TYNDP 2020 JOINT SCENARIOS METHODOLOGY

A CSEI ASSESSMENT

CSEI Copenhagen School of Energy Infrastructure

CBS DEPARTMENT OF ECONOMICS
COPENHAGEN BUSINESS SCHOOL

Written by the Copenhagen School of Energy Infrastructure (CSEI), Copenhagen Business School *July – 2021*

EUROPEAN COMMISSION

Directorate-General for Energy
Directorate C — Green Transition and Energy System Integration
Unit C.4— Infrastructure and regional cooperation

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European Commission
B-1049 Brussels

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Directorate-General for Energy

2021

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Manuscript completed in August 2021

Revised edition

Luxembourg: Publications Office of the European Union, 2021

PDF ISBN 978-92-76-40107-0 doi: 10.2833/872954

EXECUTIVE SUMMARY

The Ten-Year Network Development Plan (TYNDP) scenarios are jointly developed by the European Network of Transmission System Operators for Electricity (ENTSO-E) and the European Network of Transmission System Operators for Gas (ENTSOG) to devise possible pathways for the development of the energy system of the European Union by 2050. The building of the scenarios stems from a mandate in the European regulations 714/2009 and 715/2009 respectively, requiring both Energy Transmission Systems Operators (ENTSOs) to develop scenarios. Additionally, the regulation of Trans-European Networks for Energy (TEN-E) from 2013, tasked the ENTSOs with delivering an interlinked model of electricity and gas sectors that includes the transmission infrastructure, storage systems, and Liquefied Natural Gas (LNG) facilities to be delivered by 31 December 2016. Based on this requirement, the ENTSOs started to deliver joint scenarios since the TYNDP 2018. These joint scenarios form the basis for the assessment of the needs for the European energy infrastructure development, the identification of Projects of Common Interest (PCIs) through the application of Cost-Benefit Analysis (CBA), the application of a Cross-Border Cost Allocation (CBCA) method to concrete cases, and applications for grants under the Connecting Europe Facility (CEF) co-funding mechanism.

The European Commission and the Agency for the Cooperation of Energy Regulators (ACER) are consulted along with other stakeholders in the process of developing the scenarios. However, due the scale and scope of the exercise, the number of actors involved in their development, and the impact on networks' core activities, the scenarios are scrutinised by various stakeholders. Although there is no formal approval, the scenarios are subject to an opinion from ACER. There remain important differences in viewpoints among the stakeholders, notably concerning estimates of demand for gas and thus the need for gas infrastructure.

CSEI has been commissioned by the European Commission to assess the TYNDP 2020 scenarios with a particular focus on the identification of methodological aspects and provide recommendations to improve these on the basis of energy economics research. To begin with, it has to be said that planning for future entails constraints and risks. In an intricated case such as the TYNDP, these limitations can limit building of long-term scenarios. In consequence, our analysis will be carried out recognising the ambitious and challenging task of developing the TYNDP scenarios by ENTSOs. The scale and scope of a TYNDP inevitably leaves it open for many views on various aspects of the plans presented. We also recognise that in a complex, constantly evolving, and uncertain planning environment such as the TYNDP, many general or detailed views and interests can be presented. Therefore, the motivation is to assess the TYNDP scenarios and assist the policy framework with a view to inform the current as well as the future development plans. We avoid suggestions that promote particular views to the extent possible.

We identify several areas of improvement for the scenarios: transparency and accessibility, complex planning environment, uncertainty, and dynamic analysis. In addition, we discuss the feasibility of the most relevant assumptions: translation from storylines into scenarios, energy imports, carbon emissions, role of hydrogen, and the role of GDP and its effect on the demand. Our assessment touches upon the issue of interlinkage of sectors and how this has been addressed both organisationally and in the modelling exercise. Finally, we provide considerations for improving future scenarios: policy target and cost-effectiveness, network investments, prices and discounting, sensitivity analyses, no-regrets and co-benefits, equity and impact on consumers/citizens/taxpayers, and behavioural aspects and public acceptance issues. Finally, based on the previous assessment we provide both methodological and organisational recommendations.

Methodological

1. The TYNDP scenario development exercise is a complicated task. The communication and dissemination of the documentation need to be made clearer to facilitate the understanding of the scenarios from third parties. The data available online need to be well organised and include descriptive information, source, and reference to the part of the scenarios in which they are utilised.
2. Scenario descriptions, assumptions and analysis need to be made more transparent, accessible, and replicable. The use of open access models could help to improve these aspects. The inclusion of equations and programming codes in the reports would also be an important step forward.
3. A Business-as-Usual (BAU) scenario could be used as a baseline scenario to analyse cost-effectiveness. Moreover, to the extent possible the scenarios should be relatively stable and evolve smoothly over time.
4. The different types of uncertainties such as economic, technological and demand need to be made explicit and then subjected to sensitivity analysis.
5. The building of the scenarios should become a fully integrated exercise between ENTSO-E and ENTSOG that appropriately reflects future interlinkages between gas and electricity. This needs to be achieved through joint sector modelling.
6. Sector coupling will inevitably require integration at distribution level and a proper modelling of an interface TSO/DSO. Coordination with DSOs and practical implications of this development should be considered.

Organisational

1. It is crucial and beneficial to all parties to ensure that the TYNDP process is sufficiently resourced.
2. It is difficult to perceive scenario development without active participation of the ENTSOs.
   a. However, due to the direct influence of the scenarios on the selection of PCIs, scenarios could be considered for approval by the European Commission. Moreover, it is possible to distinguish between three distinct elements of a scenario: the storylines, the assumptions derived from them, and the modelling and quantitative exercise.
   b. The scenario storylines and assumptions could additionally be subjected to early approval of the European Commission, having done so the task of modelling and quantitative analysis can then be delegated to the ENTSOs.
   c. ACER and ENTSOs represent a diverse set of interests of a diverse set of stakeholders. The scenario building process can be aided through structured recommendations by an advisory board composed of ACER, ENTSOs, and other members from a broad range of stakeholders to reflect on differing viewpoints.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ABBREVIATIONS

ACER	Agency for the Cooperation of Energy Regulators
BNEF	Bloomberg New Energy Finance
CBA	Cost-Benefit Analysis
CBCA	Cross-Border Cost Allocation
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Utilisation and Storage
CEF	Connecting Europe Facility
COP21	2015 United Nations Climate Change Conference
CSEI	Copenhagen School of Energy Infrastructure
DG Energy	Directorate-General for Energy
DOE	Design of Experiments
DSO	Distribution System Operator
EC	European Commission
ENTSO-E	European Network of Transmission System Operators for Electricity
ENTSOG	European Network of Transmission System Operators for Gas
EU ETS	European Union Emission Trading Scheme
GHG	Greenhouse Gas
IEA	International Energy Agency
INEA	Innovation and Networks Executive Agency
IoSN	Identification of System Needs
LNG	Liquefied Natural Gas
MSPS	Multi-Sectorial Planning Support
NRA	National Regulatory Authority
NECP	National Energy and Climate Plan
NGO	Non-Governmental Organisation
P2G	Power-to-Gas
PCI	Project of Common Interest
TEN-E	Trans-European Networks for Energy
TSO	Transmission System Operator
TYNDP	Ten-Year Network Development Plan

GLOSSARY

Approach	It refers to the manner of addressing a question or a problem. In this report, it is used interchangeably with methodology (see the definition below).
Business-as-Usual Scenario	Scenario that projects contemporary developments continuously into the future, i.e., they assume that no new decision-making processes or actions whatever are to be initiated. Their goal is first to explore what will happen "if we continue as up to now". Secondly, these scenarios serve as reference scenarios in comparison with scenarios which study the possible alternatives for deciding on how to act and what actions are to be taken (i.e., policy scenarios) (Kosow & Gassner, 2008).
Carbon Budget	This is the amount of carbon dioxide the world can emit while still having a likely chance of limiting average global temperature rise to 1.5°C above pre-industrial levels, an internationally agreed-upon target. (ENTSO-E & ENTSOG, 2020b).
Cost-Benefit Analysis	Cost-Benefit Analysis (CBA) is utilised as a synonym of Social Cost-Benefit Analysis (SCBA) in this report. The SCBA is a decision support tool that measures and weighs various impacts of a project or policy. It compares project costs (capital and operating expenses) with a broad range of (social) impacts (CIVITAS: https://civitas.eu/).
Forecast	Estimate of what is likely to happen in the future. It can be subject to the realisation of certain conditions, i.e., if X happens, then the forecast is Y.
Gas-to-Power	Gas-to-Power describes the process in a combustion engine that can convert natural gas (or other liquid fuels) to mechanical energy. This energy then drives a generator that produces electrical energy (GE Gas Power: https://www.ge.com/gas-power).
Interlinked Model	Approach developed by the ENTSOs to meet the requirements of Regulation (EU) No 347/2013. The key element of the model submitted by the ENTSOs is the joint development of scenarios that constitute the basis for the cost-benefit analysis of gas and electricity infrastructure projects. Once the scenarios have been commonly established, the submitted model proposes that each of the ENTSOs performs the cost-benefit analysis of infrastructure projects based on their specific tools and methodologies (Artelys et al., 2019).
Methodology	Contextual framework that describes the choices made by researchers in a coherent and logical way. It can include quantitative, qualitative elements or both.
Model	Simplified representation of the reality. It requires making simplifying assumptions that ideally should not imply an important loss of information.

Power-to-Gas	Technology that uses electricity to produce hydrogen (Power to Hydrogen – $P2H_2$) by splitting water into oxygen and hydrogen (electrolysis). The hydrogen produced can then be combined with CO_2 to obtain synthetic methane (Power to Methane – $P2CH_4$) (ENTSO-E & ENTSOG, 2020c).
Risk	Exposure to the possibility of loss, injury, or other adverse or unwelcome circumstance; a chance or situation involving such a possibility (Oxford English Dictionary: https://www.oed.com/)
Robustness	Insensitivity of the scenarios to changes in future conditions (Maier et al., 2016). A robust scenario shall behave well in (slightly) different conditions, meaning that it is immune to small changes in the conditions it was designed for (Barrico & Antunes, 2006).
Scenario	A set of assumptions for modelling purposes related to a specific future situation in which certain conditions regarding electricity and gas demand and supply, infrastructures, fuel prices and global context occur (ENTSO-E & ENTSOG, 2020a).
Sector Coupling	Most commonly, it means replacing the traditional separation of the energy sectors of electricity, heating and cooling, transport, and industrial consumption processes in favour of a holistic approach. Sector coupling aims at decarbonising the national economy by converting the energy supply as completely as possible to electricity, finally reaching an "All Electric Society". A prerequisite for this is the use of the complete flexibility potential of producers and consumers as well as the storage of energy in its various forms (Next Kraftwerke, 2021).
Sensitivity Analysis	The study of how uncertainty in the output of a model (numerical or otherwise) can be apportioned to different sources of uncertainty in the model input (Saltelli et al., 2004).
Storyline	Storylines represent realistic paths towards European targets, co-designed by the whole electricity sector, consumers and NGOs thanks to an extensive engagement and consultation process, jointly with the gas sector (ENTSO-E & ENTSOG, 2020a).
Tool	Instrument utilised to get a job done. It is a means to achieve a concrete purpose.
Uncertainty	It can be defined from a subjective interpretation in which the degree of confidence that a decision maker has about possible outcomes and/or probabilities of these outcomes is the central focus. A person is uncertain if s/he lacks confidence about the specific outcomes of an event. Reasons for this lack of confidence might include a judgement of the information as incomplete, blurred, inaccurate, unreliable, inconclusive, or potentially false. Similarly, a person is certain if s/he is confident about the outcome of an event. A person may feel certain but has misjudged the information (i.e., his/her judgement is wrong) (Refsgaard et al., 2007).

1. INTRODUCTION

1.1. Background

The Ten-Year Network Development Plan (TYNDP) scenarios present possible pathways for the energy system of the European Union until 2050.[1,2] These scenarios are jointly developed by the European Network of Transmission System Operators for Electricity (ENTSO-E) and the European Network of Transmission System Operators for Gas (ENTSOG). Currently, they represent ways towards the objective of making Europe the first climate-neutral continent by 2050, a goal set by the new European Green Deal.[3]

The origins of the TYNDPs can be traced back to Article 8(3)(b) of Regulation 714/2009[4] and Article 8(3)(b) of Regulation 715/2009,[5] which respectively requested ENTSO-E and ENTSOG to publish their individual TYNDPs every two years. The focus of the TYNDPs has evolved overtime. The network development plans were initially focused on the supply adequacy and the resilience of the gas and electricity systems as separate exercises. Following a request in the regulation of Trans-European Networks for Energy (TEN-E) (Article 11(8) of Regulation 347/2013)[6] and starting in the 2018 edition, the TYNDP scenarios are jointly developed by ENTSO-E and ENTSOG. The TYNDP scenarios are tasked with reflecting the interactions between electricity and gas systems in a future carbon-neutral energy sector in Europe. The scenarios should be seen first and foremost in the context of EU energy policy objectives, but they can also be viewed in the broader context of the energy trilemma of balancing security of supply, energy affordability, and environmental sustainability (World Energy Council, 2020).

The TYNDP scenarios have a pivotal role for achieving the European climate goals and form the basis for further actions involving the identification, promotion, and funding of infrastructure projects deemed important for the development of the EU energy market integration. Figure 1 summarises the process and shows the critical position of scenario development at the beginning of the TYNDP process. The subsequent steps following the scenarios involve the Identification of System Needs (IoSN) and the application of Cost-Benefit Analysis (CBA) for the selection of Projects of Common Interest (PCI). Afterwards, some PCIs are subject to the application of a method for Cross-Border Cost Allocation (CBCA) and the granting of Connecting Europe Facility (CEF) funding. It is important to note that this process directly emanates from TEN-E regulation.

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[1] https://eepublicdownloads.azureedge.net/tyndp-documents/TYNDP_2020_Joint_Scenario_Report_ENTSOG_ENTSOE_200629_Final.pdf
[2] https://2020.entsos-tyndp-scenarios.eu/wp-content/uploads/2020/06/TYNDP_2020_Scenario_Building_Guidelines_Final_Report.pdf
[3] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1576150542719&uri=COM%3A2019%3A640%3AFIN
[4] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32009R0714
[5] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32009R0715
[6] https://eur-lex.europa.eu/legal-content/en/TXT/?uri=celex%3A32013R0347

TYNDP process

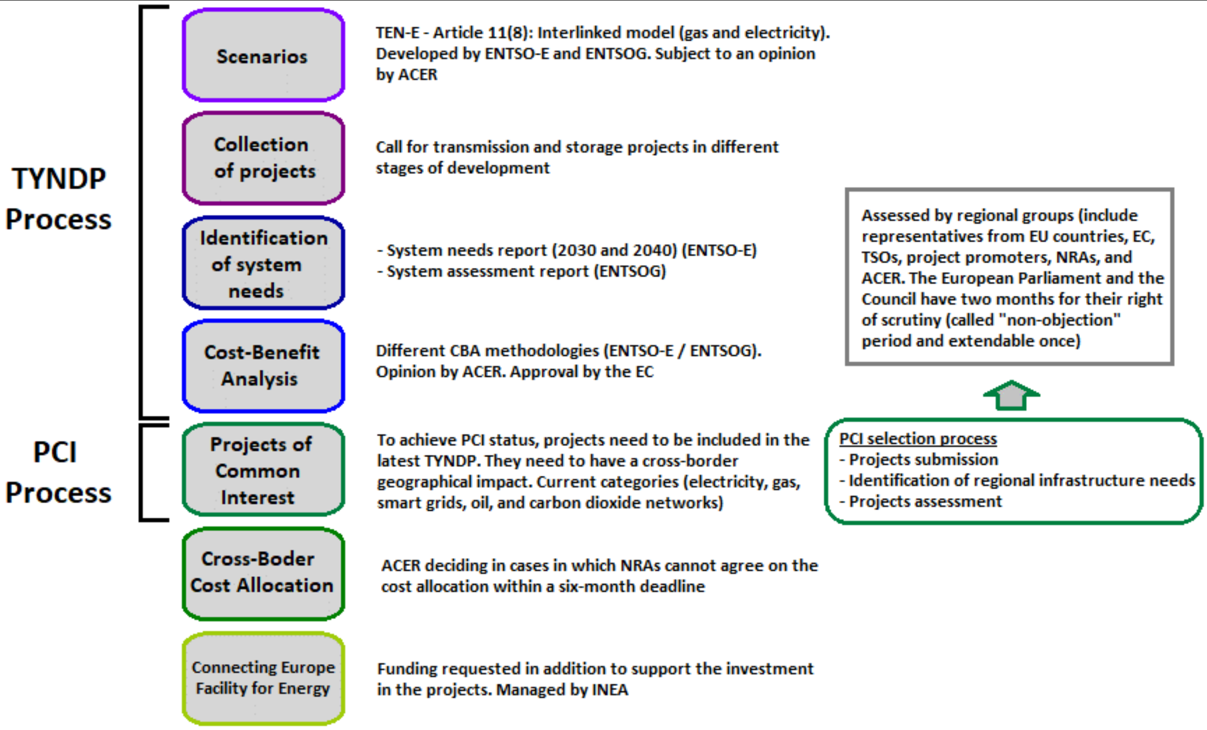

Figure 1: Diagram of the TYNDP and PCI Processes, CBCA, and granting of CEF funding
Source: Own elaboration based on information from different reports

Due to their profound impact on the European energy system, the scenarios need to consider the viewpoints of different stakeholders. This is evidenced in the diverse workshops, webinars, and consultations organised by the ENTSOs to receive comments on the draft scenario and TYNDP reports. The scenarios are currently developed by the ENTSOs and subjected to an opinion from the Agency for the Cooperation of Energy Regulators (ACER). During the June 2020 webinars on the revision of the TEN-E guidelines organised by the Directorate-General for Energy (DG Energy) of the European Commission, some participants expressed concerns about the TYNDP scenarios. Some pointed to the need for increasing the engagement of stakeholders, for example, through extensive consultations at early stages of their development.[7] Some suggested to give the responsibility to approve the scenarios to the European Commission or to further empower ACER to issue binding guidelines on the main infrastructure-related deliverables and amendments on the draft of TYNDP.

Some stakeholders appeared to be asking for a discussion over how and by whom the scenarios are defined and developed. Irrespective of the differing views on the scenarios, it is clear that there remain questions among some stakeholders. Broadly, this is an 'old' dispute that frequently arises in regulated sectors and has its roots in the 'agency problem', an established concept in the economics literature (Mitnick, 1975; Ross, 1973). Companies

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[7] In the webinars and more broadly in stakeholder consultations, participants consisted of TSOs and national competent authorities, NGOs, citizens, project promoters, and industry associations, among others. For more details about the consultation see: https://ec.europa.eu/energy/sites/ener/files/revised_ten-e_regulation_.pdf.

involved in the development of the scenarios have more information than other stakeholders and possibly not the same interests, which may lead to stakeholder concerns related to moral hazard,[8] as evidenced during the TEN-E webinars.

1.2. Role of the Copenhagen School of Energy Infrastructure (CSEI)

The Copenhagen School of Energy Infrastructure (CSEI), based at Copenhagen Business School, is well placed to contribute to the appraisal and discussion of the TYNDP scenarios. CSEI carries out independent research in energy topics with a particular focus on European energy infrastructure from an economic policy point-of-view. It has been established with the endorsement of the European Commission and with the purpose to support the policy work of the Copenhagen Energy Infrastructure Forum.

With the aim of grasping a better understanding of possible issues in the development of the scenarios based on economic principles, CSEI has been contracted by the European Commission for a service with the following tasks:

- Analysis of the ENTSOs TYNDP 2020 scenarios report with the focus on the methodological approach,
- Identification of any methodological gaps in developing the TYNDP 2020 scenarios covering all steps of the scenario development and in particular the carbon setting per sectors, the demand, the interlinkage elements in the scenarios, e.g., (but not limited to) power-to-gas, and
- Suggestion of methodological improvements and ways to implement these improvements.

Given these objectives, in the present report CSEI aims to undertake a constructive assessment of the TYNDP scenarios with a view to improving the task and the process for the benefit of all the parties involved. The goal is to evaluate the approach, premises, and assumptions of the TYNDP scenarios from a neutral, academic, and economics-informed perspective. We offer some specific recommendations and practical solutions to the European Commission.

1.3. CSEI's Approach to the Assessment of the TYNDP Scenarios

Planning for future entails constraints and risks. In an intricated case such as the TYNDP, these limitations can limit building of long-term scenarios. In consequence, our analysis will be carried out recognising the ambitious and challenging task of developing the TYNDP scenarios. The scale and scope of a TYNDP inevitably leaves it open for many views on various aspects of the plans presented. We also recognise that in a complex, constantly evolving, and uncertain planning environment such as TYNDP, many general or detailed views and interests can be presented.

Therefore, the motivation is to assess the TYNDP scenarios[9] and assist the policy framework with a view to inform the current as well as the future development plans. We avoid suggestions that promote particular views (e.g., developing additional scenarios that

[8] Moral hazard can be defined as "any situation in which one person makes the decision about how much risk to take, while someone else bears the cost if things go badly" (Krugman, 2009, p. 63).

[9] Our assessment is essentially based on the information provided in the final version (June 2020) of the two main reports of the TYNDP 2020 scenarios: the Scenario Report (ENTSO-E & ENTSOG, 2020c) and the Scenario Building Guidelines (ENTSO-E & ENTSOG, 2020b). The links to these documents can also be found in footnotes #1 and #2. Additional sources of information for our assessment are the scenarios data and the online visualisation platform (see footnote #12).

imply minor modifications to the existing ones or suggesting specific analytical exercises without a clear purpose) to the extent possible.

As mentioned, the TYNDP scenarios have important implications for the CBA methodology used for the selection of PCIs that represent key European cross-border infrastructure developments. Consequently, there is a varied set of internal stakeholders (ENTSO-E and ENTSOG) and external stakeholders (regulators, representatives of the gas and electricity industries, customers, environmental NGOs, and the EU member states) that view the TYNDP scenarios with strong interest due to major influence that these have for their future activities. As part of our analysis to improve the scenarios methodology, we have sent a questionnaire and organised interviews with different stakeholders to find out their main concerns about the development of the scenarios.[10] We have used stakeholders' experience and knowledge to inform our assessment of the TYNDP scenarios. However, by no means this implies any interference in the impartiality of CSEI's review.

Our assessment includes comments and suggestions on several general matters, in addition to specific points concerning the scenarios, approach, and assumptions. This assessment uses the academic literature (in energy, environmental, and business economics), but also by projects, alternative scenarios, and reports from international organisations. For the purpose of clarity, when possible, we provide examples to illustrate our remarks along with potential solutions and ideas to explore. The following general issues are discussed in **Section 2** of the report:

- **Transparency and accessibility** – This point refers to the facility with which individuals not directly involved in the development of a model or scenario can observe and understand how it has been built.
- **Complex planning environment** – Complexity can affect the robustness of the scenarios depicted and hence it has to be properly addressed.
- **Uncertainty** – This concept should be an overarching consideration in scenario development, model analysis, and data utilised.
- **Dynamic Analysis** – In dynamic terms, sector coupling, or more generally systems integration, effectively requires a coevolution of the sectors involved. This turns the TYNDP scenarios development into an interlinked and dynamic optimisation exercise.

Section 3 discusses aspects related to the main assumptions made in the scenarios, while **Section 4** presents an assessment of how the interlinkage between gas and electricity is addressed in the process of development of the scenarios and also how that is reflected in the scenarios.

In addition to the needs for physical connections, the development and performance of a well-functioning coupled electricity and gas system ultimately depends on the wider context and incentives derived from economic, regulatory, and policy frameworks. The considerations that are examined in **Section 5** include:

- **Policy target and cost-effectiveness** – Public policy making is a complex decision environment where economic efficiency per se is often not the sole objective and a set of social, environmental, energy security priorities need to be balanced. In this context, the cost-effectiveness of achieving the objectives is important.

[10] CSEI would like to thank the following participants that responded to our request for an interview and offered their views: ACER, CAN Europe, Energinet, ENTSO-E, ENTSOG, Eurelectric, GASCADE, GD4S, GIE, and Riccardo Vailati.

- **Network investments** – Aspects of innovation in energy networks and potential alternatives to network investments also have to be analysed.
- **Prices and discounting** – Prices send strong signals that influence the development of energy sectors and hence have to be adequately considered in the scenarios. Although discounting is central aspect of CBA, it is an element that also needs to be discussed in the scenario development due to its impact on the assumptions and the viability of future projects.
- **Sensitivity analyses** – Uncertain factors can influence the consistency of the scenarios. This is commonly addressed in the form of sensitivity analyses.
- **No-regrets and co-benefits** – The scenarios show alternative paths towards decarbonisation. Due to the impact that they have in CBA, scenarios should pursue this objective in such a way that maximises the co-benefits of decarbonisation.
- **Equity and impact on consumers/citizens/taxpayers** – Funding of the energy infrastructure is expected to differ between scenarios. The impact of the alternatives has to be examined.
- **Behavioural aspects and public acceptance** – Behavioural changes and public acceptance issues that may affect the patterns described in the scenarios need to be explicitly considered.

Section 6 concludes and offers recommendations for future scenarios development.

2. METHODOLOGICAL ISSUES OF SCENARIO DEVELOPMENT

2.1. Overview and methodological definition of scenarios

How can we plan the future? This question often entails constraints and risks. In an intricated case such as the TYNDPs, these limitations can greatly add to the difficulties of building long-term scenarios (Martelli, 2014). The present report is an economics-informed assessment of the TYNDP scenarios mainly focused on the methodological aspects. First, we emphasise the ambitious and tough task of developing a TYNDP. The magnitude and reach of this task, also leaves it open for many opinions on diverse features of the development plans.

Prior to the assessment of the TYNDP scenarios, we define some concepts that will be essential to carry out our task. The first question is: what is a scenario? There is no unique definition to describe what a scenario is because it is a "fuzzy concept that is used and misused, with various shades of meaning" (Mietzner & Reger, 2004, p. 50). According to Kosow & Gassner (2008, p. 11) a scenario is described by numerous authors as "a description of a possible future situation" that includes "paths of development which may lead to that future situation". This means that a scenario needs to go beyond a simple depiction of hypothetical future (which is known as a 'conceptual future') and also represent all the pathway towards that hypothetical situation.

Based on Börjeson et al. (2006), scenarios can be classified in three groups, namely predictive, explorative, and normative. While the first and the second type try to respond respectively to the questions 'what will happen?' and 'what can happen?', the last type (i.e., normative scenarios) focus on how 'specific objectives' can be accomplished. TYNDP scenarios seem to be normative scenarios in which the main target is to reach a carbon neutral energy system by 2050.[11] It is important to note that scenarios can be used for several purposes which can be categorised in four type of functions: explorative and/or scientific, communicative, goal-setting, and decision-making and strategy formation (Kosow & Gassner, 2008). There is no unique method that can be applied to evaluating scenarios in every case. Quantitative tools that utilise data are more adequate for evaluating short-term scenarios, whilst qualitative appraisals can be appropriate for long-term scenarios (Fauré et al., 2017).

There are some criteria proposed in the literature to evaluate scenarios and their development. Although scenarios are hypothetical exercises, this does not mean that they can be arbitrary. By collecting information from other studies, Kosow & Gassner (2008) propose the following features as distinctive of a 'good scenario': plausibility, consistency, comprehensibility and traceability, distinctness, transparency, degree of integration, quality of reception, participants, time and effort involved. Similarly, Godet and Roubelat (1996) state that the usefulness and credibility of a scenario methodology depend on four preconditions: relevance, transparency, coherence, and likelihood. We will not describe here these characteristics. However, to the extent possible we will use these as a reference for our assessment and hence we will discuss the criteria which are most relevant to the context of the TYNDP scenarios.

The scenarios have a central role in the TYNDP. They form the basis of decision-making in the next steps. TYNDP 2020 is composed of three scenarios, one bottom-up, called National

[11] They can also be considered partly explorative since they try to look at 'what can happen if we act in a certain way'.

Trends (NT), and two top-down, called Global Ambition (GA) and Distributed Energy (DE). National Trends is the central policy scenario and its horizon is 2040. This scenario is based on the member states' National Energy and Climate Plans (NECPs) and TSOs knowledge of the electricity and gas sectors. The other two scenarios are compliant with the 1.5° target of the Paris Agreement and their horizon is 2050, when carbon neutrality has to be reached. For this reason, they are also called the COP21 Scenarios. The top-down scenario Distributed Energy represents a decentralised energy sector with small-scale solutions and active customers. The other scenario is called Global Ambition and is more reliant on large-scale renewables, imports, and use of Carbon Capture and Storage (CCS).

We recognise that in a complex, constantly evolving, and uncertain planning environment such as TYNDP, many general or detailed views and comments can be presented. Therefore, we aim to avoid suggestions that promote particular beliefs and carry out a constructive and unbiased analysis. As already mentioned, the motivation is to assess the TYNDP scenarios and assist the policy framework with a view to inform the next stages of the current as well as the future development plans.

In order to organise the assessment of the methodology and assumptions used in the scenarios, we propose a set of overarching aspects of scenario development in the following sub-sections.

2.2. Transparency and accessibility

Transparency refers to the facility with which individuals who are not directly involved in the development of a model can observe and understand how it was built (Carlsen et al., 2017). It serves mainly two purposes: i) to offer a non-quantitative description to readers who simply pursue a basic understanding about how the model works, but also ii) to provide technical information (often in a quantitate from) to experts who need to assess the model at a higher level of detail. Failing to provide a good level of transparency, even when models are robust and consistent, can lead to problems such as delays in the evaluation processes, project development, and decision-making.

Transparency in the definitions and assumptions used in modelling would enable a common understanding of the complexities of the sectors and would facilitate reaching compromises when elaborating the methodologies and scenarios. Transparency is also important to make the production and collection of data from Transmissions System Operators (TSOs) easier and the replicability and interpretation of the scenarios. Databases like Eurostat, the International Energy Agency (IEA) or Bloomberg New Energy Finance (BNEF) are cited as sources for the assumptions made in the Scenario Methodology Report, while it is not clear how these are used. Moreover, bottom-up data from TSOs are utilised to obtain a so-called 'Best Estimate' scenario for the years 2020 and 2025, which includes "a merit order sensitivity between coal and gas in 2025" (ENTSO-E & ENTSO-G, 2020a, p.13). However, in other parts of the reports (Figure 2) it seems that apart from National Trends, Global Ambition and Distributed Energy, there are three additional scenarios (or one scenario and two sensitivity analyses): Best Estimate in 2020, Best Estimate – Coal before Gas in 2025, and Best Estimate – Gas before Coal also in 2025. The definition, building, and purpose of these scenarios / sensitivity analyses are not clearly described in the reports.

Framework for Scenarios

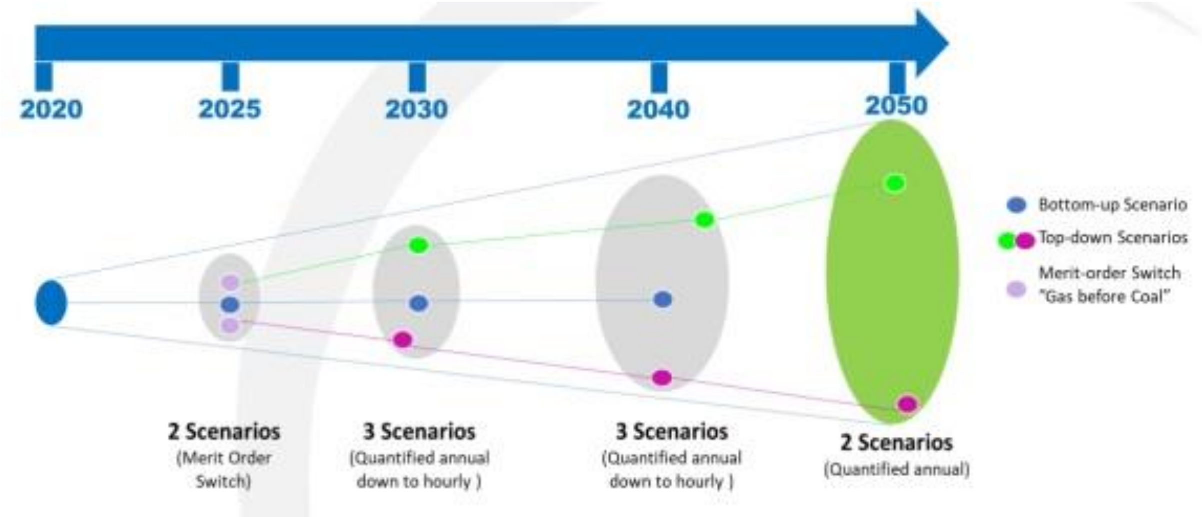

Figure 2: High level framework for joint ENTSO-E & ENTSOG storylines
Source: (ENTSO-E & ENTSOG, 2020b)

There is a helpful online visualisation platform of the TYNDP 2020.[12] However, it only provides information about the scenarios' outcomes. This platform does not show how the tools are built and how the outcomes are computed, and consequently it does not promote the transparency of the methodology and does not allow the users to experiment with alternative scenarios. There are examples of tools developed from other projects that could be used as benchmarks in order to improve TYNDP scenarios data visualisation platform in the future (e.g., the SRF Optimiser tool[13] allows British road freight transport companies to calculate the energy consumption, costs, and GHG emissions derived from certain decisions; the Blackout Simulator[14] permits assessing the economic consequences of simulated power outages in regions of the European Union countries; E-GRIDMAP[15] allows developers and investors to calculate the Capex and the return on investment of potential projects connected to the Estonian electricity grid).

The documentation of the scenarios, methodology, and data is extensive. However, these are not always easily accessible and need a clearer structure. This is important for communicating the process and results as well as allowing insight into third-party actors. The approach consists of applying different tools to building the scenarios. However, it is not apparent whether the design of the whole approach is consistent, i.e., if there is coherence between all the assumptions in the diverse parts of the model. We understand that the root of this problem is the manner in which the process has been approached. This is not to suggest that ENTSO-E and ENTSOG have consciously been unclear in the development of the scenarios, but the application of different tools by different actors (this is related to the complex planning environment described below) over a longer period of

[12] https://tyndp-data-viz.netlify.com/
[13] http://www.csrf.ac.uk/srf-optimiser-2/
[14] https://www.blackout-simulator.com/
[15] https://vla.elering.ee/?lang=en

development might collectively have led to an unintended lack of transparency of the overall approach utilised.

Moreover, it is not always evident how different data have been used and for which specific purpose. All the data used seem to be available in TYNDP's website.[16] However, these databases do not seem to contain much descriptive information and are not organised in such a way that can be easily consulted and used. Perhaps it would be useful that all data are structured and presented in a single appendix including sources, descriptions, and detailed information with characteristics of how data are utilised in the scenarios (e.g., tools in which the data are used, whether they are inputs/outputs, exogenous/endogenous, etc.). This is commonly expected from a major report with far reaching public policy implications or a data intensive academic publication. A completely clear and transparent presentation would also support a transparent discussion between the actors and their stakeholders including NGOs and could prevent misunderstandings.

2.3. Complex planning environment

The development of electricity, gas, and other network industries (e.g., heat and transport) depends on a set of intertwined factors (technical, political, regulatory, institutional, and economic, among others). The specific nature and historical particularities of each European country have shaped the development of their energy networks and hence the characteristics of the companies participating in these industries. The heterogeneity of the companies from member countries and beyond, and their sometimes diverse priorities, influence how scenarios are defined and developed. This needs to be acknowledged and used to inform the development of the scenarios.

An extension of Arrow's impossibility theorem to this realm implies that in a complex international framework it is not possible to define a choice procedure that generalises the preferences of every stakeholder in order to establish a 'common interest' (Arrow, 1950, 1986). This implies accepting that some basic economic principles and objectives, such as assuming profit maximisation or economic efficiency, will not hold for every actor involved and evidences the need of reaching agreements to arrive at feasible solutions for an effective integration. It may be worth to consider reframing the division of roles in the scenario development process (e.g., the establishment of an advisory board composed of members from a broad range of actors to oversee the process) to ensure the scenarios consider all viewpoints, which may help to alleviate the problems derived from lack of trust in the scenarios.

While the involvement of diverse actors in the development of the scenarios can be positive in order to represent different perspectives, it also presents some coordination issues. The Joint Foreword of the Scenario Report states that "a set of ambitious and technically robust scenarios" (ENTSO-E & ENTSO-G, 2020b, p.3) have been built by ENTSOs joint work. However, considering the information available in the scenario and methodology reports, the internal consistency of the methodology cannot be assessed. The final methodology appears as an amalgam of different analytical tools and working teams (Ambition Tool, PEMMDB, TRAPUNTA, PLEXOS, SoS tool, biomethane tool, etc.). However, there is no comprehensive and unified description of the whole approach and there are no mathematical equations that show how the individual tools work and how they are

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[16] https://2020.entsos-tyndp-scenarios.eu/download-data/

combined. Therefore, as mentioned in the above, it is not feasible to assess the robustness of the scenarios.

For instance, Figure 3 shows a simple representation of the process followed to produce top-down scenarios (i.e., Global Ambition and Distributed Energy). However, the chronology of the analysis needs to be clearer, e.g., where output from one step is used as input for another step. Figure 4 shows how the hourly electricity demand profiles are built and how different working groups are involved in the process. Nevertheless, the figure seems to present some interactions between TRAPUNTA and Ambition Tool that are not clearly reflected in Figure 3. These seemingly different descriptions exemplify the difficulty of describing the scenario building processes in their current form and lead us to another question: why use a set of tools that do not bi-directionally speak to each other instead of linking/integrating them?

Top-down scenario process – The Ambition Tool steps

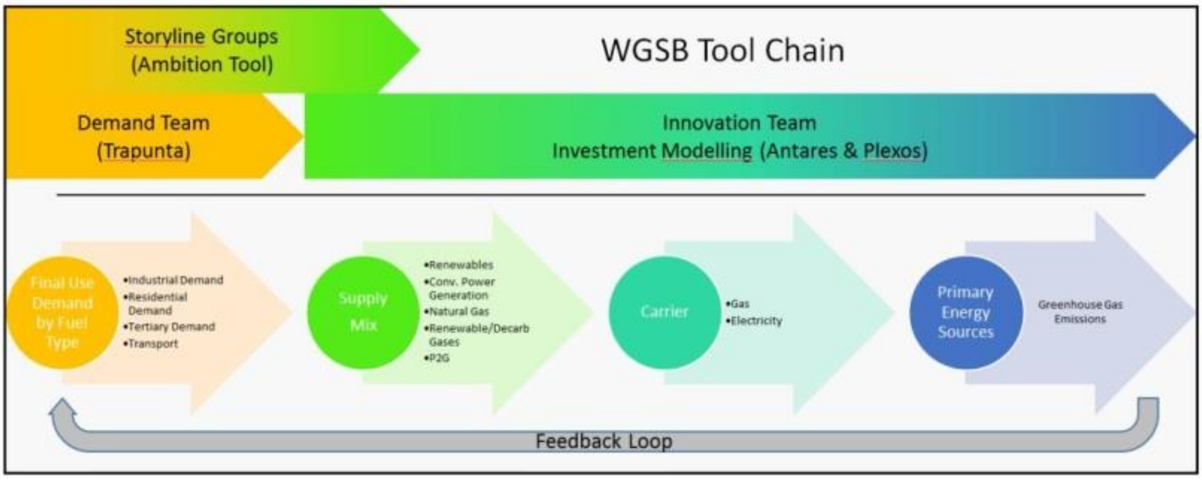

Figure 3: Top-down scenario process – The Ambition Tool steps
Source: (ENTSO-E & ENTSOG, 2020b)

Demand File Building Process

Figure 4: Electricity demand file building process – Team interactions
Source: (ENTSO-E & ENTSOG, 2020b)

Regarding options for modelling complex systems, we understand that there might be different alternatives with their own advantages and disadvantages. It is often difficult to compare different methodologies. Nevertheless, a good strategy is to check the robustness and adequacy of the results obtained for a given approach by using a sensitivity analysis (see Section 5 of this report). In addition, there is not always a direct relationship between the forecasting accuracy of models and their complexity. In scenario building, it can be said that "what is too simple is stupid and wrong, what is too complex is useless" (Godet & Roubelat, 1996, p.166). Solutions could be somewhere in the middle. Therefore, simpler models might be an appealing possibility (e.g., gravity models or other econometric models that account for spatial interactions).[17] In any case, the applied models need to be open and accessible (e.g., integrated assessment models such as Nordhaus' DICE/RICE models – see Nordhaus (2018)) so they can be implemented and understood by other experts, which would help to mitigate some of the transparency issues mentioned in the previous point. A better integration of the different parts of the TYNDP would also contribute to the transparency objective.

Having a number of diverse tools makes it difficult to response to suggested changes from stakeholders. Simplicity increases the responsiveness towards feedback and can help reduce delays in the development of the scenarios. In processes that are frequently revisited, such as long-term scenarios development, integrated and flexible models can be easier to adjust and rerun when there are shocks or obvious discrepancies between the reality and the assumptions made in the past. Clear examples are the withdrawal of the UK from the EU or the impact of the COVID-19 pandemic, major game changers that have not been part of the reports yet. These reinforce the idea of presenting a flexible, centralised, and 'responsive' model.

2.4. Uncertainty

Uncertainty represents the lack of exact knowledge of an outcome irrespective of the cause of this lack (Refsgaard et al., 2007). Uncertainty should be an overarching consideration in scenario development, model analysis, and data used. In the Scenario Report of the TYNDP, it is said that "for the longer term, they include three different storylines to reflect increasing uncertainties" (ENTSO-E & ENTSO-G, 2020b, p.13). This appears to be how the scenarios relate to uncertainty in the report. However, the scenarios presented differ in many respects. This partly reflects the fact that future is uncertain, influenced by various risks, and can evolve in a number of different paths. This may be due to factors such as development of demand[18] or as a result of wider contextual factors such as geopolitics or economic development.

As such scenarios are inherently uncertain and tend not to evolve in the expected path. Therefore, there needs to be a strategy to reflect the uncertainty in them. Do the scenarios describe a 'convex set'? I.e., can we be sure that what we will see in reality will be a combination of the three scenarios? There is probably no way to discern this, because one can never be sure about the future. However, it seems important to address uncertainty within each of the scenarios.

[17] It should be noted that these simpler models would not completely substitute the whole modelling exercise but act more as high-level ancillary models to test the validity of the main model utilised and offer some overall outcomes and policy implications easy to interpret.

[18] In fact, it is difficult to disentangle the nature of the demand growth in the scenarios due to different steps and the blend of different tools utilised (see Section 5 of Scenario Building Guidelines).

Additionally, despite the efforts to harmonise the data, the fact remains that they originate from different countries, sources, and methods and therefore carry a degree of uncertainty regarding their accuracy and consistency. Uncertainty may need to lead to identification of contingencies and risks if major elements of the scenarios do not materialise.

At the moment, it is not evident how uncertainty has been addressed in building the scenarios and incorporated in the tools utilised. There are no clear references to randomness/stochasticity or probabilities in the approach utilised. The uncertainty of the outcomes resulting from the different scenarios should be assessed in some way. This is relevant for public policy-makers due to the potential uncertainties. The main idea is to provide a more realistic depiction of the range of possible outcomes, or in other words, how wrong the central predictions of models turn out.

Problems may be even more acute when the final scenarios are produced using different tools that provide their own uncertainty-subjected inputs to the model. The overlook of these uncertainties may lead to wrong decisions. Some options that can be considered to evaluate the uncertainties of the outcomes are: sensitivity analysis (this will be discussed in more detail below), model evaluation, temporal and spatial variability in the model outputs, statistical approaches, expert judgement, or the use of multiple models (Uusitalo et al., 2015).

2.5. Dynamic Analysis

The TYNDP scenarios present the main features of the alternative pathways along which the European gas and electricity sectors can evolve towards decarbonisation. Energy sector coupling or system integration is inherently a dynamic concept. In dynamic terms, sector coupling effectively requires a co-evolution of the sectors involved. This co-evolution also involves feedback loops between the two sectors. This turns the TYDNP exercise into an interlinked and dynamic optimisation one. This exercise is an iterative process that is revised every two years. In addition, placing the sectors on the trajectory of particular scenarios needs to overcome the incumbent path dependency or inertia that needs to change. The capital-intensive nature of the sectors and the longevity of the assets also add to the path dependency.

Given the above points, the co-evolution and feedback between the energy sectors and the dynamic nature of the paths of the scenarios need to be an integrated part of the scenario development and analysis as well as the different stages of the TYNDP process as a whole. To the extent possible the scenarios should be relatively stable and evolve smoothly over time, instead of presenting a new set of pathways when TYNDPs are presented every two years. Moreover, despite being an interlinked exercise, the level of interlinkage between the modelling of gas and electricity has been deemed as insufficient in the past (ACER, 2017; Artelys et al., 2019) and unclear in the current TYNDP 2020 scenarios (ACER, 2020). At the same time, there are also plans to incorporate more sectors in the TYNDP (ENTSO-E, 2020) and to create multi-sectorial planning scenarios. However, this will add more complexity to the scenarios and projects assessment and will imply more interlinkages and the involvement of more stakeholders.[19] Therefore, due the increasing complexity of the system, transparency and simplicity will become even more relevant. In

[19] In fact, being a proposal of a higher energy integration, it is strange that only ENTSO-E and not ENTSOG or even other relevant actors have signed the document of the roadmap for a Multi-Sectorial Planning Support (MSPS).

fact, the application of an open-source model is one of the recommendations of ENTSO-E in the roadmap for a MSPS (ENTSO-E, 2020).

The number of storylines has been reduced from five (National Trends, Distributed Energy, Global Transition, European Focus, and Delayed Transition) to the current three. As previously mentioned, it is not our intention to demand additional scenarios just for experimenting with different future possibilities. That should be avoided unless the scenarios become obsolete over time. This type of demand from different stakeholders can lead to a never-ending update of scenarios. In our opinion, what is more relevant is to preserve knowledge and experience from the current setup. The TYNDP scenarios are built on previous ones to facilitate the development of new scenarios and avoid past mistakes. This can become crucial considering the difficulty that knowledge-intensive organisations have to retain institutional memory due to the move of their staff to other areas or other organisations (Jamasb et al., 2020).

3. ASSUMPTIONS OF THE SCENARIOS

One crucial but controversial aspect when building scenarios is making assumptions. Assumptions may be seen as unreasonable by some but perfectly sensible by others. Satisfising everyone is problematic and probably doomed to fail. Therefore, to give confidence about the scenarios, the best possible strategy is to use reliable external sources to the extent possible. When internal knowledge and expertise represent the main source of information for scenario assumptions, these should be sufficiently justified. Moreover, it should be clear which assumptions represent political ambitions and which ones represent technical hypotheses. While some of the comments in the previous section may affect assumptions made in the scenarios, there are some additional aspects about assumptions that deserve to be discussed here.

- **From storylines into scenarios:** The development of TYNDP storylines is well documented and has been subjected to consultations.[20] The Storyline Central Matrix presented in Table 2 of the Scenario Report (ENTSO-E & ENTSOG, 2020c) presents a qualitative vision of the main drivers for the European energy system in 2050. This matrix uses + and – signs to indicate how the different components of the energy mix and the energy demand are expected to change with respect to present time in each scenario. However, it is not clear how these changes have been translated into quantities in the scenarios. The Scenario Building Guidelines mentions that "the purpose of the Ambition Tool is to translate qualitative storylines into quantified total energy scenarios" (ENTSO-E & ENTSO-G, 2020a, p.29). The Ambition Tool is an energy model tool developed in-house by ENTSOs. It does not seem to be accessible to external parties. Therefore, it is not possible to observe how the final numbers are obtained.

- **Energy imports:** Although the focus of the TYNDP is on the European networks, it becomes necessary to look beyond the boundaries of Europe to describe future scenarios. For instance, it is stated that share of natural gas imports was 70% in 2015, but there will be an increase in the coming years. For National Trends, the import share is obtained as the difference between demand and national production. In the Global Ambition scenario, it is assumed that gas imports will remain at 2015 level until 2050. In the Distributed Energy scenario, it is assumed that the share of imports will be 35% of the total gas demand. Can these assumptions be justified? Moreover, in the scenario building guidelines (Figure 37, p. 96) it is reported that CO_2 neutral methane will be dominant in 2050. How that will be done? Is it CCS assumed for the imported natural gas? Or do we assume all of it is from renewables? In any case, other factors (e.g., the availability of gas outside the EU, future international gas prices, or climate) could affect energy security and the TYNDPs in different ways and with different level of implications. The possibilities of industrial relocation outside Europe due to EU policies could also be reflected in the scenarios. Other regions of the world are developing hydrogen strategies (e.g., Japan or USA). These strategies can have an impact on the European scenario, especially if Europe is unable to produce the amount of hydrogen needed to meet the demand.

[20] https://eepublicdownloads.entsoe.eu/clean-documents/Scenarios/190408_WGSB_Scenario%20Building%202020_Final%20Storyline%20Report.pdf.

- **Carbon emissions:** In order to limit the global warming to +1.5° C by the end of 2050, there is a maximum quantity of GHG that EU, including the energy system, can emit. In the TYNDP scenarios, the carbon target has been translated by internal stakeholders (ENTSO-E and ENTSOG) working with CAN Europe and Renewables Grid Initiative (RGI) into a carbon budget in CO_2 equivalent. The scenarios describe different roadmaps to achieve carbon neutrality while the tools to achieve these reductions could be further discussed. At present, EU Emission Trading Scheme (EU ETS) is viewed as a cost-effective emission reduction solution and it is the only concrete market-based policy tool in the scenarios as emission control instrument. Indirect effects stemming from changes in the EU ETS, energy prices, and changes in the fuel mix also have energy efficiency implications. A series of policies that improve the efficiency of energy markets and pass-through of price mechanism are further required to remove the market monopolies, and facilitate investment in green decarbonisation technologies, such as nuclear power, CCS, and Carbon Capture, Utilisation and Storage (CCUS).

- **Role of hydrogen:** In the TYNDP, as well as in the European Commission's hydrogen strategy,[21] hydrogen is viewed as one of the contributors to the full decarbonisation objectives. In these two works, domestic hydrogen is considered to be produced from electrolysis in Power-to-Gas (P2G) facilities fired by renewable electricity sources. However, it should be noted that there are other technologies run by renewable energy sources that can allow the production of hydrogen (Piebalgs et al., 2020). Different factors related to demand, production, policies, and regulation, can impact the development of hydrogen as enabler of the energy transition. Development of the hydrogen sector is also dependent on the evolution of demand by different consumer groups and their adoption of technologies to use hydrogen. Moreover, scalability in production can impose additional constraints. Finally, the choice and implementation of policy and regulation framework will ultimately determine the weight of hydrogen in the energy system. These need to be discussed in the scenarios. Will 'clean' hydrogen be cost competitive against fossil fuels in sectors in which electrification is highly unlikely (e.g., aviation or maritime transport)?

- **Role of GDP and effect on demand:** GDP is an indicator that reflects the economic activity of a country for a particular year. Traditionally GDP has been correlated with energy consumption and environmental impact. However, these correlations will likely be increasingly challenged by resource decoupling (i.e., economic growth will be less dependent on energy consumption over time) and impact decoupling (i.e., economic growth will have reduced impact on the environment). Therefore, there are two major sources of uncertainty related to GDP for the development of energy scenarios. The first is related to the prediction of GDP itself. The second has to do with the level of decoupling between GDP, energy use, and environmental impact that will be achieved. The TYNDP 2020 scenarios "draw extensively on the current political and economic consensus" (ENTSOG & ENTSO-E, 2020b, p.6), but it is not specified how this is re translated into the inputs utilised to produce the scenarios. In the scenario report it is

[21] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0301.

mentioned that the demand for both gas and electricity is driven by GDP growth among other factors at least until 2025. Moreover, it is added that the storylines assume that GDP growth is accompanied by strong energy efficiency measures, so final energy demand is reduced. The scenario building guidelines do not seem to offer further details about these high-level and general comments so the role of GDP in the scenarios and in particular on the demand and emissions cannot be addressed.

4. Interlinkage Assessment

The interlinked model initially developed for the process of TYNDP 2018 seems to have been improved for TYNDP 2020. This interlinked model is the approach to jointly create storylines and develop the corresponding scenarios for both the gas and the electricity sectors that are utilised for grid development modelling. By joining forces on building the scenarios, the ENTSOs answered to the requirement of developing an interlinked model indicated in the TEN-E regulation. Figure 5 shows the interlinked approach to the scenario building process used for the TYNDP 2018 and onwards. The building process starts with the development of common storylines that are then to be turned into quantitative scenarios. It follows a data collection process driven by common inputs but conducted independently by ENTSO-E for the electricity data and ENTSO-G for gas data. Based on collected data the two markets are studied in separate simulations subject to coordination. The outcome of the process is the publication of the scenario report that presents the different scenarios among others along installed capacities, demand, emissions, and the energy mix.

Interlinked Model

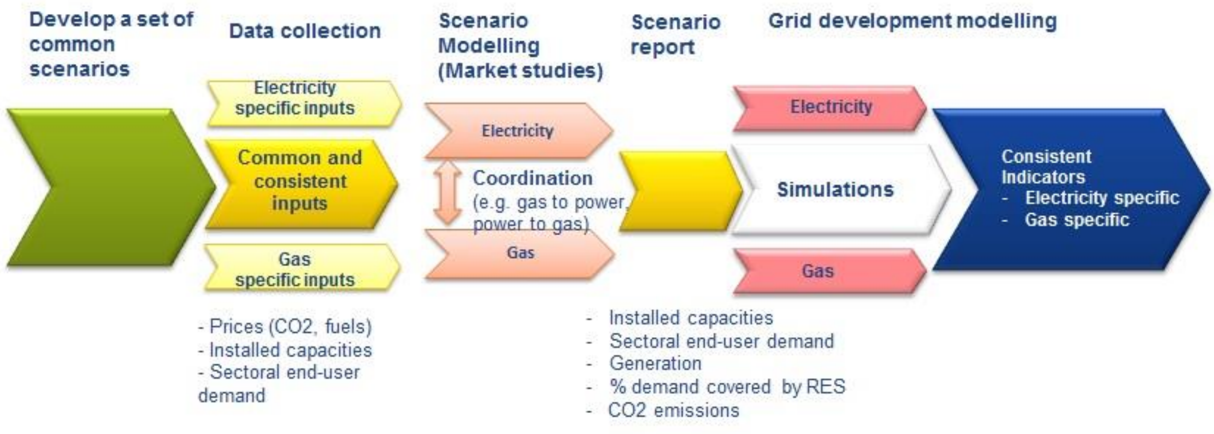

Figure 5: The interlinked model
Source: Energinet slides for the ESIG Spring Technical Workshop, 14 April 2020 (Online Workshop)

The aim of introducing an interlinked model instead of a separated process run by the gas and electricity TSO independently can be backed by the increasing number of indications that integrated energy sectors can increase the technical efficiency and reduce energy use (Cambini et al., 2020). Reflecting a level of interlinkage between the gas and electricity sector with regards to infrastructure planning is a first step and needed step towards integration.

The chosen methodology for scenario building allows for coordination and consistent assumptions among the two sectors upfront via the storylines but cannot clearly incorporate synergies due to the separated approach of demand curve construction and market simulation. Besides synergies, the independent analysis cannot account for challenges that may emerge from a closely linked and interdependent system.

Operational benefits and co-evolution of new infrastructure can in a coordinated case lead to an increase in efficiency and reaches closer to the target of energy system integration. Those effects are currently not being captured as market simulation is run independently on similar and concise assumptions.

While the overall energy sector needs to decarbonise, the dependencies of the two targeted sectors shift position. Gas has up to now served as source for electricity through Gas-to-Power technologies. In the case of a decarbonised gas sector electricity will need to serve as source for the gas sector. Existing infrastructure can support in both ways: stabilise and flexibilise the electricity sector while maintaining and making use of current/existing infrastructure. This raises the question if increased number of links between existing infrastructure may be able to serve as a buffer and avoid new investments. Moreover, some of the links to couple both gas and electricity sectors are expected to take place at the distribution level, something that needs to be reflected in the recreation of an integrated energy system. The lack of interlinked modelling in the phases of simulation does, at present, not allow to gain insights about this aspect.

As also shown in Figure 5, Power-to-Gas is the only explicit link between the sector along the modelling. Gas-to-Power is an existing and traditional approach to power generation and cannot be considered as an increased representation of linkage. While National Trends scenario measures Power-to-Gas capacity along with excess electricity from the power market simulation, the remaining scenarios add capacity for Power-to-Gas separately and feed this back into the simulation of gas and electricity markets. It is not clear how this makes use of synergies and co-benefits and does not lead to overestimation of capacities and thus overinvestment into infrastructure. Moreover, looking forward, is it important to recognise that system integration will not automatically happen if there are no markets and regulation frameworks that support the interlinkages of the sectors, for example by creating level playing field between different energy vectors.

5. ECONOMIC CONSIDERATIONS AND ANALYSIS

The previous section discussed some critical aspects of the TYNDP scenarios that can be considered as general criteria to describe good scenarios. This section offers some suggestions about economic aspects to be reflected in these scenarios. As previously mentioned, a well-functioning coupled electricity and gas system (or a system that incorporates additional sectors) will not only depend on physical solutions, but also on appropriate regulatory, economic, and policy settings (Jamasb & Llorca, 2019). Therefore, scenarios should consider these aspects to better represent alternative pathways. While some of the points made in this section may seem as out of the scope of the scenarios, it should be noted that, for the purpose of consistency, these aspects cannot be ignored in scenario development if they are going to be considered at a later stage (e.g., in the application of CBA).

Policy target and cost-effectiveness

When looking at scenario development, problems are challenging to define and hence results cannot be simplified in a classification of true/false or good/bad scenarios, but in a scale of better or worse. It is therefore important to find measures to evaluate the scenarios. The top-down TYNDP scenarios essentially aim to reflect the achievement of a set of specific policy targets (net-zero emissions by 2050). In orthodox economic terms, the attainment (or not) of policy targets is often evaluated through the deviation of the actual outcome from the point of maximum economic efficiency. However, it is possible to look at the use of alternative criteria when analysing the achievement of policy targets. A policy does not automatically and simultaneously achieve economic efficiency, sustainability, and equity, among which there are known trade-offs. Therefore, a sustainability target can be subject to cost-effectiveness method, in order to achieve the set target at minimum cost (which differs from economically efficient outcome). This assumes the cost-effectiveness equi-marginal principle, which implies that the marginal cost of emissions abatement should be equal across all the actors.

Network investments

In economics, traditionally there is a disagreement between Schumpeter's and Arrow's view regarding the influence of competition on innovation (which broadly could be extended to investment). Schumpeterian opinion is that monopolies favour innovation while Arrow defended that competition favoured innovation. Following the first view, monopolies could indefinitely enjoy positive economic profits and hence benefit from investment in R&D. When that is not the case, and monopolistic positions do not foster innovation, regulation is instrumental to promote it (Jamasb et al., 2020).

In general, there are three modes of developing the networks: central planning, market, and regulated (incentive based or otherwise). The TYNDP scenarios require that TSOs forecast demand and supply. Although these networks are regulated, the demand and supply take place within a certain market framework. Although difficult, the features of that market need to be discussed and taken into account. Generation and network development are coordinated. Markets signal to networks and networks signal to markets for efficient development and use of the markets. Demand, supply, market type, technology, geography, etc., all play a role.

In general, there are potential alternatives to network investments: (1) demand side response, (2) distributed generation, (3) storage, and (4) alternative fuel or energy source. Although some of these are included in the scenarios (e.g., in the Distributed Energy scenario, small scale solutions and prosumers have a key role), a deeper discussion on the suitability and the impact of these alternatives and subsequent analysis would be beneficial for the presentation of the scenarios.

Prices and discounting

Prices send strong signals that influence the development of energy sectors. Information about input prices in energy generation, consumer/industrial prices in the energy demand, or capital costs of adopting distributed generation technologies by households or communities, could serve calculation of price elasticities and elasticities of substitution that reflect the sensitivity of these variables to changes in others (e.g., substitution effect between gas and electricity after changes in their prices).

The use of sources such as IEA's World Energy Outlook 2018 (New Policies), Bloomberg NEF, IHS Markit or PRIMES, to provide and benchmark energy and carbon prices is acknowledged in the reports. However, it is not clear how these have been reflected in the models, and how the different prices influence each other. It is possible that some of the prices are correlated (Naeem et al., 2020). Moreover, it is important to examine the prices of related sectors that can influence the scenarios. For instance, if a large share of biomass is from purposefully grown energy crops instead of waste, agricultural prices should somehow be incorporated in the model.

Although the application of CBA to assess candidate PCIs comes at later stage, another important aspect that would need to be addressed in the scenarios is discounting. For instance, in the scenarios building guidelines the competitiveness of electrolysers is based on Capex, Opex, gas and CO_2 prices, and the application of a 4% discount rate over 25 years (ENTSO-E & ENTSOG, 2020b, p. 135). However, there is no additional information on how this discount rate is calculated, what it includes, and when and where it is applied. Moreover, discount rates for other technologies are not explicitly mentioned, but it makes sense to assume that there is some implicit discounting. It is important to note that the forecasting exercise carried out in the TYNDP may differ depending on the type of discount rate chosen. As discussed by Schittekatte et al. (2020), energy infrastructure projects are capital intensive in which both private and environmental costs and benefits are unevenly distributed over long periods of time, so it is crucial to discuss the calculation of these discount rates which in fact would need to be 'social discount rates' that tend to be lower than private ones and need to be subjected to scrutiny and sensitivity analysis.

Sensitivity analysis

It seems that the TYDNP suggests that having three scenarios is a form sort of sensitivity analysis. However, this does not seem sufficient. Ideally, the sensitivity analyses should consider the different risks and uncertainties in the scenarios. The application of sensitivity analysis serves to evaluate the robustness of the approach by looking at how model's outcomes respond when key variables and parameters are modified. Ideally, we should try to avoid that scenarios represent 'unstable equilibria', in the sense that small disturbances in one or a few of these variables or parameters imply large changes in the outcomes of the model. If that is identified as a problem in the TYNDP, then that would undermine the trustworthiness of the scenarios. This is much related to the issue of uncertainty. If high levels of uncertainty are identified and the model is particularly sensitive to the variations of input values, the chances that the scenarios fail to correctly describe the alternative futures are very high. Therefore, there is the need to identify the key parameters of the model and carry out sensitivity analyses. Some possible key parameters for TYNDP scenarios may be pointed out by (Chyong et al., 2021). Due to their condition of flexibility providers in a decarbonised energy system, the authors run sensitivity analyses for a set of cost parameters in the areas of networks, system integration technologies, and storage technologies.

There are different options for sensitivity analysis that can yield different results (e.g., Monte Carlo or one-factor-at-a-time methods). Moreover, it is important to identify that some of these approaches may have some limitations. For instance, one-factor-at-a-time approach, although very popular and intuitive (Czitrom, 1999), is not an efficient way to solve issues unless you are dealing with a very simple problem. This type of method does not allow for identification of correlation between variables. In some contexts, such correlation or interaction may be considerable. It is generally better to perform a Design of Experiments (DOE) rather than change parameters one-factor-at-a-time.[22]

We can describe the application of sensitivity analysis in the economic assessment of grid planning through the following steps:

- Identify specific economics effectiveness evaluation indicators as the object of sensitivity analysis.
- Selecting the uncertainties to be analysed (e.g., energy efficiency, demand, CO_2 prices, population growth and costs of technologies such as CCS, P2G, biomethane, heat pumps, and electric vehicles). It is not necessary to carry out sensitivity analysis on all uncertainties, because some uncertain factors have minimal impact on scenarios outcomes.
- Determining the sensitivity of the economic impact evaluation indicators to various sensitivity factors.
- Identify the most sensitive factors of the project through analysis and comparison. According to the calculation and analysis results of the previous step, compare the different magnitudes of change of the same economic effect evaluation index caused by each sensitive factor under the same magnitude of change, and select the factor that causes the greatest magnitude of change as the most sensitive factor. The most sensitive factor is the one that causes the greatest change; the factor that causes the least change is the one that is not sensitive.

No-regret and co-benefits

The scenarios show the alternative paths towards decarbonisation. However, they should pursue this objective in such a way that maximises the total value of achieving the target. This requires how to maximise the co-benefits of decarbonisation. While the benefits of carbon reductions are global, the positive effects of the co-benefits are more direct at local/regional/national level. Therefore, although the global focus of the scenarios is on the delivery of a low carbon energy system for Europe by 2050, it would be necessary to quantify the associated co-benefits.

No-regrets decisions are those that are worth to be made no matter what happens in the future, which includes the worst-case scenario (Heltberg et al., 2009). In the context of the European energy networks, this would represent projects in which there is a net benefit regardless the scenario that actually plays out. To the extent possible the scenarios should encourage no-regrets strategies in the sense that they lead to projects that deliver benefits in alternative scenarios. However, the idea is that the no-regrets strategy is internally

[22] In DOE, all parameters settings are modified together. This implies most precise estimates of the effects of each factor, systematically estimation of factor interactions, improved prediction of the response in the factor space, and more efficient process optimisation.

consistent within each scenario. Therefore, this should not imply that a project that delivers a low net benefit in three scenarios should be preferable to one that delivers a very high net benefit but only in one of them.

Equity and Impact on consumers/citizens/taxpayers

Funding of the energy infrastructure is expected to differ between the three scenarios, especially when comparing the Global Ambitions (centralised) scenario with the Distribution Energy (decentralised) one. Although we understand that the main objective of the scenarios is to describe different paths towards a decarbonised future, some examination of their impact on countries economic welfare and inequality would be useful and informative.

Although CSEI is aware that it is not the intention of ENTSOs to favour some scenarios over others, similarly to the issue of cost-effectiveness, it is important to evaluate the scenarios and offer estimates of 'who' will burden the costs. Even if identifying equity aspects are not an explicit purpose of the scenarios, they need to be incorporated due to their influence in the future realisation of the scenarios, for instance in the form of public opposition to certain policies or projects.

Behavioural aspects and public acceptance

Behavioural aspects should be explicitly accounted for in the scenarios due to the way they may affect the patterns described. For instance, energy efficiency improvements and a decline in final use demand are assumed until 2050. However, these assumptions may be overlooking the phenomenon known as the rebound effect in the different sectors. Rebound effects describe situations in which potential energy savings after energy efficiency enhancements are not fully achieved (Gillingham et al., 2016; Orea et al., 2015). Energy efficiency improvements implicitly represent a drop in the marginal cost of providing a certain level of energy services, which may lead to an increase in the demand for those services and consequently to decreases less than proportional (or even increases) in energy consumption. We have not seen any reference to this phenomenon in the scenarios when the assumptions about energy efficiency improvements are discussed. This is a consideration that needs to be taken into account. If the size of the rebound effect is significant but it is disregarded, the gains from energy efficiency improvements may be overestimated.

There are other relevant behavioural aspects that can impact different sectors of the economy. For instance, in the case of passenger mobility, the improvement of public transport, popularisation of car renting, carpooling, or biking, and the evolution of fuel and electric vehicle prices, are factors that will shape the sector and consequently will have an influence on the energy industry. In general, it is not clear how these aspects are treated in the scenario development. These are some examples where their role is not entirely clear:

- In the Distributed Energy (DE) scenario, the role of prosumers is acknowledged: "A key feature of the scenario is the role of the energy consumer (prosumer), who actively participates in the energy market and helps to drive the system's decarbonisation by investing in small-scale solutions and circular approaches" (TYNDP 2020 Scenario Report, page 14). What is an active participation of a consumer in the energy market? A prosumer is an agent who consumes and produces electricity, but this does not necessarily mean that also participates in the market. Participating in a market might be related to changing the consumption profiles according to the market prices,

offering their flexibility to the market. How behavioural issues, incentives, etc., are addressed in this scenario?
- It is also said that the scenarios capture "behavioural changes where consumers actively reduce demand either by utilising more public transport or modifying heating and cooling comfort levels" (ENTSO-E & ENTSOG, 2020c, p. 18). Here the same question arises. How are these behavioural changes addressed?

In addition, social aspects such as public acceptance of infrastructure projects also deserve attention for scenario development. Despite the signing of the European Green Deal and the global perception that the energy sector needs to undergo a major transformation to be in the path of full decarbonisation, individual projects quite often face local opposition that may end in cancelations and delays (Tobiasson et al., 2016; Tobiasson & Jamasb, 2016). In particular, increasing public acceptance of new electricity interconnector projects is crucial for the success of EU's internal energy market (Vasilakos & Sikow-Magny, 2019). This problem needs to be incorporated in the scenarios along with the recognition that non-monetary factors are essential in forming public acceptance of infrastructures and need to be considered in the design and selection of development options. The problem of public acceptance in infrastructure projects is mostly a local issue. To make the scenarios more informed about this issue, it could be incorporated in an aggregated manner through constraints in the assumptions of the scenarios (for instance, in the assumptions for certain controversial solutions and technologies such as nuclear, biofuels or hydrogen).

6. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE

In this report CSEI analyses the TYNDP 2020 scenarios to better understand the approach utilised for building them and identify possible methodological gaps. This assessment aims to undertake a constructive assessment of the scenarios from an economics perspective. We identify several areas of improvement, discuss the main assumptions, assess sector interlinkage, and provide some further insights based on economic principles for improving future scenarios. In this section we propose a set of recommendations based on the abovementioned assessment. We acknowledge that considerable effort has been invested by ENTSOs in developing the current scenarios and point out, that the expertise gained through this exercise over the years need to be preserved.

The recommendations in this report are motivated by the desire to contribute to the improvement of future TYNDPs and scenarios, improve communication of the results, and raise the confidence of third actors in them. It should be noted that some of these recommendations do not directly refer to the need for methodological improvements, but to the framework in which the scenarios are developed. Although these recommendations seem to go beyond the mere 'technical' evaluation of the methodology, organisation of the tasks and process influence the outcome and hence deemed as relevant for the scope of the assessment. Therefore, our recommendations are organised as methodological and organisational.

Methodological

1. The communication and dissemination of the documentation of the scenarios need to be made clearer. There are different versions of the reports available online (for public consultation, for ACER opinion, etc.). While these new versions identify the month and year of publication, there have been instances of drafts with no identificatory information. This should be avoided in the future for the benefit of clarity. Moreover, large amounts of the data from the scenarios have been made available online. However, these should be organised to include descriptive information, source, and reference to the part of the scenarios in which these data are utilised.

2. Scenario descriptions, assumptions and analysis need to be made more transparent, accessible, and replicable. The use of open access models could help to improve these aspects. The inclusion of equations and programming codes in the reports would also be an important step forward. This information could be included in appendices or online. Academic conventions for peer review and replicability of scientific work can be a useful guide.

3. The scenarios have economic implications. Therefore, these need to be made explicit and translated into an economic assessment. The cost of achieving the climate neutrality goals under the different storylines should be quantified. A Business-As-Usual (BAU) scenario, which is by default a 'behind the target' scenario, could be used as a baseline to analyse cost-effectiveness. Moreover, to the extent possible the scenarios should be relatively stable and evolve smoothly over time, instead of presenting a different snapshot of pathways developed from the scratch when TYNDPs are presented every two years.

4. The different types of uncertainties such as economic, technological and demand need to be made explicit and then subjected to sensitivity analysis (e.g., energy efficiency, demand, CO_2 prices, population growth and costs of technologies such as CCS, P2G, biomethane, heat pumps, and electric vehicles). These can include rebound effect and its link to implementation of the energy efficiency first principle. One of the

consequences of decarbonisation of the economy is decoupling of economic growth from energy use and carbon emissions. Therefore, conventional assumption of the relation between economic growth and energy may no longer hold in the long run. This uncertainty needs careful consideration in the scenario analysis.

5. Currently, the development of storylines and the production of the final report seem to be jointly undertaken by ENTSO-E and ENTSOG. The data collection and modelling are developed in parallel with some level of coordination. The building of the scenarios should become a fully integrated exercise between ENTSOs that appropriately reflects future interlinkages between gas and electricity. This needs to be achieved through joint sector modelling.
6. Sector coupling will inevitably require integration at distribution level and a proper modelling of an interface TSO/DSO. Coordination with DSOs and practical implications of this development should be considered.

Organisational

The TYNDP exercise is an extensive undertaking that requires resources and coordination. The process is also repeated every two years. Once this fact is internalised by the ENTSOs and reflected in streamlining the preparation and organisation of the work the process should be expected to improve. Moreover, the stability of scenarios over time and the use of open-source modelling would help to simplify the scenario development. Likewise, over time, the communication and dissemination of the outputs should also be expected to be enhanced.

Many organisations and companies, including energy utilities, conduct and report modelling and forecasts on regular basis. Admittedly, the task of the ENTSOs is more demanding. Also, a distinct feature of the TYNDP exercise is the large number of stakeholder members of the ENTSOs. Consequently, the task of coordinating the interests of the members acts as a form of transaction cost to the ENTSOs which requires time as a scarce in the TYNDP process.

1. The various stages of a TYNDP cycle involve significant efforts by the ENTSOs in relatively short time. The outcomes of the exercise will have significant long-term energy and financial implications for the European energy sector and economy. It therefore is crucial and beneficial to all parties to ensure that the TYNDP process is sufficiently resourced.
2. Considering the knowledge, experience, and the position of ENTSOs in European energy infrastructure, they are in an advantageous position to produce good scenarios. In addition to their importance in the TYNDP process, the scenarios represent a useful instrument for the ENTSOs and their members. It is difficult to perceive scenario development without active participation of the ENTSOs.
    a. However, due to the direct influence of the scenarios on PCI selection, scenarios could be considered to be approved by the European Commission. Moreover, it is possible to distinguish between three distinct elements of a scenario: the storylines, the assumptions, and the modelling and quantitative exercise.
    b. The scenario storylines and assumptions could additionally be subjected to early approval of the European Commission, having done so the task of modelling and quantitative analysis can then be delegated to the ENTSOs.

c. ACER and ENTSOs represent a diverse set of interests of a diverse set of stakeholders. The scenario building process can be aided through structured recommendations by an advisory board composed of ACER, ENTSOs, and other members from a broad range of stakeholders to reflect on different viewpoints.

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APPENDIX

Questionnaire to stakeholders

TYNDP Joint Scenarios Methodology Analysis

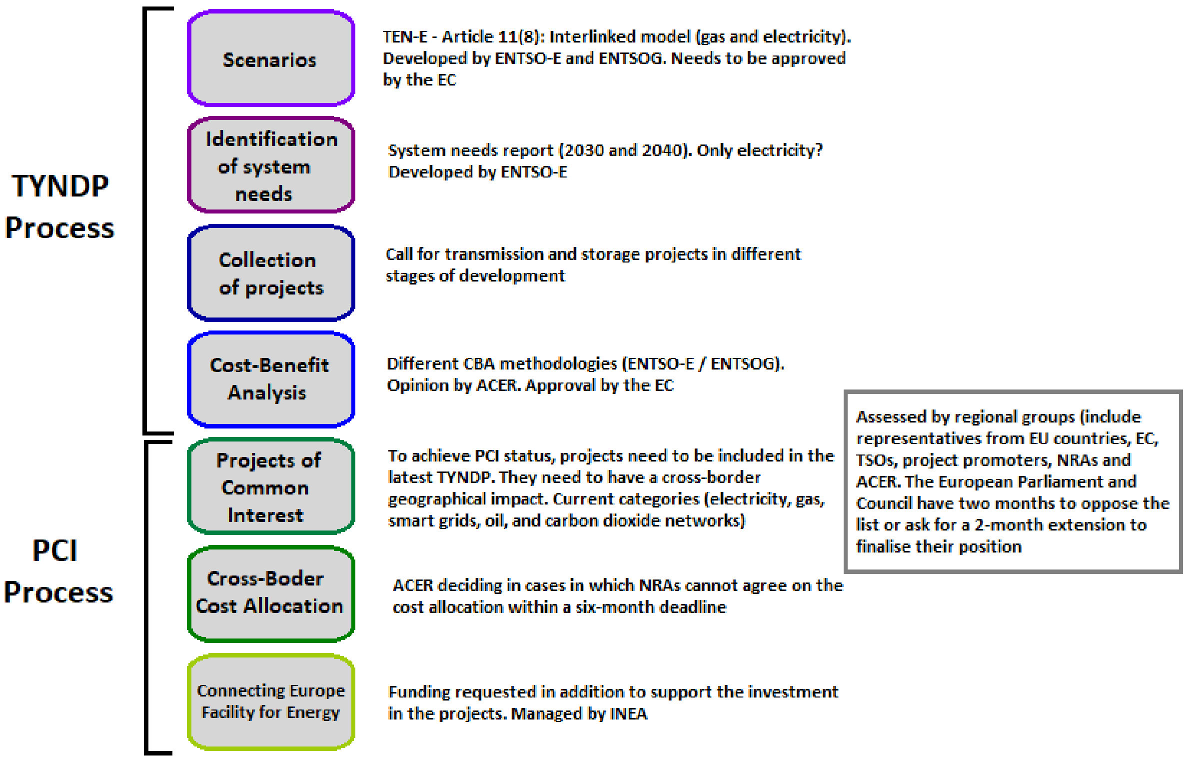
Questionnaire

Deadline: March 18, 2021

CSEI has been contracted by DG ENER to review the TYNDP 2020 scenarios report with a focus on the methodology and assumptions of the scenarios. The study will analyse the methodology, suggest improvements, and propose ways to implement those improvements.

This questionnaire will help us gain better insight for further development of the scenarios for the TYNDP process. As a major stakeholder in the European energy infrastructure sector, the experience, knowledge, and opinion of your organisation will be highly valuable for our study. Therefore, we really appreciate your efforts and time to respond to the questions below.

Prior to presenting you with the questions, we would like to share with you a diagram with a general overview of the broader TYNDP process. Do you believe there is any significant inaccuracies or missing components in the diagram?



Questions regarding the scenarios:

- How would you describe the methodology or approach utilised in the development of the scenarios? How would you asses them in terms of their 'transparency', 'accessibility', and 'consistency'? Do you think these aspects could be improved? If so, how? Do you envisage any implementation issues?
- Apart from transparency, accessibility, and consistency, what other criteria do you think define a good scenario? Do you feel TYNDP scenarios fulfil these criteria?
- In your opinion, to what extent do the scenarios serve their intended purpose?
- Do you believe 'uncertainty' has been properly addressed? What are the biggest uncertainties you can foresee in the pathways to the 2050 goals? And in the short term?
- What alternative approach(es) for scenario development (e.g., agent-based models, dynamic stochastic general equilibrium models, open energy modelling, etc.) could be applied?
- In your opinion what are the assumptions and factors (e.g., GDP or energy efficiency growth) that, if modified, should have the largest impact on the scenario outcomes? Do you think these should be treated differently in the scenario development?
- Do you feel that the scenarios are technology and energy-carrier neutral as stated in the reports?
- Are the interlinkages between electricity and gas sufficiently considered? How can they be improved?
- Do you think the three main scenario storylines (i.e., National Trends, Global Ambition, Distributed Energy) are still suitable for the purpose? Would you add/remove any scenarios? If yes, which one(s)? Do you think that the end years for the scenarios are appropriate (2040 for National Trends, 2050 for Global Ambition and Distributed Energy) or would you suggest something different?
- Has your organisation felt satisfactorily involved in the development of the scenarios? If not, do you have any suggestions of how that could be enhanced?
- How do the scenarios represent the interests and objectives of your organisation/sector?

Final open-ended questions:

- In your opinion what are the main strengths and weaknesses of the scenarios?
- Do you have any suggestions of how the scenarios could be improved in terms of storylines, methodology, and assumptions?
- How do you envisage the acceptance of the scenarios by stakeholders could be increased?

Thank you for your collaboration.

Your input will be used for the mentioned study by CSEI. By delivering your input, you agree, that the information provided by you can be included in the study. You also agree, that CSEI mentions your organisation (and name if applicable) as a contributor to the study. However, the study will not attribute specific information, comments, or views to specific contributors.

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MJ-02-21-891-EN-N

Publications Office of the European Union

doi:10.2833/872954