each project, reducing this to 1 – 2 years to deliver with 'go/no-go' milestones by fund owners is required. These milestones would halt projects that are not proceeding with tangible timely results or that are impacted by unforeseen changes in research and development i.e. disruptive technologies.

5.4 Models and Methodologies

Immediate timely development of new CEI Planning Energy Integration system modelling, tools and procedures with a common modular structure. At present software modelling tools, methodologies and processes are restricted at best to single sector-wide analysis. Development of pan-European models for electricity and gas are the most far advanced tools for assessing all interrelated projects at a European level. The ongoing project to comply with EU Reg. 2022/869 European Parliament shall work to create a consistent and integrated model between electricity, natural gas and hydrogen, for a range of transmission infrastructure, storage and electrolysers. However, the project as devised[28] currently falls short of a complete transition from present practices to prepare for future sector integrations, in favour of a more conservative extension to existing practices. Nor does the project consider the needs for inclusion of distribution networks (and their projects of common interest), development for the commercially ready new innovative technologies needed in future (e.g. in the Technopedia), or the dynamic modelling in response to increasingly common network needs and in solution selection. A more ambitious scope would provide an opportunity to develop a structure that will not only integrate these sectors but be open to ultimately integrating other sectors as well. Failure to do so will result in a stranding of the time, effort and resources involved in the project as structural reform will be required with each new sector integration.

Appendix 1 presents some identified state-of-the-art projects that provide building blocks for these developments.

Immediate timely development of new CEI Planning Energy Integration dynamic system modelling, tools and procedures for changing development needs. The increasing frequent dynamic rather than steady state issues (e.g. stability, power quality, temporary over voltage, controller interaction) require CEI planning to include these in the normal course of system-wide studies. Similarly, the underlying practical and financial ability to develop networks with traditional planning standards will require more probabilistic approaches as simpler standards (like N-1) become insufficient to manage complex needs. These developments will be needed not only for long-term planning, but also for operational and market planning.

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[26] For example, only including the charging demand from electric vehicles on electricity network needs is not sufficient. CEI planning must include this, plus the flexibility from charging on system reducing needs of electricity networks or implementing charging points or services acting as a network solution. Equally, maybe electricity from hydrogen fuel celled cars is another solution, requiring a hydrogen solution instead.

[27] Found at: https://www.entsoe.eu/news/2024/05/07/entsog-and-entso-e-publish-their-joint-electricity-and-hydrogen-interlinked-model-2024-progress-report-for-public-consultation/

[28] See: file:///C:/Users/mark.norton/OneDrive%20-%20Smart%20Wires%20Inc/Documents/currENT/currENT/ETIP%20SNET/entsos_ILM_progress_report_240430.pdf

Appendix 1 presents some identified state-of-the-art projects that provide building blocks for these developments.

The interlinking of the telcom/IT sector and heating and cooling sectors. In addition to the immediacy of the integration of electricity and gas networks, these two sectors need to be interlinked to use the waste heat and cooling of the other. Identifying how to select appropriate opportunities (i.e. a use case) and providing models, tools and the procedures to test this pan-European sector-wide is required. At present this is currently conceptual. Currently no single existing national CEI planning for these sectors has been identified, let alone at a European level. A centralised repository through Horizon Europe is in progress, but this must be scoped for the necessary data to support such modelling. For this to be an equitable process across Europe (as required under European law), a European modelling approach is also required.

New principal bodies to be involved in model and methodical development of coordinated energy infrastructure planning. Cross sector modelling requires markedly different skills sets which will require new actors from technology developers, research and development bodies, academia and policy makers (Regulators, Government, Public) in conjunction with System Operators and Asset Owners. Developers will continue to determine and realise usage individual facilities for customers.

5.5 Legislative requirements

Recommendation to apply a least worst regrets approach to ensure that solutions consider the full spectrum of network needs. It is recommended that a least worst regrets approach be applied to candidate solutions. A least worst regrets approach is required to ensure that the timing of these solutions is matched to the potential spectrum of needs that might arise, or that alternative technological solutions that could be more flexible to changing scenarios are considered and recommended if they are more robust. All commercially available innovative technologies must be included for consideration that provide the necessary flexibility (scalable, fast and multi-tasking) and the least worst regrets approach must take these into account for these. For transparency, a fully benchmarked range of technologies and their scoring in this approach should be provided as part of consultation and cost-benefit analyses.

Develop cost-benefit analysis methods for all sectors. Existing Cost Benefit Analysis (CBA) methodologies have been developed for each individual sector. However, when assessing cross-sectoral projects, the CBA will need to include the benefits in each sector from which the project will benefit from.

Furthermore, when the alternative solutions to be considered are in different sectors (i.e. a gas solution compared to an electricity solution), a CBA methodology must be available to ensure sound decision across sectors. Therefore, the current single-sector CBA methodologies need to be developed to into a multi-sector CBA methodology. This methodology development should be in line with the CEI vision roadmap. An example of an immediate area is in the offshore space, where there is a high consistency from industry stakeholders of the need to consider hydrogen pipelines as an alternative to subsea electrical cables to transmit renewable energy to shore. This would involve converting this energy to hydrogen via electrolysers and then piping this gas for use either directly or to be used to fuel electrical generators.

Issuance of guidelines by the European Commission on the application of CEI planning. Adoption of new CEI planning methods is often a slow and uncoordinated process, given the conservative nature of industry players the cost and perceived risk in doing so. European Commission guidelines have in the past been a successful tool, where divergence in practices considered sensitive to change, for example project benefit analysis has needed to be aligned across Europe. A set of guidelines for CEI planning would be able to provide detail to the existing legislative requirements for cross sector planning, stimulating the necessary faster adoption than at present.

Oversight of compliance with legislation for energy infrastructure planning. To ensure the timely adoption of CEI planning to keep track of legislative requirements, a responsible oversight body(s) should be charged or created to review and engage with the responsibility parties where there are shortfalls. In the event that a single body is not charged to do this, then a further recommendation for cross collaboration is established.

Recommendation of 2 yearly reports issued with gap analysis from oversight body. Report from oversight body[s] with resolutions proposals with timelines from bodies responsible for planning the energy networks. The report will also examine the link between CEI planning and the stated objectives for the energy sector at national and European level, in NECPs.

5.6 Fast R&D Knowledge Share

Implement widespread adoption of successful research and development tools and processes. Utilise existing European Commission structures like BRIDGE to create a new research and development WG with a focus on CEI planning. This WG could be tasked with taking the learning from a number of H2020 and Horizon projects that have yet to be integrated and championing it into widespread adoption by the energy industry, notably system operators.

Create a dedicated cross-sector platform on CEI planning best practice tools, models and procedures. We need incentives for knowledge sharing that drive all relevant stakeholders to be aware and apply existing and future R&D learning to close gaps. The responsibility to develop these incentives could rest with a number of stakeholders in Europe but should be placed with a cross-sector body to avoid bias to any one sector.

6. Role of Standardisation

The immediate research & development, and knowledge sharing actions discussed in Chapter 5, are targeted to tackle technology and knowledge gaps already identified. However, to move this work from a conceptual or piloted phase, into widespread implementation is a known and perpetual challenge. One of the keys to universal industry adoption is standardisation. Standardisation when used optimally reduces the need for re-evaluation by the industry, saving cost, but most importantly in the context of CEI planning, time.

A highly innovative environment is foreseen in the next two decades with a vast array of new technologies, and supporting processes and procedures. This represents a quantum shift in the standardisation process as well, with the number of new standards expected[29] to rise extremely quickly at a time when the pace of standard development and amendment is already challenged. In addition to just their number, the natural level of interaction between standards can also be expected to rise making this a compound challenge.

To combat this the EC has released is ‘Standardisation strategy’, with initiatives like the ‘Standarisation booster’. This platform helps beneficiaries of Horizon 2020 and Horizon Europe research fast track standard development. This provides an opportunity to move many of the existing building blocks already in development (notably those identified in Appendix 1) to widespread deployment more rapidly through the assistance of standardisation.

Along with this early work there are standardisation priorities that have been identified and arise from developing CEI planning that are recommended for consideration, notably by the High-Level Forum on Standardization. These are:

Prioritisation and Acceleration of Standardisation timelines. The existing processes by most of the European and International standardisation bodies relevant to CEI planning, for example the International Electrotechnical Commission, European Telecommunications Standards Institute, etc., have been designed to manage the existing flow rate of innovation adoption. The growth rate predicted to deliver CEI planning and wider technology adoption generally will exceed their capability. It is expected that innovation in standard development itself will also be essential. Consideration should be given to enabling standards to be drafted by first adopters based on their experiences, which then can proceed with a less intense approval rather than development process by the standardisation bodies. This would fast track standard delivery, but will require a collaborative effort by industry and the acceptance of this change by the standardisation bodies themselves.

Prioritisation of CEI planning standards. The prerequisite to widespread adoption of new technologies and practices, is being able to create development plans and make investment decisions in a consistent and repeatable method. This needs to be across sectors in line with the Coordinated Energy Infrastructure Planning Roadmap Vision timelines. It is an essential first step. Often standardisation of planning methods, tools and processes is given a low priority, due to concerns of the far-reaching impacts they can have, and therefore are much slower to change. This issue has been discussed elsewhere in this document, along with the reasons why this must change as the risk of not doing so and delaying decarbonization is far greater. Therefore it is recommended that time, effort, creation and regulatory adoption of standardisation should be prioritisation in the near term.

[29] EC Press Release New approach to enable global leadership of EU standards promoting values and a resilient, green and digital Single Market

7. Conclusions

This paper has examined the need and scope of a fit for purpose Coordinated Energy Infrastructure planning approach that will deliver on the policy objectives and legislative requirements for Europe. It considers the requirements, attributes, and challenges to the development of a CEI planning approach and suggests possible ways to address these challenges with new policy/legislation, research and development.

The vision sets out the development risk level of each building block. This risk level is based on either previous development work of mainstream solutions that are/will be applied nationally or Europe-wide, or research and development towards solutions. It was determined that of the building blocks in the near term, many have either not commenced or are going to fall short of their intended scope of work or delivery date.

The paper has considered the reasons and potential solutions to address this, to provide a series of recommended actions as to how the building blocks and the vision as a whole could be completed in a timely manner.

Appendix 1 - Main relevant EU Projects

1.1. Review and solutions

The development of a coordinated energy infrastructure planning process, tools and methodology has long been considered. Whilst much progress has been made to develop one, and to trial some of the tools and procedures needed, there is no complete system either being piloted or in operation today. In fact, the work to include some of the sectors required for full CEI planning has not begun; only early conceptual work has been accomplished so far.

However, many research and development projects have developed elements that are required in the roadmap outlined in this paper's vision of the coordinated energy infrastructure planning pathway. Of the various project materials examined, those that are seen as the most progressive and that provide the best templates to enable the move towards a full CEI planning process are presented below.

A1) Horizon 2020 Project – FLEXIGRID

Objective

Several previous publications from reputable sources[30] have emphasised the need for a flexible and integrated grid network in Europe, highlighting solutions that align closely with those offered and addressed by the FLEXIGRID project.

FLEXIGRID provides a range of solutions that significantly contribute to addressing most of the present gaps identified in infrastructure planning. The solutions use proactive planning approaches to revolutionise the energy sectors instead of the conventional reactive methods of research and innovation activities. The implementation of smart grid technologies by the FLEXIGRID project enable the integration of a wide array of energy sources into the existing infrastructure, among them distributed generation, diverse renewable energy sources, electric vehicles, and thermal storage systems into a single complex existing infrastructure.

This is achieved through the use of advanced sensors, smart meters with mapping capabilities, protections relay to allow a bidirectional flow of energy, energy box, and sophisticated data analytics software modules; the smart grid optimises grid operations, forecasting, congestion management, communications, and another platform such as Fuse.

These holistic solutions facilitate a resilient and efficient energy infrastructure ecosystem. Therefore, the FLEXIGRID project's approach aligns with most publications' recommendations in the research and innovation areas. It provides a promising step forward in bridging the gap and advancing European energy grid integration.

Relevant information and tools

The *Contribution to the Future Network Plan* report from FLEXIGRID provides a comprehensive assessment of numerous research and development projects outlined in the Ten-Year Network Development Plans (TYNDP). These reports also consider initiatives such as the 55th Electricity and Gas Projects of Common Interest (EPC) and EU plans like the 4th Energy Package, designed to foster innovation and advance coordinated energy infrastructure planning. The primary goal of these efforts is to facilitate the seamless integration of variable and decentralised energy resources and energy storage within the electricity and gas networks. By achieving better network integration, these measures significantly enhance decarbonisation strategies, paving the way for a more sustainable and efficient energy system. This enhanced network integration allows for better management of energy supply and demand, reducing wastage and maximising the use of sources.

According to the FLEXIGRID report, there are existing barriers to innovation that, if eliminated, could facilitate the deployment of new knowledge in the field of integrated energy infrastructure, including TYNDP projects. These barriers are related to adopting, transferring, and managing knowledge, which are crucial for driving innovation in the energy sector. The findings of report suggest that effective knowledge management plays a pivotal role in enabling organisations to harness the knowledge and expertise of both their personnel and stakeholders. For TYNDP projects, this means efficiently capturing and disseminating relevant information to ensure better planning and decision-making in deploying integrated energy infrastructure. Effective knowledge

[30] European Commission, European Network of Transmission System Operators for Electricity (ENTSO-E), International Energy Agency (IEA), other energy-related organisations, and other academic journals, industry reports, and research papers

management can spur innovation and control access to critical information, skills, and expertise by fostering collaboration and facilitating cross-functional learning among stakeholders involved in the TYNDP initiatives. Another significant hindrance to deploying new knowledge in the energy industry, including TYNDP projects, is the abuse of patent rights. Some innovators may misuse their patent rights to restrict others from exploring and building upon their innovations, creating a market monopoly. This practice stifles healthy competition and hampers the progress of new ideas and advancements in the energy sector.

For TYNDP projects, it may limit the ability of multiple stakeholders to freely collaborate and share innovative solutions that could improve the coordinated energy infrastructure planning process. Moreover, FLEXIGRID identified a need for more awareness of entities' innovation capacities and sufficient information to avoid delays in the market adoption of innovations and the advancement of technologies used in current and future TYNDP projects for CEI planning. Clear communication and knowledge-sharing among entities involved in TYNDP initiatives can help address these issues and speed up the implementation of innovative solutions. It concludes that, addressing these barriers to innovation, including those related to TYNDP projects, the energy industry can foster a more collaborative and innovative environment, leading to better-integrated energy infrastructure planning and enhanced decarbonisation strategies.

Key areas to be reviewed

Deliverable 2.2 Report scenarios and product design of grid services for local markets
Deliverable 2.3 Local market designs for energy exchange and grid services
Deliverable D3.1 Report on network observability and risk assessment
Deliverable D3.2 Report on grid reconfiguration and fault-initiated islanding

- Findings
    - DSO grid planning with flexibility uses:
        - Congestion management
        - Avoidance of network reinforcement investments
        - Voltage management
    - Grid state estimation and prediction
    - Examination for forecasting techniques
    - Probabilistic Power Flow Method development
    - Network reconfiguration techniques
- Provides new tools and methods for long term network planning network

Building block contribution to the coordinated energy infrastructure planning pathway vision

This work from this project is deemed to make significant contributions[31] to achieving the following building blocks:

Table 3: FLEXIGRID Building block contribution in CEI planning

Building Block	Title/Topic/Brief synopsis
E23.2	Network modelling tool (software) and methodology for European wide steady state and dynamic analysis
E23.3	Cost Benefit Analysis methodology for investment decisions and approval
E23.4	Develop scope of electricity and gas cross sector integration model, tools and methodologies
TR23.1	Improved transport models into network planning models.
TR24.2	Production of a Common European Energy Space for Mobility

[31] to the CEI planning pathway vision in chapter 3

A2) Horizon 2020 Project – FLEXPLAN

Objective

Besides FLEXIGRID, an additional R&I project whose outcomes are quite relevant for the CEI planning process, particularly when looking at the electricity grid, is the Horizon 2020 project FlexPlan. This project focused on developing a novel grid planning methodology and tool to integrate energy storage systems (ESSs) and flexibility resources (e.g., large-scale consumers providing demand-response) into electricity transmission and distribution (T&D) grids. The main objective, in line with the goals and principles of the EC package Clean Energy for all Europeans was to assess whether and to what extent such resources could be considered as a profitable alternative to building additional elements of the grid infrastructure, e.g., power lines or transformers.

Relevant information and tools

The grid planning tool developed by the project introduced innovative features to electricity infrastructure planning, such as integrated T&D planning, comprehensive environmental analysis as well as probabilistic contingency methodologies in lieu of the conventional N-1 criterion. To demonstrate its application in real-case scenarios of different time horizons, the tool was used to analyse six regional cases covering nearly the entire European continent, considering multiple scenarios for three years, i.e. 2030, 2040 and 2050. Based on simulation results, project developments and insights from consortium's partners and external stakeholders, FlexPlan's members drew up guidelines and recommendations for pan-European legislation, policies and strategies, focusing not only on the integration of storage and flexibility resources into electricity grids, but also on TSO-DSO cooperation for integrated planning.

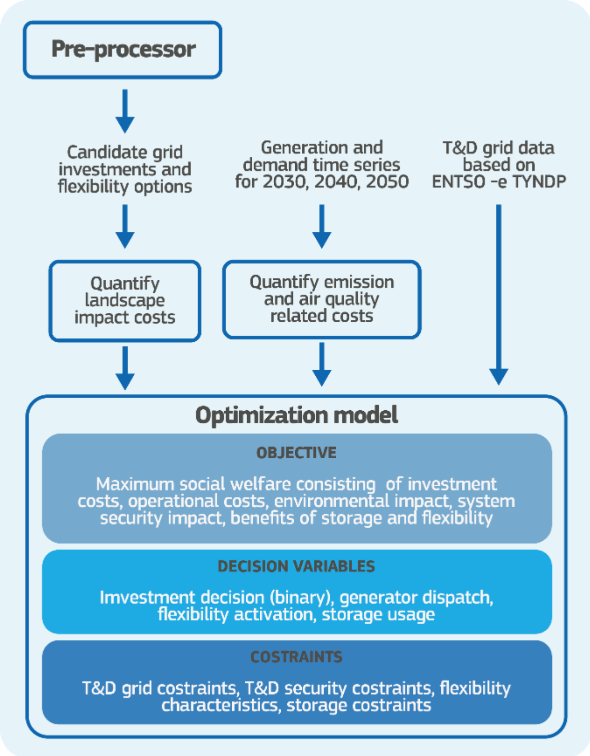

Figure 4: FLEXPLAN Optimisation model

The results of the project emphasised that both TSOs and DSOs should integrate ESSs and flexibility resources into grid planning processes, not only as direct competitors to conventional grid expansion investments, but also as complementary candidates, that, in synergy with new grid's elements, are able to reduce the overall system costs. Moreover, the project highlighted the real need for close cooperation between TSOs and DSOs to define future Network Development Plans (NDPs). As a matter of fact, in some regional cases investments in distribution networks contributed to relieving potential structural congestion in the transmission grid, meaning that individual NDPs of the transmission and distribution systems would have led to an over-investment. However, provided that a fully integrated planning strategy could not be achievable in most cases, both due to computational complexity and data privacy concerns, FlexPlan suggested a T&D decomposition approach, where data exchange is limited to the border of the observability region of TSOs and DSOs. This methodology enables efficient optimisation of overall system costs by integrating T&D electricity infrastructure planning, but, at the same time, it does not compromise internal data privacy policies of each SO, nor computational efforts of the planning process[32].

Furthermore, the *Impact assessment of the results of the FlexPlan project*[33] identified additional technical issues and barriers to integrated infrastructure planning, encountered when applying FlexPlan grid planning methodology, used to evaluate the impact of ESSs and flexibility resources into integrated T&D grid planning. Among the main impediments, the report mentions the mammoth computational effort demanded of the grid planning tool when solving the optimisation problem. In fact, the high complexity of infrastructure models, enhanced by the integration of multiple networks, such as transmission and distribution grids in this case, defies the viability and algorithmic efficiency of simulations. Although the numerous simplifications (e.g., T&D decomposition, Benders' decomposition) contributed to significantly simplifying the problem, the plethora of grid

[32] FlexPlan, Impact assessment of the results of the FlexPlan project, 2023
[33] FlexPlan, Impact assessment of the results of the FlexPlan project, 2023

nodes as well as the presence of elaborated energy installations, such as pumped hydro energy storage (PHES), and battery energy storage systems (BESS) did not achieve the desirable running time for the simulations performed during FlexPlan's project. Yet, the report suggests that a parallelisation of the optimisation using multiple processors, which could not be carried out during the project, would have considerably reduced the execution time.

The lesson learnt from FlexPlan emphasises the need to couple CEI planning with cutting-edge technologies in the field of grid optimisation and computer processing, particularly when incorporating different sectors and infrastructure, such as electricity and gas networks, telecoms, heating & cooling and transport, which, with respect to the case of FlexPlan, would boost even more the complexity of the optimisation problem. To this end, new R&I work is required to exploit synergies between EU's energy and digital agenda, focusing on the use of data and tools for energy system integration and planning, as recommended in the EU action plan for digitalising the energy system[34].

An additional barrier encountered during the FlexPlan project, relevant for the purpose of this paper, concerns the coordination of TSOs and DSOs for the preparation of NDPs. The report *Lessons and recommendations on pan-European level regulation, policies and strategies*[35] highlights the need for the exchange of large data streams between SOs, with the data being protected by internal privacy policies on both ends. Without such a flow of information, cost-efficient and integrated T&D planning would not be achievable, possibly leading in some cases to over-investments in one of the networks. However, there is a lack of legislation defining which and via which means data should be swapped between SOs without compromising its confidentiality. In fact, the current legislation[36] for TSOs of EU members primarily focuses on real-time and structural data exchange between TSOs and DSOs rather than on infrastructure planning information. To tackle this, although the report does not set a standard for the data exchange, it instantiates a model bundling together all relevant information on the grid, focusing exclusively on the border of SOs' observability regions.

Key areas to be reviewed

Deliverable D2.3: Flexibility elements analysis preprocessor simulation tool
Deliverable D3.1: Planning tool software, including GUI

- Findings
    - Coordinated TSO/DSO grid planning
    - Embedded environmental analysis (air quality, carbon footprint, landscape constraints)
    - Simultaneous mid- and long-term planning calculation over three grid years: 2030-2040-2050
    - Full incorporation of CBA criteria into the target function
    - Probabilistic elements (instead of N-1 security criterion)
    - Numerical *ad hoc* decomposition techniques to reduce calculation efforts (Benders, T&D)
- Provides new tools and methods for long term network planning network

Building block contribution in Coordinated energy infrastructure planning pathway vision

The work from this project is deemed to make significant contributions[37] to achieving the following building blocks:

Table 4: FLEXPLAN Building block contribution in CEI planning

Building Block	Title/Topic/Brief synopsis
E23.1	High Fidelity European Integrated Electrical Network Model suitable for steady state and dynamic analysis
E23.2	Network modelling tool (software) and methodology for European wide steady state and dynamic analysis
E23.3	Cost Benefit Analysis methodology for investment decisions and approval
E23.4	Develop scope of electricity and gas cross sector integration model, tools and methodologies
E24.1	Production of a Common European Energy Space for Energy
TR23.1	Improved transport models into network planning models.
TR24.1	Development and adoption of network planning criteria rules
TR24.2	Production of a Common European Energy Space for Mobility

[34] EUR-Lex - 52022SC0341 - EN - EUR-Lex (europa.eu)

[35] FlexPlan, Lessons and recommendations on pan-European level legislation, policies and strategies, 2023

[36] Regulation - 2017/1485 - EN - EUR-Lex (europa.eu)

[37] to the CEI planning pathway vision in chapter 3

TR25.1	Network modelling tool (software) and methodology for European wide steady state and dynamic analysis
TR26.1	Adapt CBA methodology for electricity and gas cross sector to include transport for European and national use

A3) Horizon 2020 Project – FARCROSS

Objective

Develop and introduce advanced software solutions that will increase cross-border capacity and the potential of cross-border grid services. Demonstrate hardware and software technologies and relevant concepts in realistic environments; the FARCROSS project engages TSOs and energy producers.

Relevant information and tools

- Provides new tools and methods for operational, market and network planning.

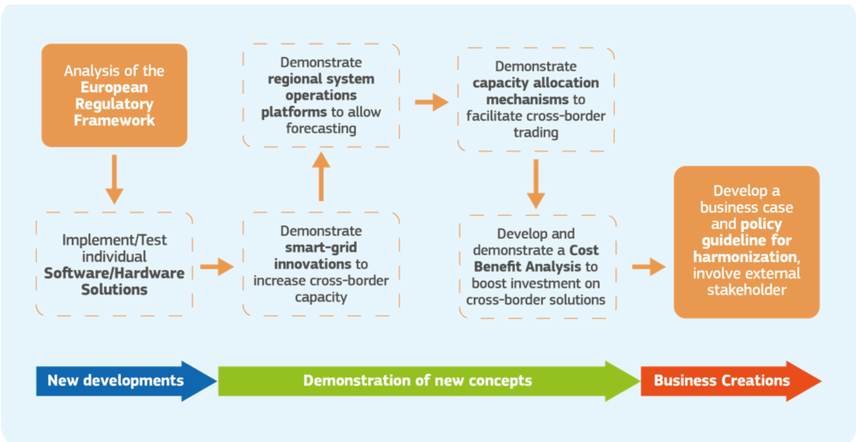

Figure 5: FARCROSS business creation process

Building block contribution in coordinated energy infrastructure planning pathway vision

The work from this project is deemed to make significant contributions[38] to achieving the following building blocks:

Table 5: FARCROSS Building block contribution in CEI planning

Building Block	Title/Topic/Brief synopsis
E23.2	Network modelling tool (software) and methodology for European wide steady state and dynamic analysis
E23.3	Cost Benefit Analysis methodology for investment decisions and approval
E24.1	Production of a Common European Energy Space for Energy

A4) Horizon 2020 Project – TRINITY

Objective

To develop a novel methodology and deliver a multi-modular toolset which will enhance the Southeast European Transmission System Operators (TSOs) and Regional Security Centres (RSCs) business processes related to:

- power system operational security forecasting and monitoring,

[38] to the CEI planning pathway vision in chapter 3

- capacity calculation,
- redispatching cost sharing,
- adequacy assessment,
- emergency and restoration processes and
- automatic frequency regulation.

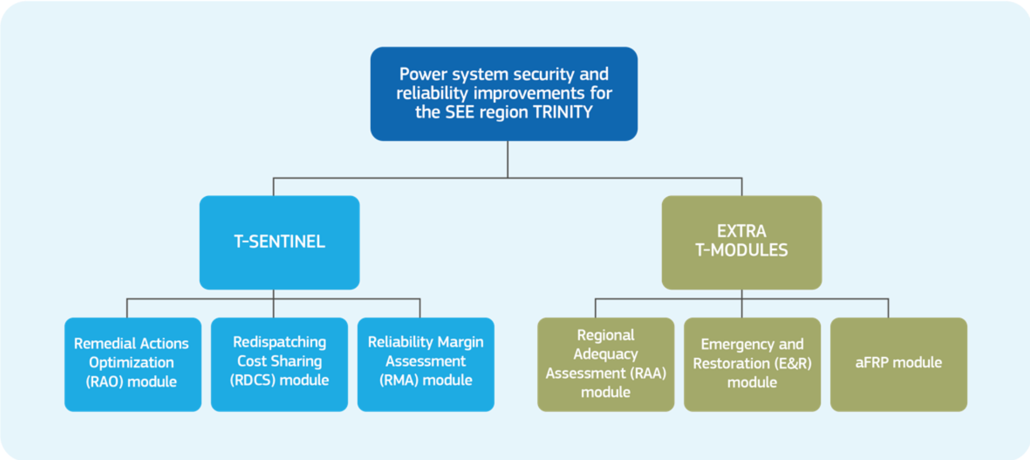

Figure 6: TRINITY methodology

Relevant information and tools

- Provides new tools and methods for long term network planning network
- First thoughts to be developed by team
- Use for electrical sector coupling as state of the art developments
- Need to offer adjustments for other sectors inclusion
-

Building block contribution in coordinated energy infrastructure planning pathway vision

This work from this project is deemed to make significant contributions39 into achieving the following building blocks:

Table 6: TRINITY Building block contribution in CEI planning

Building Block	Title/Topic/Brief synopsis
E23.1	High Fidelity European Integrated Electrical Network Model suitable for steady state and dynamic analysis
E23.2	Network modelling tool (software) and methodology for European wide steady state and dynamic analysis
E23.3	Cost Benefit Analysis methodology for investment decisions and approval
E23.4	Develop scope of electricity and gas cross sector integration model, tools and methodologies
E24.1	Production of a Common European Energy Space for Energy

A5)Horizon 2020 Project – PLATONE

Objective

The PLATform for Operation of distribution NEtworks (PLATONE) project aimed at establishing new approaches to increase the observability of renewable energy resources and of the less predictable loads while

[39] to the CEI planning pathway vision in chapter 3

exploiting their flexibility. It developed advanced management platforms to unlock grid flexibility and to realise an open and non-discriminatory market, linking users, aggregators and operators.

To manage energy transition, DSOs require innovative tools. Volatile renewable energy sources in combination with less predictable consumption patterns call for higher levels of observability and exploitation of flexibility. PLATONE proposed an innovative approach to offer joint data management for both using a blockchain based platform. The platforms were tested in three large pilots in Europe and analysed in cooperation with a large research initiative in Canada.

Relevant information and tools

Platone open-source framework (POF) provided three open-source components:

- Open-source DSO Technical Platform for the deployment of distribution grid services and compatible with DSO existing proprietary and cloud-based platforms.
- Flexibility Market Platform which allows the implementation of a fair flexibility market, involving all the energy stakeholders including the customers.
- Blockchain Access Layer (1) which enables secure energy data sharing and ensures the data ownership and governance.

As part of this it created grid automation hardware and software tools notably:

- A modular distributed Optimal Power Flow (OPF) solving OPF problems for AC, DC, and AC/DC systems.
- Deep-learning open-source Probabilistic Load Forecasting comprising recurrent neural network to predict consumption, PV, and wind time series

Building block contribution in coordinated energy infrastructure planning pathway vision

The work from this project is deemed to make significant contributions40 to achieving the following building blocks:

Table 7: PLATONE Building block contribution in CEI planning

Building Block	Title/Topic/Brief synopsis
E23.1	High Fidelity European Integrated Electrical Network Model suitable for steady state and dynamic analysis
E23.2	Network modelling tool (software) and methodology for European wide steady state and dynamic analysis
E23.3	Cost Benefit Analysis methodology for investment decisions and approval
E24.1	Production of a Common European Energy Space for Energy

A6) CRESYM - MUESSLI

Objective

MUESSLI ("Multi-Energy System Smart-Linking Integration") is CRESYM's workstream covering all works regarding multi-energy, cross-sectorial, R&D issues. It recognises that the emergence of an integrated hydrogen and electricity system will involve, integrate and/or transform all other present energy carriers (e.g. methane) and/or networks (heat, cold, transportation, etc.), at local, regional and global level, in order to be efficient and swiftly implemented. Challenges related to sector coupling and making the "multi-energy system" (MES) are many:

- The coupling may have to encompass a very wide range of sectors from power, hydrogen/methane, heat, cold, but also transportation, etc.

[40] to the CEI planning pathway vision in chapter 3

- Interactions may happen at all stages of the value chain (production, wholesale and retail, distribution, consumption), representing many possible risks (ability to accommodate end-uses with a decarbonated system) and opportunities (reduced investment costs thanks to integrated planning, flexibility provided by sector integration to cope with the integration of variable RES).
- The sector characteristics are diverse, from one European-wide power system to many local heat or water networks.
- The study range spans from investment (optimisation) to operation.
- There are many novel components (industrial electrolysers, H2-reduced steel plants, etc.).
- The energy transition requires flexibility in the implementation, as sector issues and technologies will evolve and constantly new simulation tools will have to be plugged in.
- As a result, state of the art in cross-sector simulation methods will soon be exhaustive: soft-linking (with time and convergence issues, challenging if more than 2 sectors) or hard-linking (with complexity, scalability and upgradability issues). Some “smart-linking” must then be invented.

Relevant information and tools

Its first objectives are as follows:

1. Architecture for a new fully open-source platform to model, optimise and better plan the future multi-energy system and relying, as much as possible, on existing tools and models;
2. Invent the smart-linking method, enabling scalable cross-sectoral simulations, demonstrating it with power/gas/hydrogen for operation simulators and investment scenario assessment (starting with a simplified network modelling);
3. Expand smart-linking to cross-sectorial investment optimisation if appropriate, or at least investigate and highlight key issues in cross-sectorial investments;
4. Expand smart-linking to other sectors, starting with heat;
5. Expand smart-linking to allow for networks detailed modelling and constraints consideration.

+ beyond research works:

6. Develop the flexible and modular opensource platform, populate it with existing opensource tools and
7. Foster a living opensource project and community of users and developers to populate it and enrich it, taking advantage, when time comes, of new mathematical tools, increased computing ability, etc.

Building block contribution in coordinated energy infrastructure planning pathway vision

The work from this project is deemed to make significant contributions41 to achieving the following building blocks:

Table 8: MUESSLI Building block contribution in CEI planning

Building Block	Title/Topic/Brief synopsis
E23.1	High Fidelity European Integrated Electrical Network Model suitable for steady state and dynamic analysis
E23.2	Network modelling tool (software) and methodology for European wide steady state and dynamic analysis
E23.3	Cost Benefit Analysis methodology for investment decisions and approval
E23.4	Develop scope of electricity and gas cross sector integration model, tools and methodologies
E24.1	Production of a Common European Energy Space for Energy
G23.1	High Fidelity European Integrated Gas Network Model suitable for steady state and dynamic analysis
G23.2	Network modelling tool (software) and methodology for European wide steady state and dynamic analysis
G23.3	Cost Benefit Analysis methodology for investment decisions and approval
G24.4	Develop scope of electricity and gas cross sector integration model, tools and methodologies
H23.1	High Fidelity European Integrated H2 gas Network Model suitable for steady state and dynamic analysis
H23.2	Network modelling tool (software) and methodology for European wide steady state and dynamic analysis
H23.3	Cost Benefit Analysis methodology for investment decisions and approval
H24.4	Develop scope of H2 model, tools and methodologies for electricity and gas cross sector integration
EGH24.1	Develop electricity and gas cross sector integration model

[41] to the CEI planning pathway vision in chapter 3

HC23.1	Development of first national report on the potential for district heating and cooling systems to provide balancing and other system services (EU Directive 2018/2001 with RED 3. 2021/0218 amendments).
HC23.2	Heating and cooling technologies models suitable for integrated Electricity, Gas and Transport network analysis
HC24.1	Network modelling tool (software) and methodology for European wide integration
HC24.2	Common European data spaces for Heating and Cooling

A7)CRESYM – COLib

Objective

Appraising the behaviour and reactions of such new items is critical for network operators to simulate and anticipate system operation, and for this, component models are required that are available, reliable, up to date and possibly specifically targeted. However, having a library of components indirectly connected (e.g. to neighbouring, coupled networks, such as electricity or gas grids or across sectors) and future connected ones (latest technology and proprietary manufacturer models) is hugely challenging for individual operators. Researchers also suffer from the lack of all the necessary component models, and are slowed down as a result.

COLib looks to create a complete library of reliable energy system components models easily available for all. It seeks to create a structured standard framework to also ease the integration of new technologies and interoperability of simulation tools.

Relevant information and tools

COLib seeks to develop the technical framework, to make the models and their documentation and assessments available, enabling global overview of the models and the test cases, and models and datasets.

Provide a database of existing components and test cases for the different time simulation cases (steady state / slow / quick / transient dynamic), coming from existing portals and initiatives (e.g. G-PST/pillar 5, IEEE, EPRI, etc.). From this, the existing frameworks can be adapted to support a new cross-sector modelling format suitable for every sector. It will also add new components, identifying a list of missing components providing directions on:

- New technologies (likely to challenge the initial design)
- Existing network components that need improvement
- The completeness of models for a given dynamic type

Prior directions can also be given to:

- Large-scale power system test cases,
- Extreme cases to illustrate specific events or phenomena (loss of synchronism, voltage collapse, converter-driven stability)

Building block contribution in coordinated energy infrastructure planning pathway vision

The work from this project is deemed to make significant contributions42 to achieving the following building blocks:

Table 9: COLib Building block contribution in CEI planning

Building Block	Title/Topic/Brief synopsis
E23.1	High Fidelity European Integrated Electrical Network Model suitable for steady state and dynamic analysis
E23.2	Network modelling tool (software) and methodology for European wide steady state and dynamic analysis
E24.1	Production of a Common European Energy Space for Energy
G23.1	High Fidelity European Integrated Gas Network Model suitable for steady state and dynamic analysis
G23.2	Network modelling tool (software) and methodology for European wide steady state and dynamic analysis
G24.4	Develop scope of electricity and gas cross sector integration model, tools and methodologies

[42] to the CEI planning pathway vision in chapter 3

H23.1	High Fidelity European Integrated H2 gas Network Model suitable for steady state and dynamic analysis
H23.2	Network modelling tool (software) and methodology for European wide steady state and dynamic analysis
H24.4	Develop scope of H2 model, tools and methodologies for electricity and gas cross sector integration
TR23.1	Improved transport models into network planning models.
TR24.2	Production of a Common European Energy Space for Mobility
TR25.1	Network modelling tool (software) and methodology for European wide steady state and dynamic analysis
HC23.2	Heating and cooling technologies models suitable for integrated Electricity, Gas and Transport network analysis
HC24.1	Network modelling tool (software) and methodology for European wide integration
HC24.2	Common European data spaces for Heating and Cooling
HCIT27.1	Develop Heating and Cooling, and IT integration model

A8)SEAI Developing Real-Time Contingency Analysis and Network Optimisation Control Centre Tools and Capabilities

Objective

The main objective of the project was to develop and validate open-source software tools that will enable TSOs to capitalise on network flexibility introduced with the use of new technologies e.g. modular power flow control (PFC) technology. The project was a joint project between the Irish TSOs EirGrid and SONI, the research and development consortium Electric Power Research Institute (EPRI) and led by a manufacturer Smart Wires.

To maximise the use of new technology, new tools are required to support real-time operation and day-ahead operational planning. Such control and scheduling capabilities did not exist in any control room in the world and the open-source outcomes of the project aimed to bridge that gap.

Relevant information and tools

The project produced a set of control operational tools for market and operational use that could be used to rapidly develop new operating points on the network for use in the control environment. The tools developed were designed to inclusive of other technologies and are currently being developed to include additional technologies and services.

Building block contribution in coordinated energy infrastructure planning pathway vision

This work from this project is deemed to make significant contributions43 into achieving the following building blocks:

Table 10 SEAI Building block contribution in CEI planning

Building Block	Title/Topic/Brief synopsis
E23.1	High Fidelity European Integrated Electrical Network Model suitable for steady state and dynamic analysis
E23.2	Network modelling tool (software) and methodology for European wide steady state and dynamic analysis
E23.3	Cost Benefit Analysis methodology for investment decisions and approval

A9)ENTSO-E / EU-DSO ENTITY DIGITAL TWIN

Objective

Development of a digital twin under the indicators and mandates of the GRID ACTION PLAN[44], is to be a virtual model of the European electricity grid throughout the energy system as a whole. It will ensure the development of innovative solutions and coordination of investment in five areas:

- Observability and controllability;

[43] to the CEI planning pathway vision in chapter 3
[44] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2023%3A757%3AFIN&qid=1701167355682

- Efficient infrastructure and network planning;
- Operations and simulations for a more resilient grid;
- Active system management and forecasting to support flexibility and demand response;
- Data exchange for coordinated planning and operation between TSOs and DSOs.

The implementation plan deliverables, identified fixed by DESAP, a dedicated Task Force made by many experts from ENTSO-E and EU-DSO ENTITY, are a set of prioritised challenges, a set of Smart Grid Indicators and a Roadmap to reach them.

Relevant information and tools

DESAP's scope is about all challenges common to TSOs and DSOs or having reciprocal implications, requiring mutual solutions of digital type.

The virtual model through continuous investment and innovation efforts for years to come will ensure the development of innovative solutions and coordination investment of the five areas.

The project will provide guidance and support for network operators on sustainable and cost-effective smart investments, in smartening the grid for enhanced capacity and flexibility, plus supporting consumers to be empowered to take part in energy transition.

Building block contribution in coordinated energy infrastructure planning pathway vision

The work from this project is deemed to make significant contributions45 to achieving the following building blocks:

Table 11 ENTSO-E / EU-DSO ENTITY DIGITAL TWIN building block contributions

Building Block	Title/Topic/Brief synopsis
E23.1	High Fidelity European Integrated Electrical Network Model suitable for steady state and dynamic analysis
E23.2	Network modelling tool (software) and methodology for European wide steady state and dynamic analysis
E23.3	Cost Benefit Analysis methodology for investment decisions and approval
E23.4	Develop scope of electricity and gas cross sector integration model, tools and methodologies
E24.1	Production of a Common European Energy Space for Energy
G23.1	High Fidelity European Integrated Gas Network Model suitable for steady state and dynamic analysis
G23.2	Network modelling tool (software) and methodology for European wide steady state and dynamic analysis
G23.3	Cost Benefit Analysis methodology for investment decisions and approval
G24.4	Develop scope of electricity and gas cross sector integration model, tools and methodologies
H23.1	High Fidelity European Integrated H2 gas Network Model suitable for steady state and dynamic analysis
H23.2	Network modelling tool (software) and methodology for European wide steady state and dynamic analysis
H23.3	Cost Benefit Analysis methodology for investment decisions and approval
H24.4	Develop scope of H2 model, tools and methodologies for electricity and gas cross sector integration
EGH24.1	Develop electricity and gas cross sector integration model
EGH24.2	Produce first (pilot) network model and methodology for electricity and gas cross sector European and national use
EGH24.3	Produce first (pilot) CBA methodology for electricity and gas cross sector European and national use
EGH25.1	European adoption of piloted model and methodology in Europe
EGH25.2	Achieve national adoption of piloted model and methodology in member states

[45] to the CEI planning pathway vision in chapter 3

Appendix 2 – Detailed Gap Analysis

Steps in Vision for Coordinated planning to track with policy objectives				
	Current State	**Future State (Forced and/or chosen)**	**GAP**	**Actions to Close GAP**
What is the issue	No coordinated vision for the steps and sequence for cross-sector coupling of CEI planning timing for inclusion. Several pieces of recent European legislation (EMD, RED, EED) ask for coordination regarding network development and investment decisions without further clarification on how to achieve it.	A transparent and industry-wide accepted series of steps to achieve energy infrastructure planning with clear achievable logical progression that is being implemented in a timely manner. The previous proposal should take into account future methodologies containing guiding criteria on how to assess the capability of the different flexibility sources to cover the future needs.	1. Steps in the vision 2. Clear logical explanation of each step, the need and measure of success 3. Clear division of responsibilities for each step, notably for transport and telecoms/IT 4. Support from stakeholders to the vision 5. Establish a connection with new the regulatory requirements	1. Include in report expected vision steps 2. Provide clear logical explanation of each step, the need and potential measure of success 3. Provide clear division of responsibilities for each step, notably for transport and telecoms
Where do these occur and manifest themselves	Current integration of energy planning is centred around only gas and electricity network and is being mapped onto existing processes.	Integrate planning maintains gas and electricity focus but includes other sectors. Requires new processes to revolutionise scenario planning, network modelling and solution identification. Added interactions in other sectors, the need to plan for all future scenarios and develop least worst regrets solution with supplemental nearer term reinforcements is key to managing the dynamic nature of sector planning in new paradigm with so many independent rapidly changing and interacting sectors in decarbonization.	1. Collaborative working on all sectors integration in line with vision steps and with advanced planning for later steps 2. If required steps and timelines being mandated by EU for European scale Coordinated Energy Infrastructure Planning and national Govt./regulators for national processes 3. Additional responsible bodies identified for telecoms/IT and transport sectors 4. Development of advanced whole-system based models and tools for co-optimisation of operation and planning of future low carbon multi-energy systems (from ETIP SNET Roadmap 2022-2031)	1. Include in report expected vision steps 2. Make recommendations for timing for advancing planning for later steps 2. Make recommendation on trigger for required steps and timelines to be mandated by EU for European scale CEI planning and national Govt./regulators for national processes 3. Identify candidate additional responsible bodies identified for telecoms/IT and transport sectors

Steps in Vision for Coordinated planning to track with policy objectives				
	Current State	**Future State (Forced and/or chosen)**	**GAP**	**Actions to Close GAP**
When do we identify these	The need to integrate energy planning is in legislation, and widely accepted as necessary. At present only integration of electricity and gas has explicit requirements placed for: *By 24 January 2024, and as part of each ten-year network development plan thereafter, the ENTSO for Electricity, with the involvement of the relevant TSOs, the national regulatory authorities, the Member States and the Commission, and in line with the non-binding agreement referred to in paragraph 1 of this Article, shall develop and publish, as a separate report which is part of the Union-wide ten-year network development plan, high-level strategic integrated offshore network development plans for each sea basin, in line with the priority offshore grid corridors referred to in Annexe I, taking into account environmental protection and other uses of the sea. - EU Legislation 2022/869* By 24 June 2025, following an extensive consultation process of stakeholders referred to in paragraph 2, first subparagraph, the ENTSO for Electricity and the ENTSO for Gas shall jointly submit to the Commission and the Agency a consistent and progressively integrated model that will provide consistency between single sector methodologies based on common assumptions including electricity, gas and hydrogen transmission infrastructure as well as storage facilities, liquefied natural gas and electrolysers, covering the energy infrastructure priority corridors and areas set out in Annexe I drawn up in line with the principles laid down in Annexe V. - EU Legislation 2022/869 Q1 2025 Commission to propose guiding principles identifying conditions under which anticipatory investments in grid projects should be granted (EU Action Plan on Grids)	Steps in vision are needed to be timed to maintain progression to decarbonisation and uptake of technological disruptors.	1. Collated timelines and objectives of all sectors and understanding of expected interactions with other sectors	1. Recommended provisional timelines and objectives for all sectors 2. Recommended R&D activity to investigate with CBA timelines for other sectors and steps to include these

Steps in Vision for Coordinated planning to track with policy objectives				
	Current State	Future State (Forced and/or chosen)	GAP	Actions to Close GAP
Who is responsible	Regulators, policy makers and developers act to mandate change. Transmission electricity and gas, system operators and asset owners are the principal bodies responsible for integration.	Regulators, policy makers and developers act to mandate change. All sectors, network system operators and asset owners for the network will be responsible for delivering integration and sharing necessary salient information to enable this.	1. Identification of and mandating of network system operators and asset owners for other non-gas and electric sectors	1. Recommendation of network system operators and asset owners' bodies for other non-gas and electric sectors
How is it managed and is it effective	Development of CEI planning is being driven by policy makers through legislation, instructing system operators and asset owners to build a process, models and tools. The movement is too slow and does not include all sectors rather those that are most acute	system operators and asset owners' recognition of need drives new processes, models and tools, towards a defined vision. Necessary regulatory support for resources and oversight. Development of CEI planning instruction being widened to all sectors by policy makers through legislation if advised as necessary by regulators.	1. Recognition of the necessity of the rapid adoption of an CEI planning process inclusive and for all sectors	1. R&D research into the needs and benefits of all sectors Coordinated energy infrastructure planning, including a CBA 2. Proposed legislative support mechanisms and mandates

Identify Disruptive technologies				
	Current State	Future State (Forced and/or chosen)	GAP	Actions to Close GAP
What is the issue	Disruptive technologies create both challenges and opportunities. These technologies change both the predicted needs on a network and/or also the cost-benefit analysis of solutions that have been identified. A low number of disruptive technologies have been making major impacts e.g. wind and more recently solar renewable energy. New technologies and digitalisation can also disrupt and improve the way system operations, operational planning and grid investments are being done, but this has, to a limited extent, been achieved.	Far greater number of disruptive technologies will be employed and are expected to impact sectors dramatically e.g. new transport and network battery technology, Move to H2 in transport (in particular heavy goods), generation and heating, light rather than silicon processing, AI technologies, Internet of Things (IoT), offshore generation, etc. However, technologies that enhance the use of grids, optimisation and integration across sectors has improved efficiency and made the energy transition possible.	1. Full range of disruptive technologies are not identified or known. 2. Current energy system planning is based on known and limited technologies.	1. Report to identify as many disruptive technologies as possible as a starting point. (see chapter 2.6) 2. Recommendation for a single source of truth and body responsible for developing this list from there.
Where do these occur and manifest themselves	Disruptive technologies occur in all energy sectors and in all parts of the infrastructure, but are segregated into their sectors	Disruptive technologies occur in all energy sectors and in all parts of the infrastructure, but will have increasingly higher impact across all sectors.	1. Adjacent cross sectorial high impact disruptive technologies are not included in sector energy planning	1. Make recommendation that future sector planning processes be updated to include cross sectorial models and plans
When do we identify these	They are identified and included as they are added to the network by sectorial developers and/or are identified as fit for use by sectorial asset owners and system operators	Identification and inclusion to the network planning **will be required far in advance (typically years) by cross-sectorial** asset owners and system operators before developer applications for efficient and timely	1. Disruptive technologies need to be included in energy planning much (many years) in advance of their occurrence on the network so that plans can be adaptive	1. Make recommendation that future sector planning processes be updated to identify and include all (existing and new) disruptive

Identify Disruptive technologies				
	Current State	**Future State (Forced and/or chosen)**	**GAP**	**Actions to Close GAP**
		developments to be ensured.	to these changes (typical new developments for transmission are 12 years or longer [IEA report] require an energy planning process of at least that advanced time period)	technologies in cross-sectorial models and plans, before first application of a new disruptive technology 2. Include in CEI planning roadmap this recommendation and timing (immediate)
Who is responsible	System operators and asset owners are the principal bodies responsible for the network and developers of usage facilities for customers. Regulators, policy makers and developers act as the main secondary bodies responsible.	Technology developers and policy makers (regulators, government, public) in tandem with system operators and asset owners will be the principal bodies responsible for the network and system. Developers will continue to determine usage in individual facilities for customers.	1. New principal bodies need to be brought into and involved in sectorial energy planning 2. New energy planning process must not just consult, but actively involve the principal bodies holistically, as each will be dependent on the other to develop and manage the introduction of disruptive technologies	1. Make recommendation of new principal bodies to be involved in sectorial planning 2. Make recommendation on how the process might work between these new principal bodies 3. Include in energy CEI planning roadmap these recommendations and timing (immediate)
How is it managed and is it effective	When disruptive technology is added to the energy system plans are revisited and changes made. These can be extensive, requiring full reworking of network plans for that sector. Currently adjacent sector disruptive technologies are not effectively tracked with no automatic methodology for cross-sector identification or sharing between sectors.	An understanding of the impact of disruptive technologies will need to be the core of energy system plans in advance of their proposal to the sectorial networks. Sectorial network plans will need to be flexible for the uptake or not of any or all of these disruptive technologies, but also across sectors. Therefore, a single long-term future will cease to exist with these uncertainties and along with that a single list of fixed-scope projects that comprise the sectorial network plan. Adjacent sector disruptive technologies will need to be effectively tracked with automatic methodologies for cross-sector identification or sharing between sectors	1. Plans will need to add each and every disruptive technology across all sectors into the scenarios that the sector networks plans are using to develop network needs and solutions. 2. All scenarios will need to be used to develop a least regrets sector network plan, both for individual and collective projects. It will also need to identify a range of supplemental technologies and projects that can be implemented as uncertainty drops (as we move to future years and uncertainty reduces). Technologies/Projects must be implementable within the time limits imposed. 3. Technological/projects	1. Make recommendation that future sector planning processes be updated to identify and include all (existing and new) disruptive technologies in cross-sectorial models and plans, before first application of a new disruptive technology 2. Make recommendation on new scenarios to include all disruptive technologies to be included at the time they are envisaged to become disruptive. 3. Make recommendation on how process can change to include new scenarios and be achievable with constraints of an energy planning process, using known tools and methods, or where further

Identify Disruptive technologies				
	Current State	Future State (Forced and/or chosen)	GAP	Actions to Close GAP
			solutions from any sector should be available for needs in one sector. This requires the ability to 'call for' solutions in other sectors, system operators, asset owners. In principle one sector asset operator/owner must be able to apply to a developer of a solution project in another sector to their own.	R&D is required and when. This should include cross-sectorial tools and processes. 4. Include in Coordinated energy planning roadmap these recommendations and timing (immediate)

Stranded R&D pathways				
	Current State	Future State (Forced and/or chosen)	GAP	Actions to Close GAP
What is the issue	Promising R&D pathways are being pursued that will ultimately become stranded	R&D will be stranded, time and resources will be lost	1. R&D process does not consider all future energy sector scenarios and therefore it does not know if or when stranding may occur.	1. Recommendation that R&D topics should have a centralised review date, where a continuance based on likely application is formally made in a transparent process
Where do these occur and manifest themselves	Industry-backed new technologies and processes are based on known existing and future issues.	R&D is based on holistic future energy system needs, with timely development of new R&D to be implemented to address needs as they arise	1. Adjacent cross-sectorial high impact disruptive technologies are not included in sector energy planning and formation of new R&D programmes	1. Make recommendation that future sector planning processes be updated to include cross sectorial models and plans, acting as a foundation for R&D funding programs
When do we identify these	Typically, each R&D topic and project is defined after R&D development and fund formation. Funds focus on identified needs, which are generally near term (c. max. 10 years) and incremental of existing networks and users.	Selection of R&D needs to 2050 decarbonised network and its design. These R&D needs are worked back to the year that the delivery of this R&D work in the energy system is required to be timely in addressing system needs. R&D calls and funding programmes should be commenced in line with these timelines. Any programmes which do not deliver R&D solutions on time should be stopped as counterproductive and wasteful.	1.Need to move from 10 yearly R&D programme to assess full 2050 decarbonisation needs, with tracked back delivery timelines for R&D. 2. R&D programmes need to consider R&D for adjacent sectors needs/issues that may be resolved effectively (or more effectively) in their sector, and not just their own sectors' R&D needs	1. Make recommendation that future sector planning processes be updated to identify and include all (existing and new) disruptive technologies in cross sectorial models and plans, before first application of a new disruptive technology. 2. Make recommendation that the R&D programmes have a full 2050

Stranded R&D pathways				
	Current State	**Future State (Forced and/or chosen)**	**GAP**	**Actions to Close GAP**
				decarbonisation cross sectorial needs (that may be resolved effectively or more effectively in their sector) assessed now, with tracked back delivery timelines for R&D. 3. R&D programmes need to consider R&D for adjacent sectors needs/issues, and not just their own sectors' R&D needs 4. Include in CEI planning roadmap this recommendation and timing (immediate)
Who is responsible	Fund managers, often EU, national governments, regulators, asset owners and system operators	Fund managers, often EU, national governments, regulators, asset owners and system operators	No change	No change
How is it managed and is it effective	Development of R&D funds are slow to mature, presenting a risk of perceived worthy R&D being superseded by real life developments. Disruptive technologies are a catalyst and present a high risk of stranding but are not included into funding development balance and checks.	Development of R&D funds that mature faster, based on longer-term energy network needs accounting for disruptive technologies at the outset. R&D funding stitched into updates of the network plan with regular validity checks on R&D providing balance and checks. *Note: R&D works should have an expectation of % of the programme to become stranded. At the outset R&D will account for uncertainty in the future of disruptive influences to the most likely long term network needs, therefore it is essential that come R&D is developed for the less probable future needs in case they arise but are rapidly discontinued when it becomes certain as we move forward that they will not be needed.*	1. Change the time horizons of the R&D plans to considering 2050 decarbonisation needs, with tracked delivery timelines 2. Include regular validity checks on timelines with each update of the longer-term scenarios and system needs assessments	1. Make recommendation to change the time horizons of the R&D plans to considering 2050 decarbonization needs, with tracked delivery timelines 2. Make recommendation to include regular validity checks on timelines with each update of the longer-term scenarios and system needs assessments

Necessary methods and tools for modelling, operation and project selection from need to R&D projects				
	Current State	**Future State (Forced and/or chosen)**	**GAP**	**Actions to Close GAP**
What is the issue	Current state of the art energy integration system modelling for pan-European project selection is found in the ENTSO-E and ENTSO-G 2022 methodologies and also proposed development in the 2024 ToR. National development plans are used for internal country developments and in some instances cross border connections, but are not designed for Europe-wide use of assessment. Both the ENTSO-E and ENTSO-G models use the same scenario database, but do not directly access each other's projects. These models do not assess other sectors (telecoms or transport). There are no unified transport assessment tools, with individual transport methods, rail, road, tram, bus, taxi, ferry and other types all individually modelled and developed. Electrification and move to H2 of these transports mean that cross sectorial impact is growing but not able to be incorporated with either gas or electricity network planning. CEI planning is not currently capable of modelling or taking into account the growth of gas and electricity in transport, and the new issues that arise like movement of these devices (cars and buses) on a daily basis, changes in patterns of energy usage, new technical issues (e.g. dynamic responses, or energy network stability). It is also not capable of predicting or modelling telecoms driven dynamic demand changes, like global or regional load shifting, N-1 data demand contingency responses, new patterns in consumption impact on energy usage. Existing tools and methods only focus on conventional widespread technologies and as new methodologies are needed; they are developed with these in mind.	Energy integration system modelling, tools and operation are able to assess all sectors (gas, electric, telecoms and transport). A unified transport and telecommunication assessment tool is available allowing the responses of these sectors to long-term and short-term operational impacts e.g. daily commute or data use, loss of regional infrastructure and new development. The impact (positive or negative) of a new development on all sectors is needed to enable a true energy infrastructure cost benefit analysis. CEI planning modelling taking into account the growth of gas and electricity in transport is available. Issues that arise in the operation of the energy system on a short to long term basis have the necessary capability and models of new technologies are available for modelling in each sector. These include predicting telecoms driven dynamic demand changes (global or regional load shifting) N-1 data demand contingency responses, new patterns in consumption impact on energy usage.	1. New modelling tools that can model across sectors 2. Models for new technologies 3. Methods for predicting electricity, gas, transport and telecoms needs in both the gas and electricity sectors 4. Methods for assessing the benefits of other sectors e.g. telecom load shifting on electricity or gas networks	1. Assess current EU Horizon projects and recommended new R&D work for tools that are outstanding

Necessary methods and tools for modelling, operation and project selection from need to R&D projects				
	Current State	**Future State (Forced and/or chosen)**	**GAP**	**Actions to Close GAP**
Where do these occur and manifest themselves	Models and methodologies are used in all energy sectors and in all infrastructure but are segregated into their sectors or sub-sectors. Models and methods are developed as and when new technologies or services are developed ad hoc.	Models and methodologies for all technologies are used in all energy sectors and in all infrastructure. Models and methods are developed for both disruptive and new solutioning technologies, as well as service providers. Prediction tools for capability and response for each and all of these assets and service types suitable for both market and network modelling.	1. Identification of new technologies and services without modelling capability in energy (all) sector planning tools and methods out to full decarbonisation (2050) 2. Identification of cross-sector latent capabilities/responses that can be supportive of other sectors and development of methodologies for assessment in each sector.	1. Assess current EU Horizon projects and recommended new R&D work for tools that are outstanding 2. Include in Coordinated energy planning roadmap this recommendation and timing (immediate).
When do we identify these	Modelling needs and methodologies are identified and developed as they are added to the network by sectorial developers and/or are identified as fit for use by sectorial asset owners and system operators.	Identification and inclusion of new models, technologies and methodologies to the network planning **will be required far in advance (typically years) by cross-sectorial** asset owners and system operators before developer applications in order for efficient and timely developments to be ensured.	1. Models and methodologies are needed to integrate energy infrastructure into energy planning (many years) in advance of their occurrence on the network. Plans need to be adaptive to these changes (typical new developments at transmission are 12 years or longer [IEA report] require an energy planning process of at least that advanced time period).	1. Make immediate recommendation that models and methodologies not available now in coordinated energy planning in all sectors is included in R&D calls (Horizon Europe, etc.) for all (existing and new) technologies 2. Identify in report known work that has been done in this regard in Horizon Europe projects but not in common use that is available and can be used by industry 2. Include in Coordinated energy planning roadmap this recommendation and timing (immediate).
Who is responsible	System operators and asset owners are the principle bodies responsible for the network and developers of usage facilities for customers. Regulators, policy makers and developers act as the main secondary bodies responsible.	Technology developers, R&D bodies, academia and policy makers (regulators, government, public) in tandem with system operators and asset owners will be the principle responsible bodies for the network and system. Developers will continue to determine usage in individual facilities for customers.	1. New principal bodies need to be brought into and involved in sectorial energy planning 2. New energy planning process must not just consult, but actively involve the principal bodies holistically, as each will be dependent on the other to develop and manage the	1. Make recommendation of new principal bodies to be involved in model and methodical development of CEI planning 2. Make recommendation on how the process might work between these new principal bodies 3. Include in coordinated energy

Necessary methods and tools for modelling, operation and project selection from need to R&D projects				
	Current State	Future State (Forced and/or chosen)	GAP	Actions to Close GAP
			introduction of disruptive technologies.	planning roadmap these recommendations and timing (immediate)
How is it managed and is it effective	System operators and asset owners will make adjustments to their models and methodologies as and when new technologies or projects arise. Planning standards are reviewed from time-to-time c.10 years +, and at this time consideration will be given if new standards are required to deal with new technologies or phenomena that are on the grid. The current approach is typically reactive with only changes being made when the existing methodologies fail, or new technology needs to be modelled for those methodologies (operational, market, planning) to be applied. Currently adjacent sector disruptive technologies or changes in methodology where known are not effectively tracked with no automatic methodology for cross-sector identification or sharing between sectors.	Given the radical and widespread changes in sectors like decarbonisation, electrification and H2 adoption occurring on the energy infrastructure in all sectors, network system operators and asset owners will need to prepare for these changes much more in advance (many years). This will be necessary to ensure the right solutions are adopted, that they are flexible and comprehensive and to ensure that new unexpected and unforeseen issues do not arise. The need to make much more forward-facing decisions on solutions and supplementing this with additional reinforcements will make the planning process more intensive and complex. Observability of other sectors' needs, developments and solution choices will be crucial for efficient and cost-effective solutions in any sector. Models and methodologies will be key to doing this. Moves from traditional planning standards to more probabilistic approaches will become necessary as simpler standards (like N-1) become insufficient to manage complex needs. EMT and dynamic studies will become commonplace and methods/models to enable this.	1. List of new technologies and model types for 2050 requiring models/methodology 2. Models/methods for new technologies years in advance of widespread installation suitable for use by and for all sectors 3. Lack of roadmap for models/methods development and sector integration priority	1. Include in the report a list of known new technologies and model types for 2050 requiring models/methodology 2. Recommend that an updated list of new technologies and models that are key to a sector is provided by system operators/asset owners and shared with their counterparts in other sectors 3. Report to include roadmap for models/methods development and sector integration priority 4. Make recommendation on how process can change to include new scenarios and be achievable with constraints of an energy planning process, using known tools and methods, or where further R&D is required and when. This should include cross sectorial tools and processes 5. Include in Coordinated energy planning roadmap these recommendations and timing (immediate).

Best Practice fulfillment of legislation requirements				
	Current State	Future State (Forced and/or chosen)	GAP	Actions to Close GAP
What is the issue	Existing legislations, EU Legislation 2022/869, EU Legislation 2019/944 and EU Legislation 2019/943 have requirements that are not being met with conventional energy infrastructure planning. Directive (EU) 2023/1791 (Energy Efficiency), Directive (EU) 2023/2413 (Renewables) also require coordination on network development and investment decisions.	Existing legislations, EU Legislation 2022/869, EU Legislation 2019/944 and EU Legislation 2019/943 have requirements that are being met with a revised energy infrastructure planning methodology and also fulfillment of other related legislation.	1. Current energy infrastructure planning methodologies	1. Recommendation on the necessity to change energy infrastructure planning methodology to comply with legislation.
Where do these occur and manifest themselves	A number of legislative requirements are not currently being fully implemented: (EU) Legislation 2022/869 *(36) The planning and implementation of Union projects of common interest in the areas of energy, transport and telecommunication infrastructure should be coordinated to generate synergies where it is feasible from an overall economic, technical, environmental, climate or spatial planning point of view and with due regard to the relevant safety aspects. Thus, during the planning of the various European networks, it should be possible to give preference to integrating transport, communication and energy networks in order to ensure that as little land as possible is taken up. A common vision of the networks is necessary for energy system integration in the various sectors, whilst ensuring, where possible, that existing or disused routes are reused, in order to reduce to a minimum any negative social, economic, environmental, climate and financial impact.* ANNEX V ENERGY SYSTEM-WIDE COST-BENEFIT ANALYSIS The methodologies for cost-benefit analyses developed by the ENTSO for Electricity and the ENTSO for Gas shall be consistent with each other, taking into account sectorial specificities. The methodologies for a harmonised and transparent energy system-wide cost-benefit analysis for projects on the Union list shall be uniform for all infrastructure categories, unless specific divergences are justified.	Full implementation of the legislative requirements to ensure the timely, efficient, effective and optimised cross-sectorial development of the energy, transport and telecommunication infrastructure as required and desired by the European member states.	1. Ability in process and tools to assess all sectors simultaneously 2. Process for proposing evaluating or accepting cross-sectorial candidate projects or solutions, or multitasking technologies 3. Inability to provide solutions that rely on cross-sectorial elements of a project to offer a solution 3. Cost benefit analysis limited to only one sector at a time 4. Lack of homogeneity and criteria in different jurisdictions and sectors.	1. Present and offer process and tools to assess all sectors simultaneously 2. Present and offer process and tools that can consider adjacent cross-sectorial projects and/or solutions with cross-sectorial scope of works, and multitasking technologies 2. Where these do not exist, recommend R&D funding in these areas 3. Develop cost benefit analysis method for all sectors.

Best Practice fulfillment of legislation requirements				
	Current State	Future State (Forced and/or chosen)	GAP	Actions to Close GAP
	They shall address costs in the broader sense, including externalities, in view of the Union's 2030 targets for energy and climate and its 2050 climate neutrality objective and shall comply with the following principles: ... (3) they shall establish the analysis to be carried out, based on the relevant multi-sectorial input dataset by determining the impact with and without each project and shall include the relevant interdependencies with other projects; (4) they shall give guidance for the development and use of energy network and market modelling necessary for the cost-benefit analysis. The modelling shall allow for a full assessment of economic benefits, including market integration, security of supply and competition, as well as lifting energy isolation, social and environmental and climate impacts, including the cross-sectorial impacts. The methodology shall be fully transparent including details on why, what and how each of the benefits and costs are calculated; *The planning and implementation of Union projects of common interest in the areas of energy, transport and telecommunication infrastructure should be coordinated to generate synergies where it is feasible from an overall economic, technical, environmental, climate or spatial planning point of view and with due regard to the relevant safety aspects* *A common vision of the networks is necessary for energy system integration in the various sectors…* *Sets requirements for TYNDP's* *By 24 June 2025, following an extensive consultation process of stakeholders referred to in paragraph 2, first subparagraph, the ENTSO for Electricity and the ENTSO for Gas shall jointly submit … a consistent and progressively integrated model that will provide consistency between single sector methodologies based on common assumptions including electricity,*			

Best Practice fulfillment of legislation requirements				
	Current State	Future State (Forced and/or chosen)	GAP	Actions to Close GAP
	gas and hydrogen transmission infrastructure as well as storage facilities, liquefied natural gas and electrolysers …shall cover at least the relevant sectors' interlinkages at all stages of infrastructure planning, specifically scenarios, technologies and spatial resolution, infrastructure gaps identification. (EU) Legislation 2019/944 DSO Development plan The network development plan shall also include the use of demand response, energy efficiency, energy storage facilities or other resources that the distribution system operator is to use as an alternative to system expansion. (EU) Legislation 2019/943, TSO Development plan including the cooperation of transmission system operators at European and regional level Directive (EU) 2023/1791 (Energy Efficiency) The energy efficiency first principle should in particular be applied in the context of scenario building for energy infrastructure expansion where demand-side solutions could be considered as viable alternatives and need to be properly assessed, and should become an intrinsic part of the assessment of network planning projects. Directive (EU) 2023/2413 (Renewables) Member States shall ensure that electricity transmission and distribution system operators take due account of the results of the assessment required under the first subparagraph in grid planning, grid investment and infrastructure development in their respective territories.			
When do we identify these	Requirements are for the implementation as part of the two-yearly updates of the ten-year network development plans and the DNDP (DSO Network Development Plans) and in coordination with NECPs.	Requirements are for the implementation as part of the two-yearly updates of the ten-year network development plans and the DNDP (DSO Network Development Plans) and in coordination with NECPs.	No connection with NECPs	Specific points where to seek linkage with NECPs.

Best Practice fulfillment of legislation requirements				
	Current State	Future State (Forced and/or chosen)	GAP	Actions to Close GAP
Who is responsible	ENTSO-E and ENTSO-G, member state TSOs and DSOs	ACER and national regulatory for oversight, ENTSO-E and ENTSO-G, member state TSOs and DSOs for delivery	1. Adequate oversight and steering from policy makers and enforcers to compliance with full requirements of legislation 2. Limited oversight in adjacent sectors to gas and electricity	1. Recommendation for mandated separate oversight of compliance with each article and requirement in legislation for energy infrastructure planning to bodies responsible for planning the energy networks 2. Recommendation of 2 yearly report issued with gap analysis from oversight body and with resolutions proposals with timelines from bodies responsible for planning the energy networks.
How is it managed and is it effective	Both associations supported by their members (TSOs and DSOs) produce their two-yearly update of development plans individually based on using a common scenario. Scenarios are limited to three and factor in likely changes in future years to components of their respective networks and users. They do not account for future developments or projects by transport and communications sectors, nor each other's candidate projects. These scenarios, models and plans are designed to assess only one sector but using common data. This does not meet the requirements as the proposed developments in other sectors are not included nor is their information being used in those sectors.	Both associations supported by their members (TSOs and DSOs) produce their two-yearly update of development plans individually based on the full range of possible future scenarios for each sector, accounting for disruptive technologies and candidate developments. From this range of scenarios, common beneficial needs and solutions (not restricted to solutions coming from the same sector as the network need problem it is resolving) offering least worst regret developments. Additional technological solutions for more conditional situations (i.e. those based on network needs that are dependent on only one or more scenarios) can be developed. These can use flexible technologies e.g. rescalable, locatable or short lead times, than can respond to changing needs . This will meet the requirements of legislation.	1. Candidate solutions from other sectors not assessed or included in Cost benefit analysis 2. Limited scenarios created that do not reflect full impact of disruptive technologies, policies, variation in achievement of targets, and other determining factors 3. Scenarios used in ten-year plans are static for other sectors and included changes as either not happening or certain 4. Limited scenarios assessed in ten-year plans, and therefore no least worst regrets projects can be identified 5. No recognition of the practical deliverability of projects to address network needs on time e.g. oversized, no public acceptance, too resource intensive for commercial suppliers. Hence automatic acceptance of a	1. Recommendation to adapt process and tools to enable candidates' solutions from other sectors to be assessed alongside sectors projects. 2. Recommendation to change scenarios process to provide extremity of disruptive technologies' impact to network needs, and ranges of users including parameters than can be reasonably expected in time horizons. Presentation of known projects that have developed such tools and the mechanisms behind them. 3. Recommendation to use revised software tools that can use unlimited scenario assessment and deliver within legislative timescales. Presentation of known projects that have developed such tools and the mechanisms behind them. 4. Recommendation to apply least worst regrets projects needs approach as well as full

Best Practice fulfillment of legislation requirements				
	Current State	Future State (Forced and/or chosen)	GAP	Actions to Close GAP
			project as a solution that fails to deliver and not a call for a more efficient solution to be found	spectrum on network needs. 5. Recommendation to apply least worst regrets findings to candidate solutions, and to ensure that the timing of these solutions matches needs, or that alternative technological solutions that could be flexible are considered. Presentation of known innovative technologies for consideration that provide the necessary flexibility (scalable, fast, and multitasking)

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