Storylines for Low Carbon Futures of the European Energy System exchange format and template

DELIVERABLE NO.7.1

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 835896

Deliverable No.	D7.1	Work Package No.	WP7
Work Package Title	Transition Pathways		
Status	Final Version		
Dissemination level	Public		
Due date deliverable	2019.11.30	Submission date	2019.11.30
Deliverable version	V12		

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History of Change

Release	Date	Reason for Change	Status
Draft	2019.11.20	Implemented feedback to ch. 4	included
Apply review feedback	2019.11.29	Inputs from quality reviewer	completed
Final version	2019.11.30	Final quality check and minor improvements. Also, included additional feedback from partners	Final

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Table of contents

Glossary

Storylines: A storyline is a narrative describing a possible future energy world. In the openENTRANCE project, we as the storyteller do not insist that this future energy world will occur and hence interpret the narrative in the sense that the story is a vision or idea of the future. There are too many uncertainties at present that somebody can predict one (or a most probable) robust long-term future development. Therefore, usually a number of different narratives or storylines of possible future developments are told, in order to take into account several possible determinates of uncertainties, on the one hand, but also try to span the entire possible future "development space" when telling the different stories, on the other hand. In reality, in the future, only one storyline (or a combination of several) will become true as it is simply not possible to anticipate which storyline it will be. Therefore, a storyline is a narrative only without any opinion, estimation, judgement or prediction if or if not one storyline will become true with higher probability.

Scenarios: When explaining (quantitative) scenario development in the context of narrative storyline descriptions (qualitative), it is important to note that: i) a variety of different scenario studies can be conducted inside one storyline, and ii) consistent and coherent scenario studies always can be conducted inside one storyline only, not across different storylines. In general, a scenario is a counterfactual development, usually compared to a baseline or reference. This means, that inside a storyline we have a variety of different options, strategies, technologies potential or policies (described by corresponding parameters that deviate from a reference case) we can apply. This results in a variety of different scenario outcomes inside a storyline.

- Doing so, we are able to quantify the possible solution space of the range of different scenarios inside one storyline.
- The scenario set-up (parameters, parameter settings, etc.) is tailor-made to an individual storyline. This means, that alternative storylines expect new, tailor-made scenario set-ups from the scratch for each of the storylines.

Pathways: In general, pathways are quantitative, numerical evaluations and/or trajectories of scenarios combined with storylines, incorporating also additional syntheses in terms of barrier analyses, policies and regulatory needs. The pathways delivered in the openENTRANCE project will be based on consistent and coherent combinations of:

- storylines that consist of narrative descriptions of possible future energy worlds
- a variety of quantitative scenario and case study analyses inside each of the different storylines and finally
- the synthesis/analysis on macro-economic effects and barriers as well as recommended policies and regulations.

1. Introduction

1.1 Background

The mitigation of the increasingly visible events and consequences of global warming and climate change are one of the biggest challenges of humankind. Ultimately, a global effort is necessary to implement corresponding corrective actions and strategies. A key aspect in this context is to limit GHG (greenhouse gas) emissions in the future. One of the most prominent representatives in terms of emissions is CO2. Moreover, limiting the remaining global CO2 budget in the energy and transport systems is one of the key necessities to comply with a maximum global temperature increase.

The European Commission is fully committed to several climate-related challenges and takes responsibility for immediate decisive policy actions necessary. Recently, in November 2018, the long-term strategic vision to reduce GHG emissions was presented, indicating how Europe can lead the way to climate neutrality (an economy with net-zero GHG emissions) in 2050 and beyond. Strategies and options have been explored on how this can be achieved by looking at all the key economic sectors. Anticipating climate neutrality in 2050 in a global context (i.e. 100% GHG emission reduction compared to 1990 level) would limit global temperature increase to 1.5 °C, and avoid some of the worst climate impacts and reduce the likelihood of extreme weather events and others.

Logically, Europe cannot decide on policies and strategies on global level. However, Europe at least can act on the leading edge of implementing climate mitigation policies in Europe and thus act as a global role model. In the context, one of the main challenges is to anticipate the future development of the energy system. This, however, is not easy. From today's point-of-view, it is virtually impossible to anticipate how a future energy system will look like in detail. Too many uncertainties in terms of possible future developments exist. Therefore, it is important to consider at least future narratives in terms of possible developments, cornerstones and features of a future energy system.

This is exactly, what this document, Deliverable D7.1, is about. The overall motivation of this document is to develop narratives of a few realistic and possible future energy worlds. It is important to note here, that the storyteller does not have any preference about one (or a most probable) future development. On the contrary, several of the possible narratives presented in this document can happen in the future likewise.

1.2 Objectives and scope of this deliverable

The overall objective of Deliverable D7.1 is to define the storyline "frames" of the openENTRANCE project in qualitative terms. This is used later on as a skeleton for subsequent quantitative scenario studies describing possible future pathways of the European energy system.[1] Without suggesting a preference of any of the possible future narratives developed, these consistent and coherent frames shall enable the implementation of a structured approach for quantitative scenario studies. The novelty of the openENTRANCE project concept is that the quantitative scenario studies are not only conducted by the project consortium, but they are openly available along with the open energy system model that will be used to generate these scenarios to third parties, e.g. researchers, stakeholders, decision and policy makers. Moreover, building upon the qualitative narrative/storylines[2] implemented in the openENTRANCE project, any third party user can verify and adjusted existing scenarios as well as conduct own tailor-made scenario studies in the open platform delivered in openENTRANCE. Thus the entire concept in openENTRANCE, qualitative storylines and quantitative scenario generation, should be "intuitive" and easy to understand and building upon the status-quo of knowledge and modelling expertise in scenario generation in energy system analyses.

In order to thoroughly consider the state-of-the art of knowledge in this field of research, on the one hand, and to quarantee the acceptance of the open platform delivered to the community, on the other hand, the openENTRANCE approach is founded on the following two main conenerstones from the very beginning of its development:

- The exercise of storyline definition in qualitative terms has been conducted in close coordination with external stakeholder consultations (both physical and web-based meetings as well as written feedback) and the partners of the whole consortium. The consolidated propositions presented in this document aim to give consistent narratives and guidelines as an input to perform quantitative scenario and case studies in the openENTRANCE project.
- Prior to the definition of the storylines, a comprehensive literature survey in terms of existing low-carbon pathway studies has been conducted. This task has been conducted in T7.1 "Surveying Pathways in recent studies and outcomes of related projects" of the openENTRANCE project and is presented in Chapter 2 of this document. This status quo analysis reviews exiting work and scenarios proposed by the European Commission and other related work and is used

[1] This is an immediate outcome of Task 7.2 "Pathways storyline definition" of WP7 in the openENTRANCE project. In general, the time perspective for the storyline/narrative description in openENTRANCE uses 2050 as a target year. However, it is important to note that based on a technology portfolio available or already implemented in 2050 it is also possible to conduct quantitative scenario studies for target years envisaged beyond 2050. E.g., this is important when considering a "zero GHG emission target year" beyond 2050 in the scenario studies not compliant with the global temperature increase limit to 1.5 °C.

[2] The storyline terminology used is preferentially in the openENTRANCE project context.

as a starting point for openENTRANCE. In other words, it provides an overview of main narratives and quantitative pathways developed in past projects. The objective is to understand how they have defined and created narratives describing the evolution aspects of society, policy and technology. In addition, this review summarizes the main findings and key insights achieved in the H2020-LCE21 Projects and discusses the ideas and approach for storyline and pathways definition.

Based on both inputs from external stakeholders and insights gained from the status quo analyses, the ambition of the openENTRANCE approach is to deliver progress beyond the state-of-the art, and to better understand the interplay between different uncertain developments/dimension, mainly driven by public attitude and societal behaviour, technology novelty and innovation as well as politics, policies and markets. Moreover, openENTRANCE tries to even better link and combine several other drivers responsible for a particular future development determining the structures and features of an energy and transport system in the long-term. Last but not least an important aspect of openENTRANCE storyline and scenario development is to better link climate modelling and energy modelling. This means that several climate-related aspects and interdependences need to be better combined and aligned with storytelling in the energy and transport sector. The openENTRANCE approach accepts this challenge.

At the end of this document, some initial ideas on the implementation scope (methodological approach) are outlined in terms of practical quantitative pathway generation, how to interpret the pathways and how to use the fully open modelling platform in openENTRANCE for tailor-made quantitative pathway generation.

1.3 Structure of this report

To present the foundations of the openENTRANCE storyline framework, this report is organised as follows:

- Chapter 2 presents a survey on existing storyline, scenario and pathway determination from a global perspective first. Then it focuses on EU efforts outlining possible future energy system both qualitatively and quantitatively. Subsequently, related recent European projects in this context are described.
- Based on the lessons learnt in Chapter2, Chapter 3 presents a discussion to better understand uncontrollable uncertainties and possible disruptions on determining a future energy system, on the one hand, and controllable options, strategies and policies, on the other hand. This shall support the development of an advanced storyline approach clearly beyond the state-of-the art practise and be part of the openENTRANCE project scope.

- Chapter 4 presents and discusses a novel three-dimensional storyline topology developed in openENTRANCE. This topology opens the creation of four storylines. The main drivers, features and assumptions of them are outlined and discussed.
- Finally, Chapter 5 briefly outlines the cornerstones of the fully open platform in openENTRANCE developed in subsequent work packages of this project enabling quantitative pathway scenario implementation.

2. Scenarios and pathways definitions: an overview

Scenario building exercises to some degree take into consideration technology development, energy markets, policies and geopolitical considerations, climate adaptation and mitigation, societal attitudes and others factors as part of their scenario assumptions. Typically, the climate targets and the context greatly influence the pathway perspective and its main narratives. In this regard, multiple scenario and pathways studies and literature focus on a global, continental, or country wise perspectives and their respective energy transition challenges. This chapter presents a descriptive overview on relevant existing work on defining scenarios from a global perspective and specific studies related to the European energy transition. The objective is to provide an overview (not a critical review) of the different forms of storylines, scenario and pathways definitions.

2.1 IPCC and global perspectives

The Intergovernmental Panel on Climate Change (IPCC) uses external research inputs to produce comprehensive assessments reports about the state of the scientific, technical and socio-economic knowledge on climate change, its impacts on future risks as well as the possible options that can be selected for reducing the speed of climate change.

The earliest scenario building exercises for reaching climate targets were built by IPCC in 1990. The IPCC has used emissions and climate scenarios as a central component of its work of assessing climate change research. At this stage, the IPCC developed its own scenarios by convening authors and approving the scenarios internally. Previous IPCC scenarios include the 1990 IPCC Scenario A (SA90) in for the First Assessment Report (FAR), the 1992 IPCC Scenarios (IS92) used in the Third Assessment Report (TAR) and the 2000 Special Report on Emissions Scenarios (SRES) in TAR and the Fourth Assessment Report (AR4) in 2004. For the fifth assessment, the IPCC has decided to rely on external scenarios developed by the research community. We provide an overview of the most relevant work that has contributed on defining the framework based on which the scenarios evaluated by the IPCC have been built.

A widespread concept employed to establish a basis for the definition of climate reduction scenarios is that of Representative Concentration Pathways [1] (RCPs). Most of the literature builds around this concept, often integrating it with additional dimensions to expand the socio-economical and environmental coverage of the defined scenarios. The concept of RCP bases on the possibility of splitting the narrative of a scenario into four key dimensions: socio-economic, radiative forcing level, climate model and emissions. This partitioning allows building parallel scenarios for each of the dimensions, rather than using a single storyline involving all the dimensions. Climate lays at the core of the analysis; therefore the basic dimension used as a starting point for the scenario development is the one related to the radiative forcing, which can be defined as the difference between insolation absorbed by the Earth and energy radiated back to space. Changes on radiative equilibrium that are the causes of the temperature changes over decades are called radiative forcings. Emissions scenarios leading to different radiative forcing trajectories have been labelled as Representative Concentration Pathways (RCPs). These scenarios consider mainly the level of Greenhouse Gases emissions, the short-lived emissions and the level of Land use. The isolation of a number of interesting RCPs represents the first step for defining climate scenarios. Then these pathways are compared against a number of compatible scenarios related to the other dimensions, until choosing a single narrative for each isolated RCP. Figure 2.1 shows a visual representation of the introduced concept.

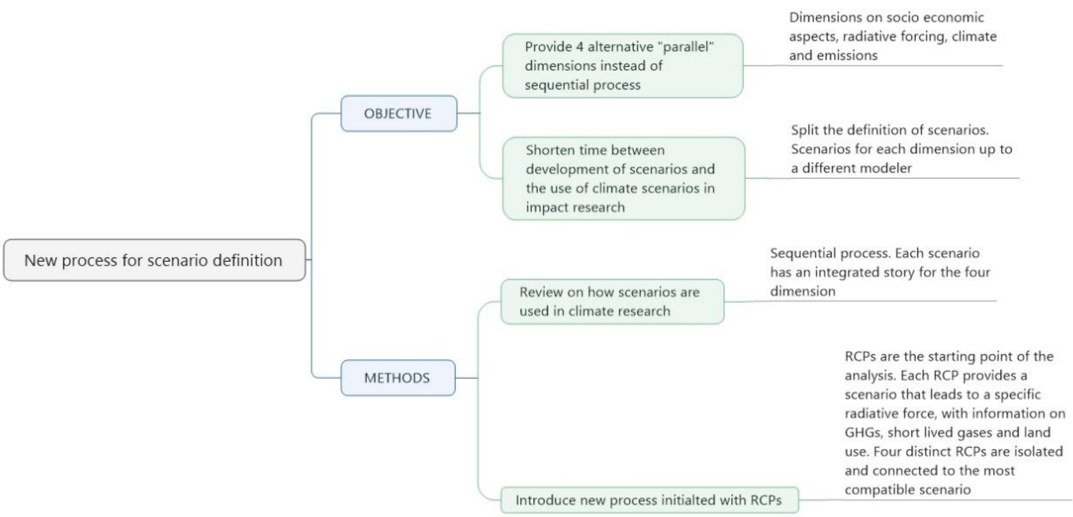


Figure 2.1 Visual Representation of Moss et al. (2010) [1]

The concept of RCPs is further expanded by [2] and showed in Figure 2.2. The authors analyse the definition of scenarios using so-called Shared climate Policy Assumptions. They claim that socioeconomic aspects, based on Shared Socio Economic Pathways (SSPs), and climate mitigations assumptions (based on RCPs) should be decoupled and used as orthogonal dimensions in a so called Scenario Matrix Architecture. SSPs normally enclose scenarios on the future economic growth, population growth and urbanization. The climate mitigation assumptions in RCPs normally only define a target, without providing information on how to achieve the target in terms of policy. The authors propose the integration of a third dimension, namely the Shared climate Policy Assumptions (SPAs) with a global coverage and shared among different studies. These assumptions include three main attributes: climate policy goals, policy regime goals and implementation limits and obstacles related to the definition of these policies. Moreover the policies are described both under the form of a narrative, describing the involved countries, the type of policy and the implementation obstacles and accompanied by quantitative information such as the extent of the mitigation targets.

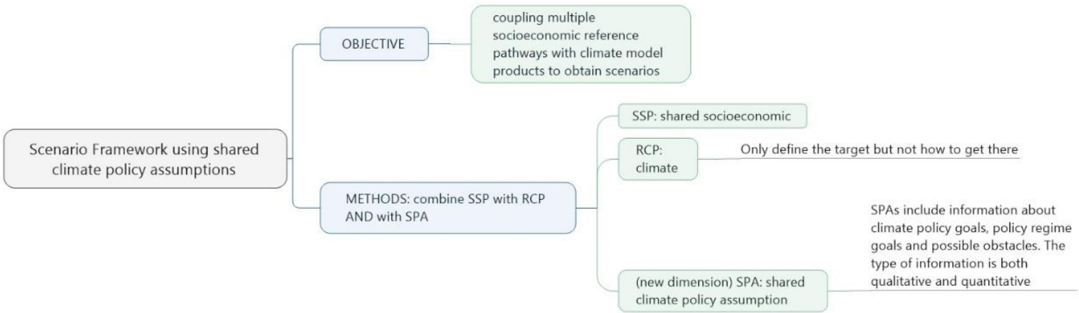


Figure 2.2 Visual Representation of Kriegler et al. (2014) [2]

The aspect of the population growth in the SSPs is tackled in [3]. They claim that a demographic evolution analysis needs to take into account a granular segmentation of the population over the dimensions of age, sex, level of education and place of residence. This allows to provide a more precise information about the future human capital related rates of fertility, mortality, migration and education levels. The SSPs are translated into a matrix grouping the considered countries by fertility levels and with different evaluations on the human capital related rates. For each of these dimensions, a different model provides future projections which are then merged to provide a unique picture of the evolution of the population.

Economic growth is considered in [4]. The SSPs are used as input to an economic growth model, based on the Solow Growth model, which considers six key drivers – physical capital, employment, human capital, energy demand, extraction of fossil fuels and total factor productivity – assigning each of these with a different growth rate depending on the selected SSP. The result is a projection of the GDP development per country. Even though the model does not consider market mechanisms for the determination of prices and lacks a solid microeconomic theoretic foundation, it is fit to provide an initial estimation of the future GDP pattern.

A good overview of the Shared Socio Economic Pathways can be found in [5] (Figure 2.3). They define the development process for the SSPs as a sequential process starting with the definition of narratives, which are then sorted by the level of challenge to adaptation. These tables serve as input to quantitative projections made with demographic and economic models. These projections include information about population growth, defined on the basis of fertility, mortality and migration rates, information about the economic activity, which use the input from the demographic growth into economic growth models such as the Solow model. Finally, based on the outputs of the previous models and the narratives the quantitative information are complemented with urbanization rates. These quality-quantity based information are used as the starting data for Integrated Assessment Models (IAM), which complement the previous information with projections for land use, energy demand and CO2 emissions. Several IAM models analyses with the same dataset provide alternative possible scenarios out of a single narrative. Thus, a subset of the total number of SSPs is isolated and defined as "marker". The marker SSPs are representatives of a cluster of SSPs and chosen based on their internal consistency and on the ability of different IAMs to highlight different features of each storyline, therefore providing information that is more comprehensive. The SSPs are then combined with RCPs and SPAs based on their mutual coherence. A comprehensive definition of the narratives for the main five SSPs used for analyses can be found in [6].

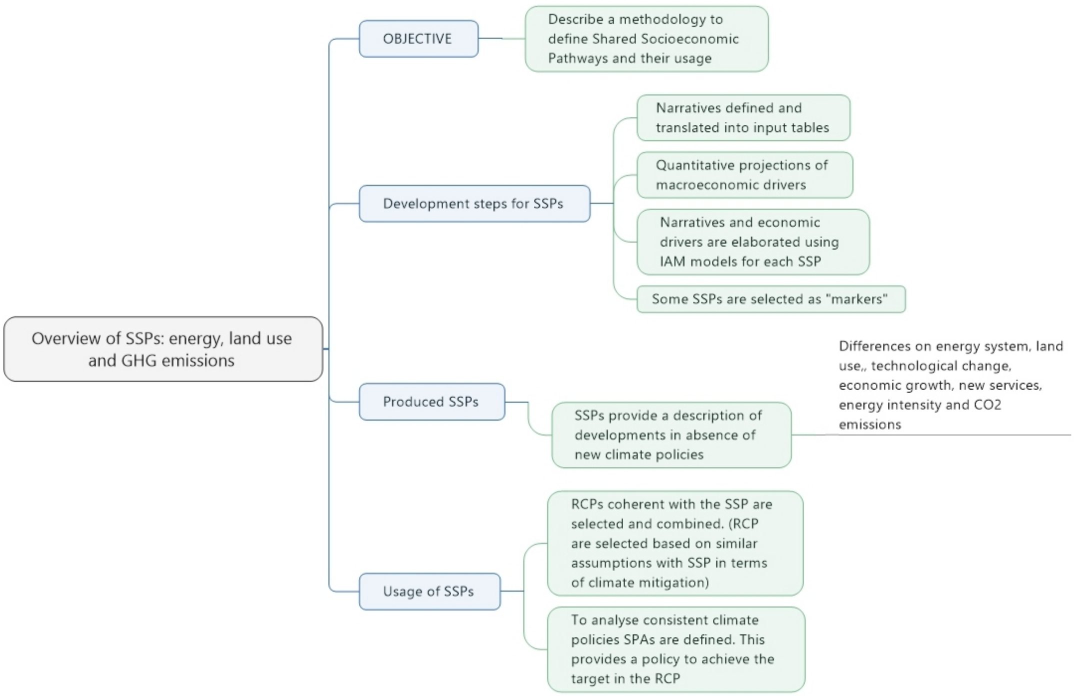


Figure 2.3 Visual Representation of Riahi et al. (2017) [5]

In [7], a case study for the quantification of a selected marker SSP is provided: the so-called SSP2 Middle-of-The-Road. The authors provide a comprehensive example of the process of selection for the quantitative assumptions for the SSP to be used in the IAM model. These assumptions cover future developments for population and economy, energy intensity (i.e. energy usage per unit GDP), fossil resources availability, bioenergy resources, technology cost developments and land use developments. For each of these dimensions, the paper provides general information on what are the drivers to be considered to formulate a quantitative assumption and deliver a projection for the considered SSP2. The quantitative assumption are then used to feed a suite of models to close the array of projections including the parameters evaluated as endogenous variables of the models. The paper also gives an overview of the suite of models used for the quantification of the scenarios and their mutual interactions. The core of the modelling suite is defined by the MESSAGE energy system model which receives information about air pollution coefficients by the GAINS model and performs a linking with the MACRO macroeconomic model. These two-model block is further linked to the GLOBIUM model, which models the level of land use. When a convergence occurs, the results are delivered to the MAGICC model, which gives responses on the climate. The paper then reports the results summary of the case study.

In [8], they point out the existing uncertainty in the future development of emissions under the different SSPs. However, they do not impute the main responsibility of the uncertainty to the scenarios themselves, but to the ambiguity in formulation of the nationally determined contributions (NDC) provided by the developing countries. Most of the developing countries provide their NDC specifications in form of potential ranges or they define them conditionally to the development of some other indicator, al the level of technological advance or international support. This ambiguity can lead to very different developments of the future emissions and might require potential costly corrective actions leading to a sudden jump of the carbon prices after 2030. Some of these uncertainties are controllable because only related to technical specifications. By requiring the involved countries to provide more precise contribution specifications as well as more precise considerations on which sources are to be accounted in the definition of the emissions it is possible to have more stable projections. Other uncertainties are harder to reduce, because they are the result of political choices and would be unaffected by technical clarifications.

The development and the analysis of a scenario fit to meet the 1.5C target is defined in [9]. The authors aim at emphasizing the pivotal role of the energy end-use side to meet the climate targets. A lower energy demand, coupled with a faster technological transition, would lead to a restructuring of the energy system allowing for renewables covering for the needed energy production and reducing the emissions. The described scenario is named LED (low energy demand) and is based on the proliferation of local, small scale and low cost energy technology, as well as on a more efficient usage of consumption goods towards a sharing economy and a more connected and digitalized society. The implication for energy are both on the demand and on the supply side. On the demand side, the scenario assumes an improved energy usage for thermal purposes as the consequence of thermal insulation interventions on buildings, an increase in more interconnected and less energy consuming devices, an industry with lower need for energy inputs and a generalized lower consumption of biofuels, because of a more efficient energy demand. On the supply side, the considered scenario assumes the proliferation of local energy production and the large scale deployment of hydrogen which together should cover close to 60% of the total final energy demand. The assumptions are quantified based on the SSP2 and analysed using iteratively the models MESSAGE and GLOBIOM as described in [7] showing that under an energy system perspective it is possible to reduce the pollutants and reach the target of 1.5C by 2050. The authors also discuss on the policy implications that need to be considered to transition into the analysed scenario.

[10] investigate on the effects of a large scale utilization of bioenergy and its relations with CO2 emissions. They run a stack of common assumptions on CO2 budget, afforestation and availability of advanced biofuel technologies (ABTs) on 11 Integrated Analysis Models and analyse the outcome. All the models consider the utilization of bioenergy with CCS, some of them encompass the production of hydrogen, in every model, fuels are combined with other primary sources to produce final energy and all models but two consider the competition for land usage between biomasses production, crops, forest and pasture land. The performed analysis spans across two dimensions: the level of emission reduction requirements and the different availability of ABTs, their cost and the time of their introduction in the system. The results vary along the utilized models, but they mostly agree on some conclusions. The CO2 budget increases the level of biofuels usage, so as it does the level of land availability. Moreover, there is significant international trade, where OECD countries are the largest consumers of biomasses, whereas Latin American countries are net exporters. The allocation of biomasses between electricity production and fuels differs along the models, while all the models agree on the fact that the transport sector will utilize also electric power and hydrogen. Finally, the degree in which biofuels will substitute conventional fuels will determine the concurrent utilization of carbon capture alongside biofuels. The sensitivity analysis on different levels of penetration of ABTs in the system result in different extents of converting pollutant energy production with a cleaner alternative with rather high impacts on CO2 prices.

Based on the SSP2 “Middle-of-the-Road” and four alternative scenarios on the level of climate mitigation, [11] project an estimation of the global investment expenditure and its technology allocation. The utilised climate scenarios span from the continuation of the current policies, the application of the NDCs pledged under the Paris Agreement to the 2C and 1.5C mitigation scenarios. These assumptions input six global modelling frameworks, each with different focus, and provide the extent of the needed investments in the energy system. In particular, the authors underline that current NDCs will not be able to initiate a transformation of the energy system, as under this assumption the increase in low carbon investment will remain below 50% of the total investments up to the end of the considered horizon. A more ambitious target of below 2C or 1.5C will instead have a negative impact on the amount of needed investments to secure a universal access to affordable energy sources, and ensure food security, while it will reduce the costs of achieving air-quality goals.

A recent narrative analysing the drivers for climate change mitigation has been developed in [12]. The paper provides four narratives covering both qualitative and quantitative aspects. The narratives are named “Business as Usual”, “Survival of the fittest”, “Green cooperation” and “ClimateTech” and are differentiated by the level of engagement of the countries in creating a cooperative action towards climate change mitigation and the level of technology available. Scenarios are initially defined as basic storylines about social, technological, economic, military, political, legal and environmental developments. These initial definitions take both a literature analysis and a brainstorming phase. In the brainstorming phase the objective is to isolate key drivers and combine them using different intensities for each driver to create many possible storylines, which are then clustered based on common themes until the definition of four main final scenarios. Then, a model that covers the whole world with certain assumptions quantifies the scenarios. The authors find that the integration of economic and energy goals across countries is of high importance for the achievement of the climate mitigation targets. This implies a strong cohesion and engagement of the civil society towards the problem of climate change. Moreover, the expansion of renewable production is not sufficient on its own to decarbonize the system.

2.2 European Commission scenarios and related studies

The European Strategic Energy Technology Plan (SET Plan) is a central element in Europe’s approach to address climate change, develop competence and strategies to achieve a low-carbon energy system. In this regard, GHG emission targets are at the centre on conducting projections and assessments to steer the development of key technologies complemented by policy measures. In this regard, the European Commission Directorate-General for Energy (DG ENER) conducts impact assessment studies that sometimes go along with policy packages for EU institutions. These analysis are quantitative based and include key visions on possible scenarios that support the framing of policy packages. In the last years, the European Commission has conducted three main impact assessment studies on policy scenarios based on technology development priorities and to outline challenges on EU committed decarbonisation targets. The following sub-sections describe the scenarios proposed under each study.

2.2.1 Energy Roadmap 2050 scenarios

The Energy Roadmap 2050 focused on sustainability, competitiveness and security of the EU energy system by analysing alternative possible futures. The main drivers and decarbonisation routes noted in the Energy Roadmap is built around four key technological developments: energy efficiency, renewable energy, nuclear energy, and carbon capture and storage. These technological choices form a roadmap combined in seven scenarios for 2050. These scenarios include assumptions on a wide portfolio of technologies, the role of consumers and investors, a specific regulatory framework [13]. In addition, these scenarios take certain emphasis on understanding the challenges and routes towards achieving the 2020 targets. Extracted from the description in [14], these scenarios main characteristics and definitions includes:

- Scenario 1 - Current Policies initiatives (1a) and Reference or business as usual (1b): These two scenarios envisions limited nuclear expansion and continuation of agreed policies. The GHG target for 2050 is 40% reduction.
- Scenario 2 - High Energy Efficiency: *"This scenario is driven by a political commitment of very high primary energy savings by 2050. It includes a very stringent implementation of the Energy Efficiency Plan and aims at reaching close to 20% energy savings by 2020. Strong energy efficiency policies are also pursued thereafter."*
- Scenario 3 – Diversified supply technologies portfolio: *"This option is mainly driven by carbon prices and carbon values (equal for ETS and non ETS sectors). This option assumes acceptance of nuclear and CCS and development of RES facilitation policies. It reproduces the "Effective and widely accepted technologies" scenario used in the Low Carbon Economy Roadmap and Roadmap on Transport on the basis of scenario 1bis."*
- Scenario 4 - High Renewables: *"This scenario aims at achieving very high overall RES share and very high RES penetration in power generation (around 90% share and close to 100% related to final consumption). Recalling security of supply objectives, this would be based on increasing domestic RES supply including off-shore wind from the North Sea; significant CSP and storage development, increased heat pump penetration for heating and significant micro power generation (PV, small scale wind, etc.)."*
- Scenario 5 - Delayed CCS: *"The delayed CCS scenario shows consequences of a delay in the development of CCS, reflecting acceptance difficulties for CCS regarding storage sites and transport; large scale development of CCS is therefore assumed feasible only after 2040."*
- Scenario 6 – Low nuclear: *"This scenario shows consequences of a low public acceptance of nuclear power plants leading to cancellation of investment projects that are currently under consideration and no life time extension after 2030. This leads to higher deployment of the substitute technologies CCS from fossil fuels on economic grounds."*

2.2.2 "Clean Energy for all Europeans" package: Reference and EUCO scenarios

The objective and scope of the "Clean Energy for all Europeans" scenarios was to assess the plausibility of the 2030 energy and climate targets of the EU [15]. The assessment horizon is up 2050 but with strong focus on the next policy package required to achieve 2030 targets. The scenarios mainly envisions a decarbonisation compatible with the 2C projection. It is framed as follows "model the achievement of the 2030 climate and energy targets as agreed by the European Council in 2014 (the first scenario with a 27% energy efficiency target and the second with a 30% energy efficiency target)" [15]. These scenarios started with the EU reference scenarios as a guiding point to then formulated 'EUCO scenarios'. The objective of the EUCO scenarios was to assess a very specific range of climate and energy targets. These are: i) GHG compared to 1990: 40% down in 2030 and 80-85% down in 2050, ii) ETS emissions: 43% less in 2030 than in 2005, 90% in 2050, iii) Non-ETS emissions: 30% less in 2030 than in 2005, and iv) Energy efficiency: reduced primary energy by 27% (1369 Mtoe) or 30% (1321 Mtoe) in 2030 compared to 2007 baseline. Figure 2.4 illustrates this family of scenarios that are briefly summarized as follows:

- Reference scenario: It is a very moderate decarbonisation scenario. It is a "Business as usual" scenario assuming no major changes on current policies and no meaningful technology developments or adoption. It reaches around 50% CO2 reductions in 2050 compared to 1990.
- EUCO 27 considers at least 40% cuts in greenhouse gas emissions (from 1990 levels), at least 27% share for renewable energy and at least 27% improvement in energy efficiency.
- Variants of the EUCO 27. As alternative strategies could emerge from strong energy efficiency measures and high RES shares in the energy mix, these scenarios address sensitivities for example under an energy efficiency of 33% (Named EUCO33) or 30% RES target (named EUCO30), see figure below.

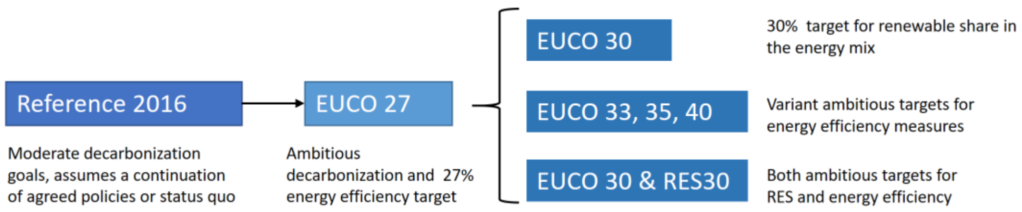


Figure 2.4 EUCO and Reference scenarios based on PRIMES model (created based on [15])

2.2.3 "A clean planet for all" scenarios

The European Commission "A Clean Planet for all" study presents a long-term vision on how "Europe can lead the way to climate neutrality by investing into realistic technological solutions, empowering citizens, and aligning action in key areas such as industrial policy, finance, or research – while ensuring social fairness for a just transition." [16]. In this report, nine scenarios consider different action areas, priorities and technological development. The study defines a baseline scenario which does not meet the GHG targets along with a set of ambitious decarbonisation scenarios. These differ on technological assumptions and emissions target. A short overview summarizes them as follows:

- An 80% GHG emission reduction (compared to 1990 levels) characterizes five scenarios. Three of these scenarios, namely Electricity (ELEC), hydrogen (H2) and e-fuels (P2X) are mainly driven by decarbonised energy carriers and examining the impacts of switching from the direct use of fossil fuels to zero/carbon-neutral carbon carriers. Other two scenarios examine how stronger energy efficiency measures (EE) or the transition to a more circular economy (CIRC) can deliver the emissions reduction target.
- The "cost-efficient combination" COMBO scenario targets a 90% emission reduction through a cost-efficient combination of the options outlined in the above five scenarios.
- Then, the next four scenarios aim at even stronger emissions reduction: reach net zero GHG emissions by 2050 to achieve a 1.5°C temperature change. In this scenario category, remaining emissions that cannot be abated by 2050 need to be balanced out with negative emissions, including from the LULUCF sink (land use, land-use change and forestry). The 1.5TECH scenario aims to increase the contribution of all the technology options, and relies more heavily on the deployment of biomass associated with significant amounts of carbon capture and storage (BECCS) in order to reach net zero emissions in 2050. The 1.5LIFE scenario relies less on the technology options of 1.5TECH, but assumes a drive by EU business and consumption patterns towards a more circular economy and (strong) lifestyle changes.

All these scenarios characteristics and main technological assumptions have been analysed and described in [16] and other related reports. This EU study is the latest analysis and communication directive published by the European Commission. Table 2.1 provides an overview based on these.

Table 2.1 Main features and building blocks of EU "A clean planet for all" scenarios (source [16])

	Electrification (ELEC)	Hydrogen (H2)	Power-t o-X (P2X)	Energy Efficiency (EE)	Circular Economy (CIRC)	Combination (COMBO)	1.5°C Technical (1.5TECH)	1.5°C Sustainable Lifestyles (1.5LIFE)
Main Drivers	Electrification in all sectors	Hydrogen in industry, transport & buildings	E-fuels in industry, transport and buildings	Pursuing deep energy efficiency in all sectors	Increased resource and material efficiency	Cost-efficient combination of options from 2°C scenarios	Based on COMBO with more BECCS, CCS	Based on COMBO and CIRC with lifestyle changes
GHG target in 2050	(-80% GHG (excluding sinks) "well below 2°C" ambition					-90% GHG (incl. sinks)	(-100% GHG (incl.sinks) ["1.5 °C" ambition]	
Major Common Assumptions	• Higher energy efficiency post 2030 • Deployment of sustainable, advanced biofuels • Moderate circular economy measures • Digitalisation				• Market coordination for infrastructure deployment • BECCS present only post-2050 in 2°C scenario • Significant learning by doing for low carbon technologies • Significant improvements in the efficiency of the transport system			
Power Sector	Power is nearly decarbonised by 2050. Strong penetration of RES facilitated by system optimization (demand-side response, storage, interconnections, role of prosumers). Nuclear still plays a role in the power sector and CCS deployment faces limitations.							
Industry	Electrification of processes	Use of H2 in targeted applications	Use of e-gas in targeted applications	Reducing energy demand via Energy Efficiency	Higher recycling rates, material substitution, circular measures	Combination of most Cost-efficient options from "well below 2°C" scenarios with targeted application (excluding CIRC)	COMBO but stronger	CIRC+COMBO but stronger
Buildings	Increased deployment of heat pumps	Deployment of H2 for heating	Deployment of e-gas for heating	Increased renovation rates and depth	Sustainable buildings			CIRC+COMBO but stronger
Transport sector	Faster electrification for all transport modes	H2 deployment for HDVs & some for LDVs	E-fuels deployment for all modes	Increased modal shift	Mobility as a service			• CIRC+COMBO but stronger • Alternative to air travel
Other Drivers	-	H2 in gas distribution grid	E-gas in gas distribution grid	-	-	-	Limited enhancement natural sink	• Dietary changes • Enhancement natural sink

2.3 Recent EU scenarios from H2020 LCE 21 2015 projects

As part of the EU Horizon 2020 research program, four research and innovation action projects addressed the common goal of identifying and analysing effective strategies for a transition to an efficient low carbon energy system. The scope of the LCE 21-2015 call aimed at "Modelling and analysing the energy system, its transformation and impacts" by building knowledge and understanding technology policy measures in the framework of the SET-Plan. These projects are:

- SET-Nav "Navigating the Roadmap for Clean, Secure and Efficient Energy Innovation".
- REEEM "Role of technologies in an energy efficient economy – model based analysis policy measures and transformation pathways to a sustainable energy system"
- MEDEAS "Modeling the renewable energy transition in Europe"
- REFLEX "Analysis of the European Energy System"

These projects performed pathways analysis in view to complement European Commission studies and to some extent, they precede the openENTRANCE project. The following describes the pathways or scenario definition of these projects at glance.

2.3.1 SET-Nav Project

The SET-Nav project developed four scenarios on the decarbonisation of the European energy system until 2050 [17]. In this project, the pathways definition is based on two major axes of uncertainty on the economic and political development: Cooperation vs. entrenchment and Decentralisation vs. traditionally centralised ("path dependency"). Hence, in the SET-Nav project, the pathways definition process focused on deriving interesting narratives by engaging into a creative process on developing the storylines of the pathways. See Figure 2.5 for a classification of the four pathways and their main features.

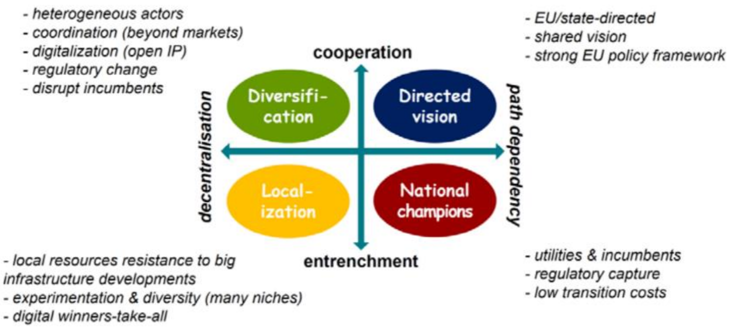


Figure 2.5: SET-Nav pathways at glance (Source: [17])

All the SET-Nav pathways fulfil the same decarbonisation target but happen in different policy environments and have different options of technologies (based on the narrative). The main features of the pathways are as follows:

- The “Diversification” pathway describes a decentralized, yet cooperative world where heterogeneous and new actors dominate the energy market. Smart technologies and appliances, prosumage and regulatory openness to new forms of cooperation and to new technologies characterize this pathway.
- The “Directed Vision” pathway envisions a strong path dependency and strict EU regulations. This helps to create a common vision for the European energy system, which is implemented top-down in the member states.
- The “Localisation” pathway is based on the depletion of local (domestic) resources. Given the differences in resource endowments, the national energy strategies of the EU member states vary strongly. Moreover, there is little exchange between member states because of the focus on domestic resources. Large, new infrastructure projects face public resistance. Instead, more and smaller niche markets are created, as well as smart technologies and smart appliances emerge as key actors.
- The “National Champions” pathway rests on a strong role for traditional energy companies. It is characterized by strong path dependency and a preference for large-scale projects. Here too, national strategies for decarbonisation are preferred. With very little cross-border electricity trade, many countries use gas-fired power plants and/or CCS as flexible back-up to integrate renewable energy sources.

Based on these narratives, the SET-Nav pathways analysis helps identifying the central drivers and role of key uncertainties for a successful decarbonisation of the energy system. This also entails discerning the consequences of the particular technological and political decisions that characterize each pathway. The four pathways are very diverse and therefore it allows investigating a large number of drivers and uncertainties for the decarbonisation of Europe. All the scenarios target 85 to 95% decarbonisation by 2050 (compared to 1990 levels).

2.3.2 MEDEAS project

The MEDEAS project defines a range of possible outcomes and consequences of the European energy transition based on three scenarios[18]. MEDEAS defines these as ‘anticipatory scenarios’ as follows: “Anticipatory scenarios (also ‘normative’ scenarios) in which the achievement of the desired future, the control of GHG emissions level, drives the Present policies and decisions, in order to gradually decrease the use fossil fuel, favouring a rapid growth of the Renewable Energy resources and a rapid decarbonisation of the society“. These scenario definitions are as follows:

- Base line or business as usual (BAU) scenario: It is a reference scenario that assumes no new policy measures to be implemented or considered. It is a continuation of already adopted or agreed upon decisions (i.e. current trends remain the same in the future).

- The alternative scenarios: These take into consideration new policies and additional measures beyond the existing EU policies, targets and directives. The alternative scenarios explore how different driving forces diverge from the BAU scenario under a higher decarbonisation target. This translates into defining a mid-level transition (MLT) scenario and an optimal transition scenario (OT).

Figure 2.6 illustrates the framework definition of these scenarios. The MEDEAS scenarios put emphasis on intermediate steps and developments throughout the next decades. For example in 2020, two possible situations: no changes in 2017-2020 (BAU) or changes between 2020 up to 2050. Here, targets are reached but in a limited way (MLT 2020) or important changes in 2017-2050 leads to achieve an efficient transition (OT in 2020, instead of BAU, and an OT in 2030). These intermediate steps are also relevant before 2050, there a trajectory where nothing changes in 2017-2030 (BAU) or good-middle progress in 2030 up to 2050 is achieved (MLT in 2030). Also, the scenario of a successful energy transition between 2017 up to 2050 (passing by the previous OT point in 2020 and the OT point in 2030, instead of BAU).

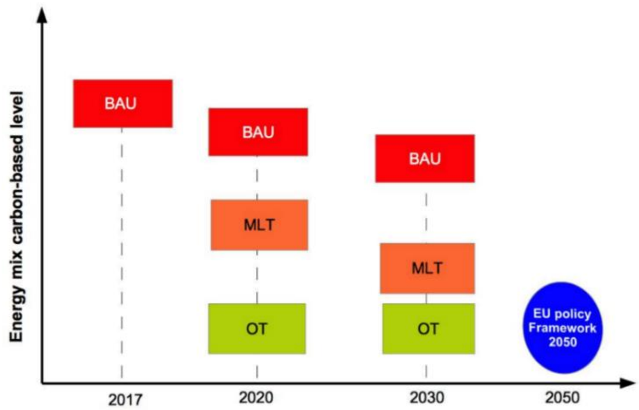
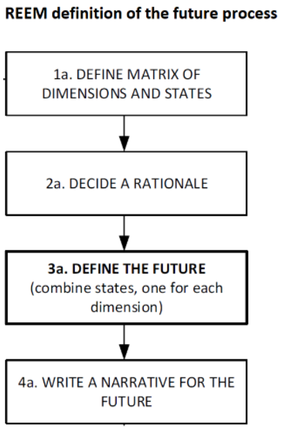


Figure 2.6: MEDEAS project scenarios features (Source: [18])

2.3.3 REEEM project

In the REEEM project, the pathways definition[3] was based on a range of stakeholders (*decision makers*, *market actors* and *consumers)* set of priorities that the scenario framing used requires to inform or prioritize.

[3] http://www.reeem.org/index.php/pathways/#section2 ; https://reeempathways.org/



Pathways formulated in REEM

Coalitions for a low-carbon path: *energy carrier suppliers take on the highest burden in the decarbonisation of the EU energy system, with consumers observing this transition in mostly a passive way and being reactive to policies as they emerge.*

Local solutions: *consumers (especially households) engage more proactively in the transition, through choices on end use appliances, energy efficiency measures and transportation technologies.*

Paris Agreement: *the EU undertakes an ambitious decarbonisation effort, with a target of 95% reduction of CO2 emissions by 2050. This overshoots the Paris Agreement pledges. Both energy carrier suppliers and consumers engage in the challenge.*

Figure 2.7: REEEM project process to define pathways and features of the three main narratives

The REEM project overall aproach to define scenarios is to first describe the state of the world under various dimensions, specifically: Political, Economic, Social, Environmental and Global factors [19]. These dimensions could evolve in several ways, described or framed by different states. Therefore, according to the project "a future represents one plausible, unified and consistent picture of how the different dimensions could play out". Therefore, in step 2a, to choose the state of each dimension (various were proposed in the project), the rationale was to focus on the degree of cooperation in the EU as it is central in ongoing debates and would have an important impact on the energy transition. This political dimension (level of cooperation) was applied as the guiding point to shape the state of the other dimensions (economic, social, environmental and global). Then, after stakeholder consultations and other relevant EU policy assessments or studies (e.g. studies in Section 2.2), the REEEM project formulated the following three narratives and pathways: i) Coalitions for a low carbon path, ii) Local solutions, and iii) Paris Agreement. Table 2.2 and Figure 2.7 illustrates a summary of the three pathways (based on REEEM website and [19]).

Table 2.2. REEEM project pathways features (source: [19])

	Coalitions for a low carbon path	Local solutions	Paris Agreement
Economy	Growth at different speeds (Population and GDP growth)		Competitiveness of the EU potentially affected by rapid shift to low-carbon economy Population and GDP growth
Policy	Stronger decision making / policy parallels within clusters of Member States	Pace of local solutions leaves policy making lagging behind in the near to medium term	The EU takes the lead in fulfilling its obligations under the Paris agreement
Society	Passive society in the transition	Change of EU citizens' perception towards climate change and resulting behavioural shifts	
Global setting	Global push to climate change mitigation driven by some regions / countries	Global push to climate change mitigation driven by some regions / countries	Global R&D push to climate change mitigation Emission trajectories for regions outside the EU aligned with 2 Degree Scenario of the IEA
Environment	EU's general recognition of the impacts of climate change Changes in heating and cooling degree days computed assuming RCP4.5	Citizens' recognition of the impacts of climate change. Changes in heating and cooling degree days computed assuming RCP4.5	General strong recognition of the impacts of climate change Changes in heating and cooling degree days computed assuming RCP2.6
Technology	Large penetration of centralised RES options Limited penetration of solar heat pumps and renovation rate of buildings in residential sector; Push to decarbonise of industrial processes; Breakthrough of floating platforms for offshore wind	Accelerated renovation of residential buildings and uptake of low carbon technologies in households and road transport Limited penetration of nuclear and CCS; Higher renovation rate of buildings in residential sector; Higher decarbonisation of transportation and residential sectors; Breakthrough of Li Ion-Air batteries	Large penetration of low-carbon energy technologies both in centralised supply and at end-use level Investments in biomass-CCS allowed; Higher renovation rate of buildings in residential sector; Breakthrough of floating platforms for offshore wind Breakthrough of building-integrated PV; Breakthrough of Li Ion-Air batteries

2.3.4 REFLEX project

The REFLEX project analysed two main scenarios strongly based on the PRIMES 2016 "reference" scenario [20] from the European Commission impact assessment analyses. These scenarios are based on observed trends and most recent projections as well as policy scenarios considered for ambitious decarbonisation pathways [21]. That is, REFLEX varies certain assumptions and features of existing scenarios to define two main pathways (see Figure 2.8):

- Moderate renewable scenario (Mod-RES): It is based on PRIMES 2016 Reference scenario [20]. It considers already decided policy targets and implemented actions. Mod-RES serves as a projection to understand the current policy scenario under ambitious decarbonisation targets and the overall effect on the current plans for the energy transition. It is comparable to a business as usual scenario.
- High renewable scenario (High-RES): Similar to Mod-RES in terms of population and economic growth but with higher decarbonisation targets and CO2 prices. It assumes a global 2°C target and fulfils the "EU 2020 energy saving target in the short term" [21]. High-RES scenario assumes the development of rapid learning curves for flexibility options to integrate a large share of wind and solar power. This scenario bifurcates in two versions: i) a centralized case in which large scale infrastructure projects and transmission grids take on the main share of renewable deployment and ii) a decentralized case characterized by distribution grids technologies and better heat supply management done locally.

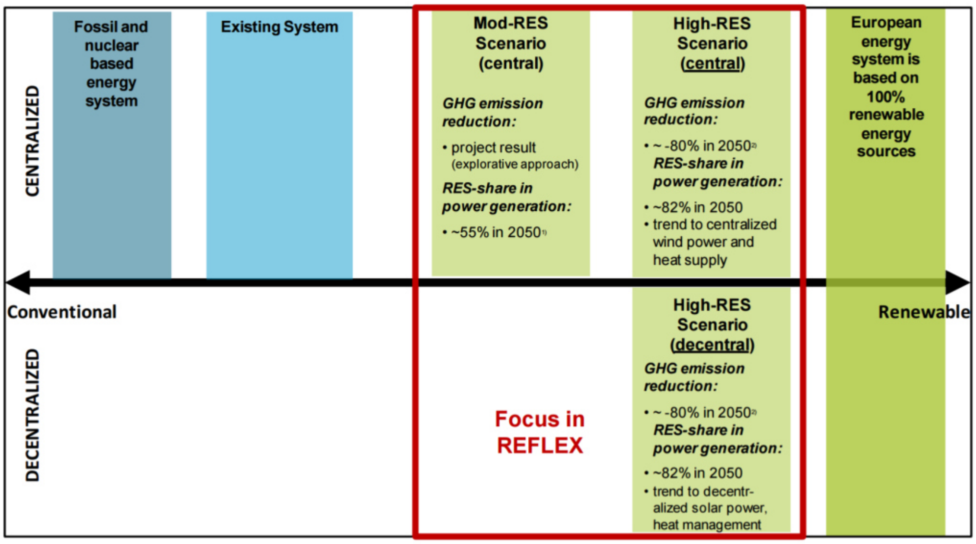


Figure 2.8: REFLEX project pathways features (source: [21])

2.4 Other European pathways

This section presents other relevant studies focused on European energy pathways. Most of these studies focus on the electricity system in the EU, and some of them consider sectors within (or linked) to the electricity system, like transport and industry. These European focused scenario and pathways work are summarized in Table 2.3.

Table 2.3: Overview and summary of related work on defining and analysing European pathways

European based Study or project	Scenario ambition (ref. 1990) & year	Sectors included	Societal/behaviour assumptions	Policy assumptions	Technology innovation assumptions
European Climate Foundation. 2010 [13]	-80% GHG red. by 2050. (ref. 1990)	Transport, buildings and industries	Economic growth	CO2 cap	Increased cost for fossil technologies, demand response
Eurelectric. 2011 [22]	-40%/-75% GHG red. by 2030/2050 (ref.1990)	Transport, residential and industries.	Public acceptance of land use for RES, electrification of transport	CO2 cap	Increased efficiency and CCS from 2025, demand response
C. Jägemann, et al. 2013. [23]	-80–95% GHG red. by 2050 (ref.1990)	Not defined (ENTSO-E country-sharp load curves)	Not defined	CO2 cap, RES targets, technology restrictions (CCS and nuclear)	Increased efficiency and CCS from 2030
Fraunhofer ISI. 2014. [24]	-95% GHG red. by 2050 (ref.1990)	Not defined	Public acceptance of land use for RES, demand growth, electrification of transport	National RES targets and required national supply (restricted import) of 85%, CO2 cap	Increased efficiency and CCS
FME CenSES. 2019 [26]	RCP 2.6/3.7/4.5 [1] by 2050	Transport, buildings and industries (GDP growth)	Not defined	CO2 cap	Increased efficiency and CCS
GENeSYS-MOD. 2019 [25]	<2°C by 2050 (carbon budget IPCC AR5)	Transport, buildings and industries	Not defined	CO2 cap	Increased efficiency and CCS
M. Child, et al. 2019. [27]	100% RES in power sector by 2050	Buildings and industries	Public acceptance of transmission	CO2 cap	Decreased costs for RES and storage, prosumer growth

The first report to provide a system-wide European assessment, including a system reliability assessment, cooperation with NGOs, major utility companies, TSOs, and equipment manufacturers across technologies and throughout Europe is [13]. The document introduces and discusses about possible pathways to investigate the technical and economic feasibility of achieving an 80% overall GHG reduction target by 2050, while maintaining or improving today's levels of electricity supply reliability, energy security, economic growth and overall prosperity. The authors conclude that the levelised cost of electricity is roughly the same under the three main pathways due to an assumed increase in the costs of the baseline, an expected decrease in the costs of the decarbonized pathways, a higher level of integration of markets across Europe, and demand responsiveness to fluctuating supply.

In [22], two major pathways are analysed: a reference case and the 'Power Choices' case. Additional analyses are done with a special focus on CCS, nuclear and limited wind development within the 'Power Choice' pathway. The scenarios revolve around reduction of emissions brought by the development of technologies for both energy demand and supply sectors. The study used the PRIMES model which is also a cost minimization model. They find that the major emission reductions happen between 2025 and 2040, and it is dependent on technological development, carbon policy, and a paradigm shift in the energy demand sector fostering smart operation.

In [23], they focus on analysing different technological pathways for decarbonizing the power system, where the main differences between the scenarios are cost development of different power supply technologies. Their modelling is based on a linear cost minimization approach, and they construct 36 different scenarios representing low, medium, and high cost development of different technologies. Results show that the decarbonization of Europe's power sector is achieved at minimal costs under a stand-alone CO2 reduction target, which ensures competition between all low-carbon technologies. If renewable energies are exempted from competition via supplementary RES targets, or if investments in new nuclear and CCS power plants are politically restricted, the costs of decarbonization significantly rise.

In [24], three main aspects shape the pathways: Development of low-carbon supply technologies, different demand projections and public acceptance. These aspects are reflected in three scenarios for policy and cost assumptions in a cost minimization approach. They find that more efficient electricity consumption is an important element of moderating the cost of decarbonization and that large shares of variable RES calls for significant transmission expansion. Also, in [25] the focus turn into the realization of policies but with a more complete perspective on different energy carriers and multi-sector coupling effects.

Other studies include a mix approach on defining and assessing scenarios by taking in consideration global perspectives. For example, FME CenSES [26] focuses on SSP1 and SSP3 to analyse both global and European power sector context. The study derives eight scenarios on Representative

Concentration Pathways (2p6 / 3p7 / 4p5) until 2050and the coupling of the emission constraints of from a global integrated assessment model to a European power system model. Therefore, it analyses the European CO2 cap imposed by the global perspective to analyse the technological possibilities and challenges for the European energy transition.

Some authors offer contributions with a more detailed focus on single aspects of the future decarbonization narratives. In [27], they study the Pathways to assess the feasibility of a 100% RES electricity generation mix by 2050 in 20 European countries and aggregated regions. The main focus of the paper is the capability of the future European grid to sustain the inclusion of a fully renewable generation system. The problem is analysed by running a generation and transmission capacity expansion model. According to the results of the paper, a centralized European expansion of the power grid would allow the power system to transition towards a fully renewable structure which results not only technically feasible, but also economically viable due to the reduction of the related levelized cost of electricity throughout Europe.

3. Mapping uncertainties of possible future energy systems

3.1 Uncontrollable uncertainties or disruptions versus controllable strategies and policies

The review of existing storylines, scenarios and pathways in the previous chapter clearly shows, that we are confronted with different kinds of inherent uncertainties and disruptions (different in nature) when trying to anticipate the future of the energy system, on the one hand. Depending on the focus of a certain study, a corresponding systematic needs to be developed to consider these uncontrollable determinates. On the other hand, somebody also has some steering options within a priori unknown future energy system boundary.

3.1.1 Uncontrollable uncertainties or disruptions

When trying to describe the future patterns and features of an energy system, the European one or any other, somebody is confronted with a variety of uncertainties and risks. In an increasingly complex global world, not even high level policy maker and/or decision maker are in the position to curb these uncertainties and risks in the proper sense that the contours of a particular future energy world could be anticipated at least with a certain probability. From today's point-of-view simply too many uncontrollable determinants of possible developments exist. Possible discontinuities or disruptions of a future (energy) world exemplarily can be of following nature and arbitrarily move alongside a scale:

- Geopolitical and economic development
- Novelty and availability of technologies
- Society's attitude and lifestyle

The geopolitical situation and economic development, for instance, in 2050 is not foreseeable. It can reach from harmonic global relationships and smart trade (without barriers and duties), on the one hand, to nationalisms and protected regional markets, on the other hand. Similar, someone cannot anticipate at present which kind of technological inventions will happen in the future and, in addition, which of the novel technologies available in the future are ready for large-scale rollout and implementation. Ultimately, society's attitude in terms of energy, environmental and climate concerns and lifestyle preferences is a big question mark in the long-term. Exemplarily, the *Friday's for Future* development has visualized what can happen, within a short period in time, in terms of solidarity for a particular matter in society. The status quo of this global phenomenon in year 2019 simple was not foreseeable a couple of years ago.

In order to overcome the dilemma outlined above, in science narrative descriptions of possible future worlds (e.g. in our case energy worlds) have been emerging. These narratives can be understood in the sense of storytelling. Therefore, they are called storylines. In the openENTRANCE projects, a small number of different storylines describe possible future developments of a low-carbon European energy system. Against the arguments presented above, the storyteller does not have any preference about one (or a most probable) robust long-term future development in Europe. On the contrary, several of the narrative descriptions (i.e. storylines) can happen in the future likewise. No preference is preselected.

3.1.2 Controllable options, strategies or policies

Taking note that we have to project our thoughts into different possible future energy worlds, which can become reality likewise, *inside a particular* future energy world there exist controllable steering options for different actors involved. Moreover, steering options not only describes different policies and strategies policy makers, market actors and also individuals can apply, but also several other resource dependent, technology dependent and societal options somebody can avail oneself.

Several of the steering options, furthermore, need to be described by corresponding tailor-made parameters, which ultimately can be scaled empirically. This empirical scaling is important to enable quantitative scenario studies. A default input setting of parameters can deliver default scenario outputs. Based on that a variety of individual and/or multiple parameters can be varied, presenting a diversity of different scenario outputs. Conducting this kind of sensitivity analyses of input parameter settings, the different scenario outputs span a so-called "solutions space" within a particular storyline, see also Figure 3.1.

As already mentioned in the glossary of this document, the scenario set-up (controllable options/strategies/policies and the corresponding parameter settings) is tailor-made to an individual storyline. This means, that alternative storylines expect new, tailor-made scenario set-ups from the scratch for each of the storylines. Doing so, different scenario outcomes (e.g. based on input parameter variations) are comparable within individual storylines only.

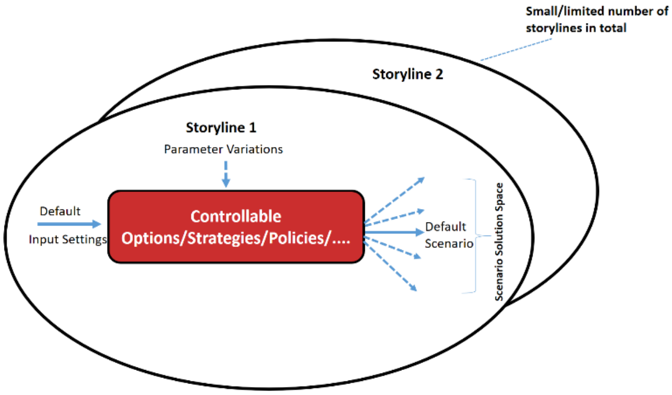


Figure 3.1: Quantitative scenario output generation inside a particular storyline

Eventually, it is important to note here, that in case of further consideration and incorporating of additional barriers, policies and regulatory needs the quantitative scenario outputs usually are denoted pathways. Moreover, pathways describe quantitative, numerical evaluations and/or trajectories of scenario outcomes taking into consideration also further constraints and drivers beyond pure parametrized drivers and features selected in the analytical scenario exercise. For a further elaboration in terms of terminology, refer to the glossary of this document, on the one hand, and the openENTRANCE storyline presentation in Chapter 4, on the other hand.

3.2 Clustering of different dimensions of future uncertainties

Building upon the lessons learnt from the previous section, in the following we try to further elaborate on the future uncertainties and risks that way that we try to better understand the driving forces for particular developments and what are the potential consequences or outcomes of these developments. Based on that we cluster and fix a small number of different dimensions of uncertainties decisive for possible future energy worlds. This shall help us facilitate designing the openENTRANCE storylines in Chapter 4.

Following up with the introductory discussion on uncontrollable uncertainties and/or disruptions from Section 3.1, in the following a more comprehensive description intends to better understand the driving forces within each of the three dimensions:

3.2.1 Geopolitical and economic development

Geopolitical development and performance of global economy have been strongly inter-linked. A future development can reach from global economic prosperity accompanied by harmonic geopolitical relationships, on the one hand. However, the other extreme someone can imagine that a struggling global economy characterised by an uneven distribution of economic wealth accompanied by geopolitical tensions, trade conflicts and subsequently either (i) isolation of regions and/or countries or (ii) claim to power for exploiting resource-rich territory. Whereas we have experience on behavioural patterns in a fossil dominated energy world only, energy transition towards a renewable and sustainable energy world will bring about a variety of additional uncertainties. This might not least triggered by the fact that existing regions/countries (e.g. primary fossil fuel exporters) will become less important, others (e.g. raw material rich countries) will rise like a phoenix from the ashes. Due to the fact that national/regional politics rather has to serve short-/medium term expectations of their voters, longer-term structural breaks usually are characterised by an inherent conflict potential (e.g. implementation of considerable carbon pricing affecting both industry and individuals). Having said that, it is important to be able to capture both extremes outlined above in a possible future energy world as well as several nuances in between:

- ➔ Smooth global energy transition towards a low-carbon society accompanied by harmonic geopolitical development and even distribution of economic prosperity.
- ➔ Disruptive global energy transition towards a low-carbon society accompanied by inherent geopolitical tensions and conflicts as well as uneven distribution of economic prosperity.[4]

3.2.2 Novelty and availability of technologies

So far, technological progress always has been a big uncertainty. Not only in the energy sector, but also in general. In these days, at energy transition related events frequently two pictures of the Easter Morning Parade on the 5th Avenue in New York in 1900 and 1913 are presented, showing the only automobile (1900) in the first picture and the lonely horse-drawn carriage (1913) in the second (see Figure 3.2). This is a paramount example of technological disruption in the transport sector.

[4] When having in mind a smaller (e.g. European) than the global geography in terms of political tensions/conflicts the BREXIT initiative of UK as well as national populism of some European Member States in different societal questions (e.g. financial assistance of Member States, migration policy) are illustrative examples endangering the coherence of the European Union. Several of these developments emerged on the agenda in recent years.

Easter Morning Parade 1900, 5th Ave, New York
Spot: Automobile
Source: US National Archives

Easter Morning Parade 1913, 5th Ave, New York
Spot: Horse
Source: shorpy.com

Figure 3.2: Easter Morning Parade, 5th Avenue, New York in 1900 and 1913

Talking about the more recent past, exemplarily, only 20 years ago almost nobody could imagine the extent and *power* of digitalization: individuals increasingly treat their i-phones/smart-phones like an extended sense organ. Combined with recently emerging energy technologies like photovoltaic systems, plug-and-play solutions on rooftops for individuals have been developed and online tracking of energy balances of smart-homes have become already standard within a couple of years. Development like these would have been almost inconceivable 20 years ago. In the photovoltaic sector the next generation of applications are already visible, as there are e.g. building integrated solutions in facades or any other component in the building skin, the implementation of local energy market clearing concepts based on peer-to-peer trading of prosumers and exploitation of leading edge information and communication technology achievements in recent years (e.g. block-chain technology). When now putting the focus in this technology segment to the future (rather the past and the status quo), somebody can image that it is virtually impossible to foresee technological innovations in the long-term (e.g. 2050). From today's point-of-view even up to 2030 the availability (as well as economic implementation) of new and novel technologies is hardly tangible. Typical nominees frequently cited in the context of low-carbon energy transition are floating offshore wind turbines, hydrogen (H2) and CCS (Carbon Capture and Storage). Several of these technology options (precondition for hydrogen: renewable-based production) could significantly support the pathway transition towards a low-carbon energy system notably in the industry and transport sector. Although technological progress to some extend can be influenced by budgets spent for research and development, ultimately technological breakthrough can't be prescribed. Moreover, in research and development falsification (that a technological process does not work and/or can't be implemented economically) is not unusual. However, when having in mind the framework in the openENTRANCE project, from today's point-of-view the entire possible bandwidth of known technological eventualities must be foreseen.

3.2.3 Society's attitude and lifestyle

Society's attitude to adapt individual and collective behaviour as well as to seriously take responsibility to support the transition towards a low-carbon energy world is another big uncertainty. The spectrum of a possible future development in this respect is supposed to be wide. Moreover, the past also has taught that there is a significant gap between the purpose/intention of sustainable lifestyle of individuals/collective groups and reality. Even in case of availability of *green* technologies, products and services human beings still tend to be reluctant to adapt. This even in case if it would be economically efficient, transaction efforts/costs for changes are minimal and/or the willingness to pay more for *green* products and services exists. Inertia of human beings accompanied with information asymmetries, technological scepticism of emerging technologies and persistence in a perceived comfort zone shall not be under-estimated. Usually, opinion turnabouts or life style changes are triggered by some innovative peer groups in somebodies personal environment and/or neighbourhood. The role of the younger generation as peers is expected to be important. Referring to the uncertainties and possible disruptive developments in this respect in the context of the openENTRANCE framework the recent phenomenon of the global *Fridays for Future* movement of the young generation is a prominent example how circumstances within a very short period of time can change. A couple of years ago it was impossible to foresee the impact and consequences of this initiative. Now the global climate and energy agenda is controversially discussed on several levels and has brought politicians under pressure to deliver framework conditions to adapt much faster. In addition, the youth also might have triggered a rethinking in their personal environment in the sense that also the elder generation is much more committed to adapt. A *smarter* society not only is restricted to awareness in climate, energy and environmental concerns but is committed to a circular economy in general, trying to minimize any kind of externalities (incl. waste, land use, ground sealing, CO2, etc.). The openENTRANCE framework thus must be able to depict this kind of smart society as well as a reluctant society not willing to adapt towards a sustainable lifestyle on a voluntary basis.

3.3 Lessons learned from existing storyline descriptions

So far, existing work and corresponding scientific literature developing climate and energy system related storylines has been relying on the following methodological approaches and frameworks enabling a differentiation of the individual narratives:

- Dimension of analyses topology determining the number of individual storylines

- Nomination of key drivers and features of the individual storylines highlighting the uniqueness of every single one

3.3.1 Storyline topologies

In terms of storyline topology, a differentiation is obvious by the number of key uncertainties describing a single storyline:

- One-dimensional topology: This approach selects the ingredients for developing a future storyline on an individual basis. There is no systematic approach trying to differentiate between different storylines. It is rather a coherent composition of different possible energy worlds emphasizing different key uncertainties in the future. The advantage is that somebody is not restricted in the number of uncertainties. The disadvantage besides the missing equidistance of a storyline to the remaining storylines is that potential criticism needs to be defended that either a too large number of different uncertainties (and thus storylines) is choose or they are selected rather arbitrarily than systematically.
- Two-dimensional topology: The implementation of a two-dimensional storyline topology is based on two key uncertainties emphasizing possible future energy worlds. Since each of these two uncertainties is characterized by both extremes, i.e. a positive as well as negative development, this topology opens up a two-dimensional space consisting of four quadrants. Although each of these four quadrants builds the frame of a separate/individual possible future energy world, two neighbouring quadrants are closely connected that way that one (out of two) uncertainty simply represents the opposite possible future development in the alternative storyline (compared to the other storyline). Thus, this might reduce diversity and meaningfulness of results of quantitative scenario studies conducted within each of the storylines. Moreover, the challenge of this kind of topology is to restrict an increasingly complex energy system to two main driving uncertainties only. When considering the elaborations in the previous sections, there are at least three bundles of key uncertainties: politics/markets, technology, and society.

3.3.2 Description of drivers and outcomes

Besides topology selection, the direction of storytelling is another design attribute of storylines. Moreover, the pattern observed so far relies on a storytelling design emphasizing two main question:

- The question *why* a certain development is expected to happen. This question relates to the key drivers characterizing a storyline.
- The question *what* happens. This question focuses on the outcomes in a storyline (triggered by the key drivers) and relates to the key elements/features of a storyline.

Based on this systematic it is possible to compose a reasoning and setting of assumptions, *why* a particular narrative is feasible, on the one hand, and *what* are the possible constraint-dependent outcomes, on the other hand. Moreover, this approach not only enables to raise key research questions in the context of long-term energy transition analyses, but also helps to anticipate the consequences of storyline implementation in qualitative terms. Even more, the consideration of different characteristics in storytelling supports the design of sensitive analyses exercises in subsequent quantitative pathway scenario studies.

The openENTRANCE storyline approach builds upon the status quo of existing work presented above as well as implements additional novelties indicating significant progress beyond the state-of-the art. These novelties of the openENTRANCE storyline approach are outlined in the following.

3.4 An innovative storyline-approach in openENTRANCE

In brief, the two main novelties of the openENTRANCE storyline approach can be summarized as follows:

- The openENTRANCE storyline topology is extended into a three-dimensional space where several of the three dimensions determines the exposure of a key uncertainty/disruption.
- openENTRANCE storytelling also directly emphasizes the ongoing global climate debate and tries to better connect both disciplines, energy and climate modelling.

3.4.1 Three-dimensional storyline topology

On the contrary, to the implementation of existing storylines topology concepts so far, in openENTRANCE three dimensions define the topology framework. In detail, the idea is to span a three-dimensional space with three exposed key uncertainties/disruptions acting as the coordinates. The farther from the centre of the coordinate system, the higher the exposure of a particular uncertainty/disruption is. The nearer to the centre of the coordinate system, the lesser the exposure is and the more we are confronted with a gradual development incorporating some elements of each of the three uncertain dimensions. Outgoing from the centre of the coordinate system to the opposite end of the diagonal of the cube (see Figure 3.3), several of the three uncertainties/disruptions are most pronounced. A situation like that describes a multiple-disrupted future energy system being fundamentally different compared to the existing one.

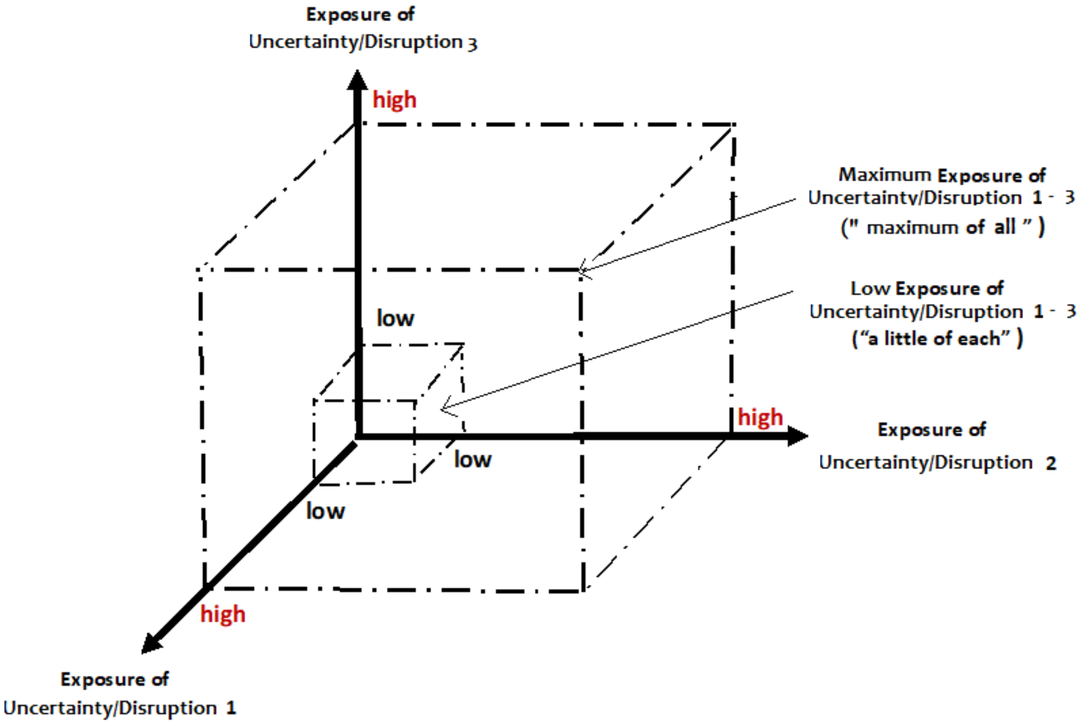


Figure 3.3: Three-dimensional openENTRANCE storyline topology

When now starting to develop narratives of possible future developments of the energy system (called "storytelling") based on the three-dimensional framework topology presented in Figure 3.3 above, it is important to have in mind, not to end up in a one-dimensional story, which mainly emphasizes a single exposed uncertainty/disruption only. This neither would be a further development of the status quo of one-dimensional storytelling nor use the potential of the three-dimensional openENTRANCE space presented in Figure 3.3. However, when emphasizing stories as a combination of at least two (or even three) uncertainties/disruptions, different combinations of possible future developments can be highlighted much better. In Figure 3.4 exemplarily some of the most interesting allocations of possible storylines are indicated in the three-dimensional openENTRANCE topology:

- When combining two exposed uncertain or disruptive developments, we are acting in the purple areas shown in the openENTRANCE cube.
- When combining several of the three uncertain or disruptive developments, we either end up in a storyline incorporating *a little of each* of the three uncertainties/disruptions (orange small

cube close to the centre of the coordinate system) or in the opposite extreme characterized by *a lot of all*. Moreover, the *maximum of all* in this extreme case indicates the orange dot in Figure 3.4.[5]

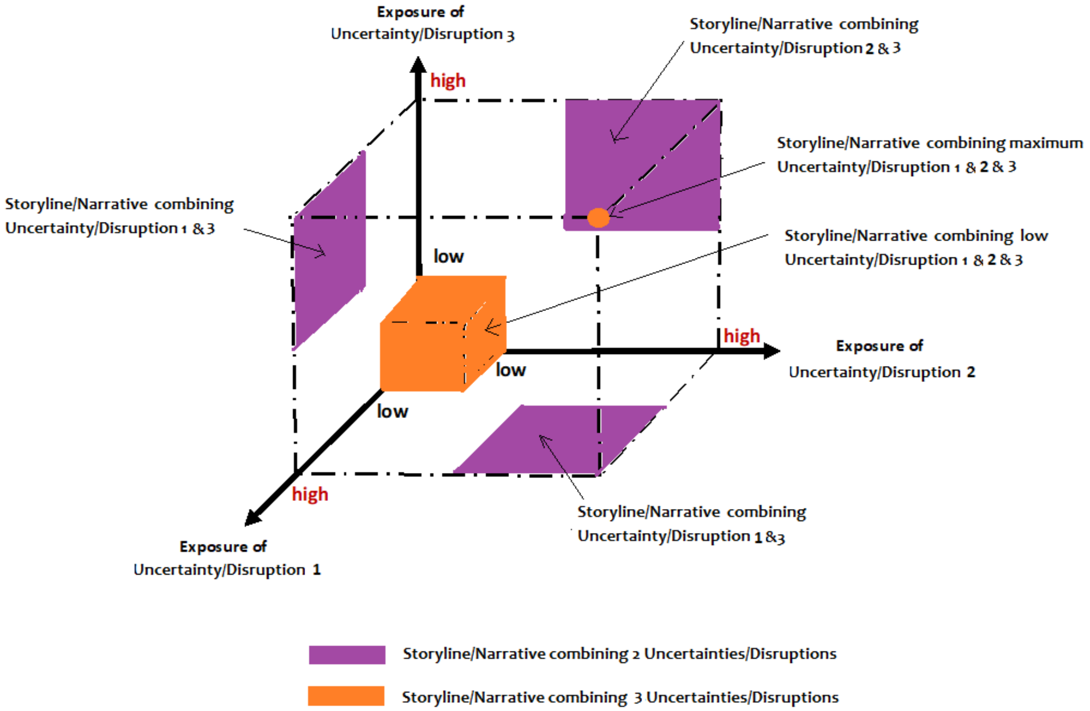


Figure 3.4: Allocation of the openENTRANCE storylines (narratives) in the three-dimensional space

When now using the openENTRANCE storyline framework presented above (describing different storylines in qualitative terms) and building the bridge to the quantitative pathway scenario studies which can be conducted inside a particular storyline (see Section 3.1 of this document in detail), the following Figure 3.5 illustrates this exercise. What is called "default scenario" inside a storyline in Figure 3.1 (Section 3.1) is allocated in the most exposed direction of this particular storyline (i.e. corresponding corner of the cube). When starting with parameter variations in the scenario exercises

[5] It is important to note, that the *maximum of all* narrative, which at first sight seems to be of great interest, also blurs the contours of the individual drivers/features behind (uncertainties/disruptions). Thus, the final insights might be less meaningful in this case than expected initially.

inside this particular storyline, the different scenario outcomes indicate a movement in the 3-dimensional space in the surroundings of this particular corner of the cube. Depending on the parameter settings and the exposure of parameter variations we move in the three-dimensional space more or less towards the focal point of the cube where a particular scenario of a storyline increasingly gets similar to another scenario from another storyline. But the scenario from the other storyline is approaching from another direction in the three-dimensional space. This is the way how quantitative scenario generation in the openENTRANCE storyline topology can be understood.[6]

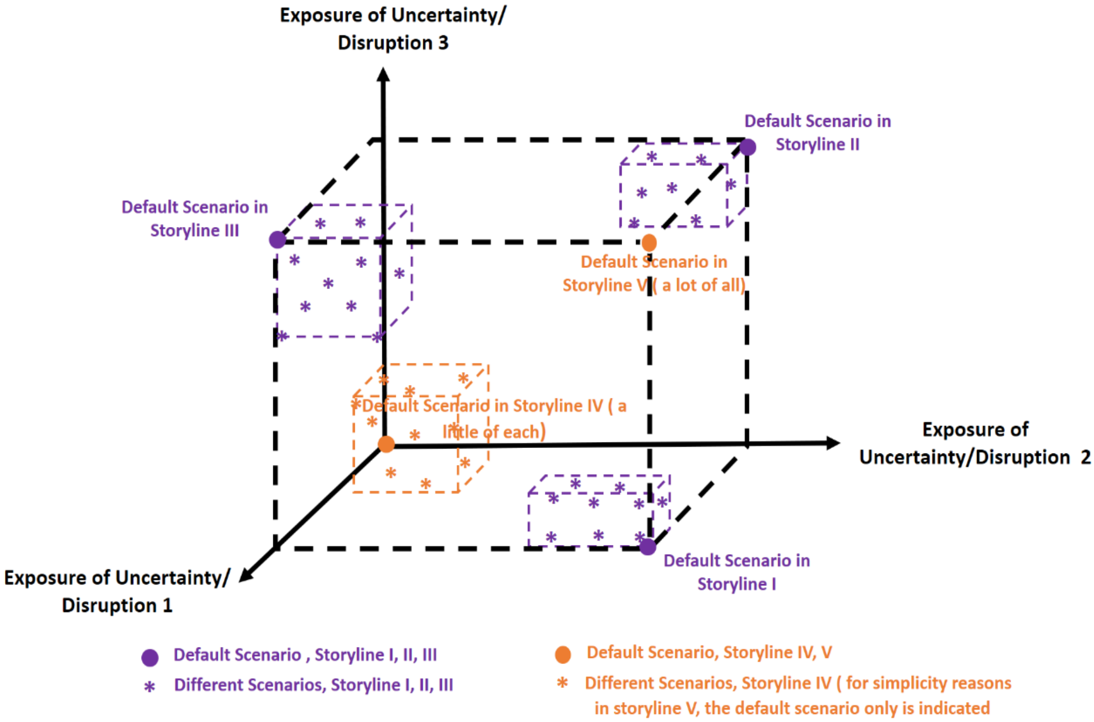


Figure 3.5: Scenario generation in the three-dimensional openENTRANCE topology

[6] As further discussed in Chapter 4 of this document, it is important to note here, that the characterization of each storyline emphasis the most salient drivers and features only that help to distinguish the storylines from one another. However, this does not mean that particular drivers/features of one storyline are not also important for other storylines (at least to certain extend). However, they are most pronounced there where they are explicitly quoted and discussed. Having said that, it is obvious that the contours of the quantitative pathway scenario outcomes increasingly are blurred the more we are moving in the three-dimensional space towards the focal point of the cube.

3.4.2 Taking into account ongoing global climate debate

As already stated at the beginning of Section 3.4, openENTRANCE storytelling also directly emphasizes the ongoing global climate debate. Moreover, it tries to better connect both disciplines, energy and climate modelling. They cannot be treated separately any more when having in mind the challenges ahead of us.

As already shown in Chapter 1&2 of this document, the European Commission is fully committed to several climate-related challenges and takes responsibility for immediate decisive policy actions necessary. Recently, in November 2018, the long-term strategic vision to reduce greenhouse gas (GHG) emissions was presented, indicating how Europe can lead the way to climate neutrality (an economy with net-zero GHG emissions) in 2050. Strategies and options have been explored how this can be achieved by looking at all the key economic sectors, based on existing and hopefully also novel technological solutions, empowering citizens and aligning action in key areas such as industrial policy, finance and research while ensuring social fairness in the energy transition process.

Anticipating climate neutrality in 2050 (i.e. 100% GHG emission reduction compared to 1990 level) would limit global temperature increase to 1.5 °C and avoid some of the worst climate impacts and reduce the likelihood of extreme weather events and others.

One of the key linking parameters between energy and climate modelling in openENTRANCE is the so-called "CO2 budget" which in turn, directly is linked to global temperature increase. This allows us directly link the different openENTRANCE storylines to a particular global temperature increase limit:

- The high exposed storylines on the corners of the cube in the Figures 3.3-3.5 relate to the 1.5 °C target.
- The low exposed storyline in the centre of the coordinate system in the Figures 3.3-3.5 relates to the 2.0 °C target.

In total numbers, according to the long-term strategy document of the European Commission, the following relationships can help to specify GHG emission reduction ambitions in 2050, on the one hand, and the corresponding global temperature increase, on the other hand:

- 80% GHG emissions reduction (excluding sinks) results in *well below* 2.0˚C global temperature increase.
- 90%-100% GHG emissions reduction (depending on storyline and assumptions; including sinks) results in 1.5˚C global temperature increase.

4. openENTRANCE storylines

4.1 Starting point

In the openENTRANCE project, four storylines describe possible future developments of a low carbon European energy system. Since, currently, there are many uncertainties about the possible future development of the European energy system, we do not have any preference about one (or a most probable) robust long-term future development. On the contrary, we are indifferent and expect several of the narratives to happen likewise. Even though there are different key drivers characterizing each of the four different storylines, the following common features can be found in all four storylines :

- The characterization of each storyline emphasises the most salient key drivers and features only that distinguish the storylines from one another. However, this does not mean that particular drivers/features of one storyline are not also important for other storylines (at least to a certain extent). But they are most pronounced there where they are explicitly quoted and discussed.
- All four storylines incorporate high shares of renewable technology penetration in the future European energy system and, in addition, (different ambitions of) demand side participation of individuals and communities/aggregates. These are prerequisites to reach the ambitious energy and climate policy goals of a low carbon future of the European energy system with which we work in openENTRANCE.
- The openENTRANCE storylines are interpreted in the context of the existing analyses of global emission reduction pathways necessary to limit global warming to 2.0˚C or the even more ambitious target of 1.5˚C. Top-down (global targets) need to be linked with the pan-European boundary. Although 2.0°C represents an extraordinary ambitious ceiling, this shall be the least ambitious target in the narrative storyline set-up in openENTRANCE and, subsequently, quantitative scenario study analyses. We will focus on even more ambitious 1.5°C pathways[7].

In general, openENTRANCE storyline descriptions are not limited to a certain (geographic) boundary, e.g. Europe. However, it can be meaningful to distinguish a European storylines from the global ones, both intellectually and politically, as Europe may pursue more ambitious climate policy instruments

[7] This means that, based on existing studies and work in this field, our ex-ante storyline description shall be realistic enough (e.g. in terms of available technologies, behaviour of actors and/or policies anticipated in a particular story) that the subsequent quantitative scenario studies are capable to endogenously approach a certain global temperature increase limit, e.g. based on a maximum CO_2 budget within the system boundary (of Europe) of analyses.

and developments that diverge from the rest of the world. Exemplarily, different scenario studies inside a storyline referring to a policy related uncertainty can tackle aspects like that.

In terms of terminology, it is important to note that storylines describe a possible future energy system in qualitative terms, whereas pathway scenario are quantitative in nature. The corresponding bridge is built in scientific modelling by parameterizing the qualitative drivers in the storyline description and thus facilitating quantitative pathway scenario studies. Against this background the presentation of the implemented openENTRANCE storylines in the following sub-sections need to be understood. They are still qualitative in nature. Quantitative pathway scenario modelling is briefly outlined in Chapter 5 and comprehensively analysed later in the openENTRANCE project.

4.2 Objectives of the openENTRANCE storylines

The objective of the openENTRANCE storylines is closely aligned with the EU long term strategy and related studies. Most current scenario building exercises about the European energy transition rely on multiple technology options, policy strategies embedded into an energy market environment and to some extend also behavioral/life style changes to outline a possible decarbonisation of Europe. In the same spirit, openENTRANCE pathways contribute to understand the drivers, uncertainties, strategies and consequences of the energy transition by exploring research questions as the following:

1. If there are no major technological developments in the next decades, to what extent can the energy transition rely on societal commitment and stronger cooperation within the EU? What drivers and strategies will be key to achieve the emissions reduction under these circumstances?
2. What technological innovations (e.g. CCS, hydrogen, and others) could have the major impact to an effective European energy transition? What policy incentives and regulatory framework will steer their succesful development and adoption?
3. In case of significant technological breakthroughs accompanied by economies of scale of sustainable energy production and use, can we rely on market forces, new business models and social innovations picking up the slack from the lack of policy action? What are the associated risks if we are mainly dependent on market decisions governing energy transition?
4. Which other options exist in energy transiation if neither significant technological innovations nor societal commitment are visible? Moreover, what to do in an even more challenging situation of a little cooperation within the EU where energy policy making rather is fragmented and collusive than homogeneous?

4.3 openENTRANCE storylines at a glance

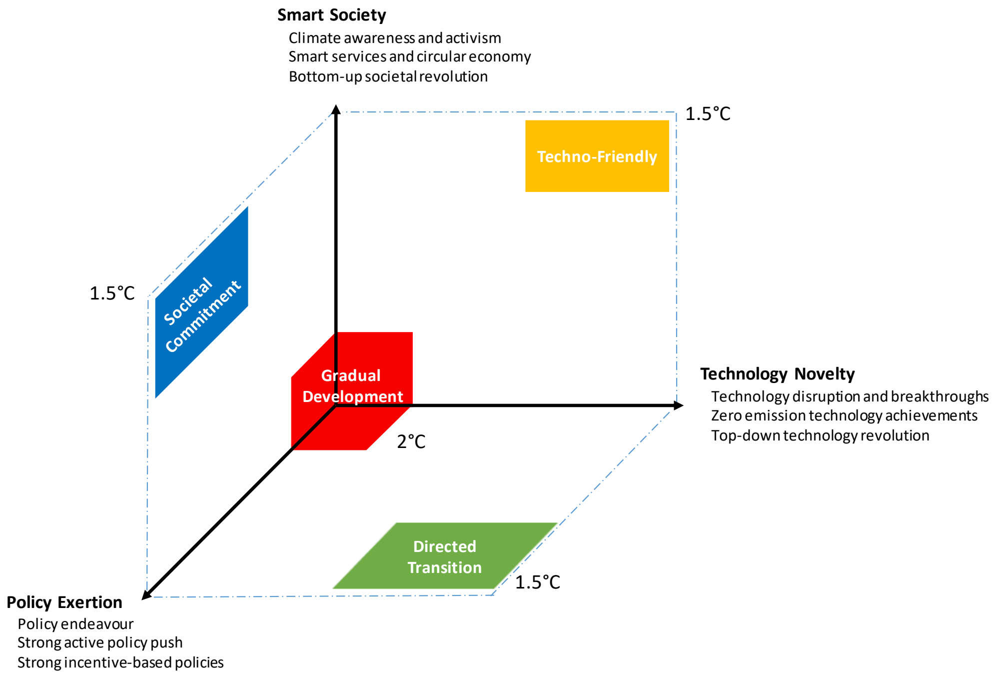


Figure 4.2: openENTRANCE storylines typology = policy exertion x technological novelty x smart society

Bringing together the major insights outlined in the previous sections of this document, the following three-dimensional topology emerges as a meaningful approach to set stories around key drivers and uncertainties of the energy transition. This topology indicates the place of three exposed future qualitative storylines (and thus quantitative pathways) on the extreme ends of a three-dimensional space as well as a more conservative future development in the centre:[8] Each exposed storyline is

[8] It is important to note, that at a later stage of the openENTRANCE project a fifth pathway is briefly analysed in addition, containing several of the main features/ingredients of the three exposed pathways presented in this framework (see chapter 5 of this document). On the contrary to the fourth pathway presented here *(Gradual Development)* containing *'a little of each'* of the remaining three, this means for the fifth pathway rather *'a lot of all'*. At this stage, however, the focus is on the four pathways only, in order not to blur the contours of the drivers/features of the remaining individual openENTRANCE pathways.

defined by the combination of two sets of (key) drivers. As depicted in Figure 4.2, we have then the four storylines:

- Directed Transition
- Techno-Friendly
- Societal Commitment
- Gradual Development

Overall, the drivers and uncertainties surrounding technology development, policymaking and societal engagement characterize the qualitative storylines. The dimensions in Figure 4.2 are conceptually shaped by considering the positive (quadrant) aspects on:

- "Smart society" dimension: Maximises the engagement and awareness of the society to take concrete actions to combat climate change. It is characterized by strong support from the public and active participation (climate activism) on changing attitudes and behaviour in lifestyles.
- "Policy exertion" dimension: Represents a world in which effective policy measures successfully steer the energy transition to decarbonisation. Institutions and regulations drive the energy transition (top-down decisions) based on cooperation, low-geopolitical tensions, centralized initiatives and a strong EU.
- "Technological novelty" dimension: Innovation and technological breakthroughs dominate the quadrants surrounding this axis. Rapid technological learning helps to bring various technological options to commerciality and hence have an active role in the energy transition.

Based on these definitions, the combination of the dimensions (shared quadrants) results into an interesting three storylines description and a middle way. In the following table, the major cornerstones of the four storylines in openENTRANCE (as well as differences between them) are described on a very general level (note that subsequently more comprehensive tables present the main drivers, features and assumptions of each of them).

Table 4.1: Overview of the four storylines implemented in openENTRANCE

Gradual Development	Techno-Friendly	Directed Transition	Societal Commitment
General: Challenging energy transition with equal part of societal, industry, and policy action Ingredients: a little of each of the remaining pathway dimensions Least ambitious narrative compared to the others Technology: Rather strong electrification of the energy and transport system (due to lack of significant technology novelty both supply and demand side), limited floating offshore wind assumed Policy/Market: Continuous policy push necessary to keep sight of short-, medium- and long-term policy goals (CO_2, RES, energy efficiency, …) Moderate market pull only increasing electrification of energy and transport system (due to lack of technology novelty) Moderate demand side participation Moderate carbon pricing only (e.g. due to divergent interest groups in politics) Society: Human inertia mitigation policies are necessary	General: Characterized by economies of scale of mainly supply-side novel technologies (candidates like floating offshore wind, H_2, CCS successful and competitive) in a globalized market Technology: Top-down technological revolution (not only supply side/centralized but also some decentralised technologies enabling smart end-user solutions (but limited demand side participation and energy efficiency ambitions) Policy/Market: Less policy push necessary Strong market pull triggering technology implementation (technology portfolio in the energy and transport sector more diverse than in other pathways) Ambitious carbon pricing Society: Openness to large-scale infrastructure projects and techno-friendly in general	General: Envisions a strong continuous incentive-based policy push (at least in Europe) at central EU level, enriched with additional aligned initiatives at Member State level Technology: Technology disruption in ICT more pronounced than in the supply-side energy/transport sector (reliance rather on existing technologies including floating offshore wind (some H_2 based energy and transport services competitive, CCS in niches) to meet reduced energy demand, but perfect exploitation of the digitalization potential on local/ decentralised level in energy/transport) Policy/Market: Significant policy push supports certain technology options both supply and demand side Moderate market pull only Ambitious carbon pricing Society: Efforts of grassroots and citizen-led initiatives is minimal	General: Accompanied by a smart life style, circular economy, advanced digitalization and avoidance of negative externalities in the energy and transport sector Technology: Strong electrification of the energy and transport system (due to lack of supply-side technology novelty (limited floating offshore wind and limited H_2 applications assumed to be established) rather reliance on existing technologies combined with digitalization) with significant demand side participation Policy/Market:Policy push possible due to ambitious carbon pricing Strong market pull triggering positive socio-economic attitudes and investments to adapt (e.g. in energy efficiency, demand response, smart local market concepts, sustainable individual and public transport, etc.) Ambitious carbon pricing Society: Bottom-up revolution of prudent and cooperative individuals, communities and decision/policy makers

4.4 Detailed description of the openENTRANCE storylines

Societal Commitment (1.5°C)

General description. High societal engagement and awareness of the importance to become a low-carbon society characterizes this storyline. Individuals, communities, and the overall public attitude supports strong policy measures to accelerate the energy transition. Both grassroots (bottom-up) and top-down government led approaches meet to drive the strong uptake of behavioural changes in energy usage and energy choices from European citizens. Hence, "green" government initiatives drive and direct ambitious measures in decarbonizing the energy and transport sectors. However, the pathway assumes that no technological breakthroughs occur and there is lack of major achievements in technology development. It relies on a policy mix that has wide-support from the public. The key driver of this storyline is that society as a whole embraces cleaner and smarter life styles with public sector working with and supporting grassroots initiatives.

Unique properties of this storyline. This storyline mainly describes a prudent society characterised by a sustainable life style and behavioural changes, which includes a significant reduction of energy use for delivering energy and transport services, the implementation of a circular (and partly sharing) economy as well as the exploitation of digitalization potentials to support individual and local service needs (including those of communities). Completely new business models and market solutions will emerge, partly only locally. These ambitions and developments will be supported by tailor-made policymaking, not least as a result of lacking breakthrough of novel technologies (except digitalization) in the energy and transport sector.

Similarities to other storylines. Similar to the techno-friendly storyline, this storyline delivers emission reductions due to a strong market pull effect. But here, in addition, also a policy push accompanies the establishment of a positive socio-economic attitude. In terms of exploitation of the storyline-specific digitalization potential this storyline is also similar to the other two exposed ones (techno-friendly and directed transition). This is also true in terms of high carbon prices.

Techno-Friendly (1.5°C)

General description. Positive Societal attitudes towards lowering GHG emissions translates into welcoming the deployment of new technologies and changes in behavioural energy choices and grassroots movements in energy. Little resistance to adopting new technologies and openness to large-scale infrastructure projects characterizes the social developments of this storyline. Centralized decision-making and policy steering are difficult to reach and hence limited in this storyline, and thus the drive of this storyline comes from grassroots initiatives and industry taking action to deliver novel technology. The narrative centres on technological novelties complemented with sustained technology uptake by citizens such that demand for new carbon-mitigating energy technologies drives market-based development of these technologies on the part of industry actors. Partly new business models and social innovations pick up the slack from the lack of policy action.

Unique properties of this storyline. This storylines focuses on the promising breakthrough of novel technologies (incl. floating offshore wind, H2 and CCS), being rolled out on large-scale to meet energy and transport service needs. In addition, this storyline is characterised by the positive attitude of society towards large-scale infrastructure projects mitigating the climate challenge. A strong globalized market-pull triggers technology choice and implementation. Active policymaking is pushed into the background. As a consequence of sufficient low-carbon technology availability, demand reduction for energy and transport services as well as active demand side participation is of little importance.

Similarities to other storylines. In terms of technology portfolio diversification (and with a less electricity dominated energy and transport system), there are similarities to the directed transition storyline. The key drivers triggering the implementation of the different technologies, however, are fundamentally different (policy support for directed transition, market-driven in techno-friendly). In terms of general positive public attitude (i.e. no reluctance of society), there are similarities to the society's commitment storyline. However, the fundamental difference here again is that it is a top-down technology revolution (rather passively welcomed by society) instead of a more active bottom-up society's life-style revolution (actively experienced by individuals, communities and society). Similar to the other two exposed storyline (societal commitment and directed transition) a high carbon price is assumed necessary to trigger the corresponding developments.

Directed Transition (1.5°C)

General description. Carbon-mitigating energy technologies emerge and require strong policy incentives for their uptake and development. The storyline assumes that the effect of grassroots and citizen-led initiatives will be minimal but that strong policy incentives can drive the needed engagement of citizens to reach the climate target. The driver of this storyline then comes from a strong centralized vision on the part of policymakers and direct partnerships with industry and technology developers who respond to incentives provided by the public sector and provide broad advances in low-carbon energy-related technologies.

Unique properties of this storyline. As a result of missing public attitude and societal commitment a strong and continuous incentive-based policy push (at least in Europe) is necessary to deploy existing and novel technologies in the energy and transport sector accordingly. At both levels European and Member State level active and aligned policy support is necessary, to optimally exploit several potentials and synergies available. In a challenging global and European market environment the industry is gaining confidence in continuous technology-specific public policy support and takes responsibility to deliver low-carbon mitigating technology portfolios in the absence of significant active societal contributions.

Similarities to other storylines. In terms of diverse technology portfolios delivered (and thus less electricity dominated energy and transport system), there are similarities to the techno-friendly storyline, but triggered based on tailor-made technology-specific public policy support (not market-based as in the techno-friendly case). In addition, tailor-made policy support for significant demand reduction and demand side participation not only plays a significant role here, but also for the societal commitment pathway. Again, similar to the remaining two exposed storylines (societal commitment and techno-friendly) a high carbon price is assumed necessary to trigger the corresponding developments.

<u>Gradual Development (2°C)</u>

General description. This storyline envisions that the climate target (2°C) is reached through an equal part of societal, industry/technology, and policy action. Knowing that a continuation of current public policies and developments are expected not to be sufficient, significantly higher efforts are needed than the current level of commitment of several of the actors. Thus, this storyline entails ingredients of *'a little of each'* of the remaining openENTRANCE storylines and therefore represents an already ambitious reference scenario in openENTRANCE.

Unique properties of this storyline. The uniqueness of this storyline is that it describes the challenging energy transition with an equal part of societal, industry/technology, and policy action. Several of these three dimensions take responsibility and deliver tailor-made contributions to reach the least ambitious climate mitigation target (2°C; remaining storylines envisage 1.5°C). Carbon pricing in this pathway is more conservative compared to the others.

Similarities to other storylines. Briefly summarized, it can be stated that the ingredients of this storyline contain *'a little of each'* of the remaining three.

4.5 Comparison of main features of the openENTRANCE storylines

The following four tables 4.2(a)-(d) summarize the main **(preliminary)** elements of the individual storylines in a consistent manner in more detail compared to table 4.1. In order to enable the development of a comparative overview, a clustering of the different topics has been conducted according to the following structure:

- **Geopolitics:** Geopolitics can reach from a harmonic relationship across the globe, on the one hand, to geopolitical tensions, on the other hand. This also influences energy and climate policy making and determines the degree of alignment, coordination and coherence of policies. Global economic prosperity is expected to be more even distribution in case of less tensions in politics across the globe.
- **Markets and economic development:** One of the key questions in terms of future energy markets will be which technologies and structures (centralized versus decentralized/local) as well as actors (incumbent versus predominantly entrepreneurs) will prevail and thus determine successful future business models. Market integration of new technologies and concepts not only depends on technological innovations and/or resource availability, but also on the price levels energy markets will be cleared in the future. In particular, this means, if currently not considered externalities of energy and transport service provision will be internalised into the market clearings or not. If so, the relevance of carbon price levels and/or resource-efficiency will significantly increase. Moreover, a circular economy needs to take care about raw material-efficient and resource-efficient energy transition, trying to minimize several negative externalities resulting in a negative ecological, social and ethical footprint (e.g. incl. land use, surface sealing, social and ethical standards, etc.). A recent study, [28], elaborates on these important aspects on how resource-efficient pathways towards greenhouse gas neutrality could look like. Depending on the individual storyline in openENTRANCE, aspects mentioned above are differently pronounced.
- **Climate and energy policies:** Climate and energy policies are important "steering" instruments to support and accelerate GHG emission reductions. The carbon price level, which can be set based on a tax and/or tradeable certificate schemes with a certain maximum quota (varying over time), is expected to be one of the key parameters determining the future economics and deployment of technologies. There exist, however, also additional policy instruments, like technology standards (and others), to trigger technology diffusion. Policymaking is also important on end-user/prosumer level, i.e. to activate demand side participation. Exemplarily, incentives to invest into energy efficiency measure or flexible pricing/tariff design are fitting instruments in that respect. When considering GHG emission reduction, ultimately, technologies and/or measure able to handle "negative emissions" are relevant. This addresses policies deploying technologies like CCS (Carbon Capture and Storage) or policies for measures and processes in the bioenergy and agricultural sector delivering the corresponding contributions.

- **Technology portfolio in energy & transport:** This technology overview cluster is split into the role and responsibilities of (i) existing/known technologies, (ii) new/novel technologies and (iii) the support and potential of digitalization. Existing technologies comprise several known renewable generation technologies in all sectors (incl. bio-energies) and low-carbon production technologies (nuclear, gas-fired) as well as several known complementary technologies like energy storage and any combination in terms of sector-coupling (PtX). In addition, also any smart energy and grid solutions are incorporated exploiting the full digitalization potentials. In terms of new technologies, mainly the role and possible deployment of candidates like floating offshore wind, hydrogen (H2) and Carbon Capture and Storage (CCS) are addressed. In case of entirely renewable-based H2 production, offshore floating wind generation with its high annual full load hours could play an important role in the future. As well as gas imports to Europe exist already right now and are also considered in the different openENTRANCE storylines in the future, this also can be true for secondary energy carriers like H2. This means that a coexistence is possible of both H2 production in Europe and H2 imports.
- **Society's attitude & lifestyle:** In the individual openENTRANCE storylines society and lifestyle aspects are differentiated concerning the level of commitment and cooperation, the willingness to pay/invest, the willingness to unlock demand side flexibilities, and the contributions to a circular economy. For several of these categories a variety of parameters exist enabling the quantification of the corresponding contributions in the pathway scenario studies (e.g. the willingness to invest can be described by the WACC (Weighted Average Cost of Capital) factor). In the interest of brevity, further details are not given here.
- **Energy sector in detail:** A detailed consideration of the energy sector comprises per storyline (i) resource and raw material related questions as well as distribution of them, (ii) capital availability and investor-related aspects, (iii) technologies and infrastructures (including possible asset stranding) along the energy supply chain reaching from production to energy service delivery and finally (iv) a detailed consideration of the structures, energy efficiency implementation and energy demand in the main sub-sectors: industry, commercial/tertiary, and private/buildings
- **Transport sector in detail:** Similar to the energy sector, the detailed consideration of the transport sector is split into the corresponding categories and sectors. In addition, the aspect of different possible mobility patters needs to be addressed per storyline. The different subsectors anticipating different drives and fuels are split as follows: aviation, fright transport (heavy and light duty vehicles), public transport, maritime, and individual/private transport. Further details shown in the following tables in the transport sector seem to be self-explaining.

Table 4.2(a) openENTRANCE storyline - Directed Transition

Storyline features	Directed Transition
Geopolitics	
General Mood	geopolitical tensions
Performance of Global Economy/Markets	uneven distribution of economic wealth
Global/International Climate Policies	partly aligned global policies, but some outlier regions/countries
Markets/Economic Development	
Macro-economic Impact of Energy Transition	
Resource Exploitation	more even distribution of resource exploitation (due to incentives)
Expected Additional Job Creation	high
Trade-Offs in Decision Making	
Role of Fossil Fuel Prices	low fossil fuel prices still relevant; policy incentives for technology switch needed
Role of Carbon Prices	high CO2 Prices trigger technology switch for several actors
Market Actors	
Incumbents versus Entrepreneurs	dominated by incumbents, enriched by some entrepreneurs
Business Models	partly different to status quo
Circular Economy	
Level of Importance	moderate
Net Effect (e.g. Externalities)	GHG emission reduction only, remaining externalities not affected
Climate and Energy Policies	
GHG emission reduction targets	approaching minus 80-90% GHG emission reductions (excl. sinks)
Carbon Pricing Ambitions	very ambitious (trading system for industries & taxes for individuals)
Existing/Known Technologies&Services	
Preferable Policy Incentives (if any)	still significant supported to accelerate large-scale deployment
Unlocking Technology Diffusion Barriers	focus on removal of regulatory and administrative barriers
Novel Technologies	
Incentives for Research&Development/Pilots	very high
Preferable Policy Incentives	technology-specific support
Unlocking Technology Diffusion Barriers	focus on removal of regulatory and administrative barriers
Incentivizing Demand Side Participation	very high
Technology Portfolio in Energy & Transport	
Role of Existing/Known Technologies	still urgently needed, although there exist some limited noval technologies
Candidates (Production, Complementary)	RES, PtX, gas, nuk, storage, smart grids, EV
Potential/Competitiveness in Energy Transition	candidates deliver in still electricity dominated energy system
Advantages/Disadvantanges	high energy densities of electricity / still limited diversification in energy system
Role of Novel Technologies	floating offshore wind available; limited applications only (H2, partly CCS)
Candidates	floating offshore wind (available), H2 & partly CCS (limited)
Potential/Competitiveness in Energy Transition	large-scale electricity prod. (floating offs. wind) and transport/industry (H2, partly CCS)
Advantages/Disadvantanges	contribution to more balanced diversification / no commercial large-scale roll out
Role/Potential/Support of Digitalization	very important
Society's Attitude & Liefestlye	
Life Style	adaptation depending on policy incentives
Level of Commitment and Cooperation	moderate
Willingness to Pay / Invest	moderate
Willingness to Unlock Demand Side Flexibilities	high
Contributions to Circular Economy	moderate
Energy Sectors (Electricity, Heat/Cooling, Gas/Fossils)	
Resources	both existing/known resources/raw materials + new ones (policy dependent)
Capital (Market-driven, Venture, Private, ...)	market-driven, venture capital, partly private, incentivized by policies
Infrastructure/Technologies	
Production/Generation (incl. Complementary)	RES incl. floating offshore wind, PtX, gas, nuc, energy storage, H2 (limited), CCS (niche)
Transmission/Distribution	smart electricity grids, smart gas grids, local heat grids
Energy Service Delivery	noval smart energy managment systems governed by digitalization
Sub-Sectors (Structure, Demand)	
Industry	policy-triggered incentives for demand reduction & fuel switching
Commerical/Tertiary	policy triggered incentives for demand reduction & fuel switching
Private/Buildings	policy triggered incentives for demand reduction & fuel switching
Transport Sector in Detail	
Mobility Patterns	multi-modal transport, mainly ownership, public transport, autonomous driving
Capital (Market-driven, Venture, Private, ...)	market-driven, venture capital, partly private, incentivized by policies
Infrastructure/Technologies	
Production/Resources	policy-driven production & resouce allocation (location policy)
Supply Chain	mainly dependent on global allocation/purchases
Mobility Service Delivery	moderate demand on individual mobility services and corresponding infrastructure
Sub-Sectors (Structure, Demand)	
Aviation	electric (short distance), hybrid (long distance)
Fright	electric (light duty vehicles), hybrid/partly RES-based H2 (heavy duty vehicles)
Public Transport	electric, partly RES-based H2
Maritime	electric (light duty vehicles), hybrid/partly RES-based H2 (heavy duty vehicles)
Individuals/Private	electric

Table 4.2(b) openENTRANCE storyline – Societal Commitment

Storyline features	Societal Commitment
Geopolitics	
General Mood	harmonic geopolitical relationships
Performance of Global Economy/Markets	global economic prosperity
Global/International Climate Policies	coordinated & coherent global climate policies
Markets/Economic Development	
Macro-economic Impact of Energy Transition	
Resource Exploitation	even distribution of resource exploitation (due to recycling chain)
Expected Additional Job Creation	very high
Trade-Offs in Decision Making	
Role of Fossil Fuel Prices	fossil fuel prices increasingly irrelevant, even if low
Role of Carbon Prices	high CO2 Prices trigger technology switch mainly for individuals/communities
Market Actors	
Incumbents versus Entrepreneurs	many new market actors/entrepreneurs on local level
Business Models	completely different compared to the status quo
Circular Economy	
Level of Importance	very important
Net Effect (e.g. Externalities)	not only GHG emission reductions, but also many other externalities
Climate and Energy Policies	
GHG emission reduction targets	approaching minus 80-90% GHG emission reductions (excl. sinks)
Carbon Pricing Ambitions	very ambitious (trading system for all)
Existing/Known Technologies&Services	
Preferable Policy Incentives (if any)	still selective support needed to unlock particular developments
Unlocking Technology Diffusion Barriers	focus on removal of regulatory and administrative barriers
Novel Technologies	
Incentives for Research&Development/Pilots	moderate
Preferable Policy Incentives	market-based instruments (technology-neutral)
Unlocking Technology Diffusion Barriers	focus on removal of regulatory and administrative barriers
Incentivizing Demand Side Participation	very high
Technology Portfolio in Energy & Transport	
Role of Existing/Known Technologies	urgently needed due to limited novel technologies as alternatives
Candidates (Production, Complementary)	RES, PtX, gas, nuc, storage, smart grids, EV
Potential/Competitiveness in Energy Transition	candidates deliver in electricity dominated system with significant lower demand
Advantages/Disadvantanges	incentive to adjust demand & lifestyle / lack of diversification
Role of Novel Technologies	limited applications only
Candidates	floating offshore wind, H2
Potential/Competitiveness in Energy Transition	large-scale electricity production (floating offs. wind) and transport sector (H2)
Advantages/Disadvantanges	contribution to more balanced diversification / no commercial large-scale roll out
Role/Potential/Support of Digitalization	very important
Society's Attitude & Liefestlye	
Life Style	sustainable, cautious, self-disciplined, prudent
Level of Commitment and Cooperation	very high
Willingness to Pay / Invest	very high
Willingness to Unlock Demand Side Flexibilities	very high
Contributions to Circular Economy	very high
Energy Sectors (Electricity, Heat/Cooling, Gas/Fossils)	
Resources	both existing/known resources/raw materials + new ones (need dependent)
Capital (Market-driven, Venture, Private, ...)	market-driven, venture capital, private (high Willingness to Pay/Invest)
Infrastructure/Technologies	
Production/Generation (incl. Complementary)	RES, floating offshore wind (limited), PtX, gas, nuc, energy storage, H2 (limited)
Transmission/Distribution	smart electricity grids, smart gas/H2 grids, local heat grids
Energy Service Delivery	noval smart onsite/local energy managment governed by digitalization
Sub-Sectors (Structure, Demand)	
Industry	very high ambition for demand reduction & fuel switching (partly RES-based H2, PtX)
Commerical/Tertiary	very high ambition for demand reduction & fuel switching (RES, PtX)
Private/Buildings	very high ambition for demand reduction & RES fuel switching (RES, PtX)
Transport Sector in Detail	
Mobility Patterns	multi-modal transport, mainly sharing, public transport, autonomous driving
Capital (Market-driven, Venture, Private, ...)	market-driven, venture capital, private (high Willingness to Pay/Invest)
Infrastructure/Technologies	
Production/Resources	low production quantities/resources due to established sharing/public transport
Supply Chain	combination of global allocation/purchases and local circular/recycling economy
Mobility Service Delivery	low demand on individual mobility services and corresponding infrastructure
Sub-Sectors (Structure, Demand)	
Aviation	electric (short distance), hybrid (long distance)
Fright	electric (light duty vehicles), hybrid/partly RES-based H2 (heavy duty vehicles)
Public Transport	electric, partly RES-based H2
Maritime	electric (light duty vehicles), hybrid/partly RES-based H2 (heavy duty vehicles)
Individuals/Private	electric

Table 4.2(c) openENTRANCE storyline – Techno Friendly

Storyline features	Techno-Friendly
Geopolitics	
General Mood	harmonic geopolitical relationships
Performance of Global Economy/Markets	global economic prosperity
Global/International Climate Policies	coordinated & coherent global climate policies
Markets/Economic Development	
Macro-economic Impact of Energy Transition	
Resource Exploitation	concentrated to a few regions/countries only
Expected Additional Job Creation	limited
Trade-Offs in Decision Making	
Role of Fossil Fuel Prices	fossil fuel prices increasingly irrelevant, even if low
Role of Carbon Prices	high CO2 prices trigger technology switch mainly for stakeholders
Market Actors	
Incumbents versus Entrepreneurs	both incumbents (joint ventures) and new market actors
Business Models	comparable to existing ones (based on economies of scale)
Circular Economy	
Level of Importance	hardly emphasized
Net Effect (e.g. Externalities)	GHG emission reduction only, remaining externalities not affected
Climate and Energy Policies	
GHG emission reduction targets	approaching minus 100% GHG emission reductions (incl. sinks)
Carbon Pricing Ambitions	very ambitious (trading system for all)
Existing/Known Technologies&Services	
Preferable Policy Incentives (if any)	none
Unlocking Technology Diffusion Barriers	focus on removal of regulatory and administrative barriers
Novel Technologies	
Incentives for Research&Development/Pilots	very high
Preferable Policy Incentives	market-based instruments (technology-neutral)
Unlocking Technology Diffusion Barriers	focus on removal of regulatory and administrative barriers
Incentivizing Demand Side Participation	moderate
Technology Portfolio in Energy & Transport	
Role of Existing/Known Technologies	needed, but there exist supplements of additional noval technologies
Candidates (Production, Complementary)	RES, PtX, gas, nuc, storage, smart grids, EV
Potential/Competitiveness in Energy Transition	candidates deliver where most appropriate in the energy system
Advantages/Disadvantanges	contribution to balanced diversification of energy system / no disadvantages
Role of Novel Technologies	very important, commercially available
Candidates	floating offshore wind, H2, CCS
Potential/Competitiveness in Energy Transition	significant potential for large-scale production (economies of scale)
Advantages/Disadvantanges	contribution to balanced diversification / underrepresentation of demand side
Role/Potential/Support of Digitalization	very important
Society's Attitude & Liefestlye	
Life Style	some changes compared to status quo
Level of Commitment and Cooperation	high
Willingness to Pay / Invest	high
Willingness to Unlock Demand Side Flexibilities	high
Contributions to Circular Economy	low
Energy Sectors (Electricity, Heat/Cooling, Gas/Fossils)	
Resources	both existing/known resources/raw materials + new ones (need dependent)
Capital (Market-driven, Venture, Private, ...)	market-driven, venture capital
Infrastructure/Technologies	
Production/Generation (incl. Complementary)	RES incl. floating offshore wind, PtX, gas, nuc, energy storage, H2, CCS
Transmission/Distribution	smart electricity grids, smart gas/H2 grids, local heat grids in niches only
Energy Service Delivery	noval smart energy managment systems governed by digitalization
Sub-Sectors (Structure, Demand)	
Industry	low incentives for demand reduction, fuel switching to RES-based H2, industrial CCS
Commerical/Tertiary	low incentives for demand reduction & fuel switching
Private/Buildings	low incentives for demand reduction & fuel switching
Transport Sector in Detail	
Mobility Patterns	multi-modal transport, sharing+ownership, public transport, autonomous driving
Capital (Market-driven, Venture, Private, ...)	market-driven, venture capital, private
Infrastructure/Technologies	
Production/Resources	market-driven production & resource allocation (noval technology dependent)
Supply Chain	market-driven global allocation and purchases
Mobility Service Delivery	high demand on mobility services building upon a smart infrastructure
Sub-Sectors (Structure, Demand)	
Aviation	electric (short distance), hybrid (long distance)
Fright	electric (light duty vehicles), RES-based H2 (heavy duty vehicles)
Public Transport	electric, RES-based H2
Maritime	electric (light duty vehicles), RES-based H2 (heavy duty vehicles)
Individuals/Private	electric

Table 4.2(d) openENTRANCE Storyline – Gradual development

Storyline features	Gradual development
Geopolitics	
General Mood	geopolitical tensions
Performance of Global Economy/Markets	uneven distribution of economic wealth
Global/International Climate Policies	non-aligned & fragmented policies, isolation of regions/countries
Markets/Economic Development	
Macro-economic Impact of Energy Transition	
Resource Exploitation	concentrated to a few regions/countries only
Expected Additional Job Creation	moderate
Trade-Offs in Decision Making	
Role of Fossil Fuel Prices	low fossil fuel prices still relevant; policy incentives for technology switch needed
Role of Carbon Prices	high CO2 Prices trigger technology switch for several market actors
Market Actors	
Incumbents versus Entrepreneurs	dominated by incumbents, enriched by some entrepreneurs
Business Models	partly different to status quo
Circular Economy	
Level of Importance	moderate
Net Effect (e.g. Externalities)	GHG emission reduction only, remaining externalities not affected
Climate and Energy Policies	
GHG emission reduction targets	approaching minus 70-80% GHG emission reductions (excl. sinks)
Carbon Pricing Ambitions	moderate (trading system for industries & taxes for individuals)
Existing/Known Technologies&Services	
Preferable Policy Incentives (if any)	still significant supported to accelerate large-scale deployment
Unlocking Technology Diffusion Barriers	focus on removal of regulatory and administrative barriers
Novel Technologies	
Incentives for Research&Development/Pilots	high
Preferable Policy Incentives	technology-specific support
Unlocking Technology Diffusion Barriers	focus on removal of regulatory and administrative barriers
Incentivizing Demand Side Participation	high
Technology Portfolio in Energy & Transport	
Role of Existing/Known Technologies	urgently needed due to lack of novel technologies as alternatives
Candidates (Production, Complementary)	RES, PtX, gas, nuc, storage, smart grids, EV
Potential/Competitiveness in Energy Transition	candidates deliver in increasingly electricity dominated energy system
Advantages/Disadvantages	high energy densities of electricity / lack of diversification
Role of Novel Technologies	limited applications only
Candidates	floating offshore wind
Potential/Competitiveness in Energy Transition	limited addtional potential which needs still support
Advantages/Disadvantages	additional electricity production / still elctricity dominated energy system
Role/Potential/Support of Digitalization	important
Society's Attitude & Liefestlye	
Life Style	limited adaptation depending on policy incentives
Level of Commitment and Cooperation	moderate
Willingness to Pay / Invest	moderate
Willingness to Unlock Demand Side Flexibilities	moderate
Contributions to Circular Economy	moderate
Energy Sectors (Electricity, Heat/Cooling, Gas/Fossils)	
Resources	building upon existing/known resouce (RES, gas) and raw material potentials
Capital (Market-driven, Venture, Private, ...)	market-driven, venture capital, incentivized by policies
Infrastructure/Technologies	
Production/Generation (incl. Complementary)	RES, floating offshore wind (limited), PtX, gas, nuc, energy storage
Transmission/Distribution	smart electricity grids, smart gas grids, local heat grids
Energy Service Delivery	advanced existing/known technologies&services, supported by digitalization
Sub-Sectors (Structure, Demand)	
Industry	moderate incentives for demand reduction & fuel switching
Commerical/Tertiary	moderate incentives for demand reduction & fuel switching
Private/Buildings	moderate incentives for demand reduction & fuel switching
Transport Sector in Detail	
Mobility Patterns	comparable to existing mobility patterns
Capital (Market-driven, Venture, Private, ...)	market-driven, venture capital, incentivized by policies
Infrastructure/Technologies	
Production/Resources	comparable to existing patterns
Supply Chain	mainly dependent on global allocation/purchases
Mobility Service Delivery	still high demand on individual mobility services and corresponding infrastructure
Sub-Sectors (Structure, Demand)	
Aviation	fossil, hybrid
Fright	electric (light duty vehicles), hybrid/fossil (heavy duty vehicles)
Public Transport	electric, hybrid
Maritime	electric (light duty vehicles), hybrid/fossil (heavy duty vehicles)
Individuals/Private	electric, hybrid

5. The openENTRANCE platform and pathways analysis

5.1 Overall implementation

The pathways require models and methodologies to analyse and quantify the future development of an European Energy Transition. Therefore, as part of the openENTRANCE project, a data exchange platform is set up which serves as a central data repository and a models interaction hub (i.e. linking models). The objective of this platform is to: i) provide a central location where all the information can be found in a transparent, convenient and standardized way and ii) enable frictionless data-exchange for the models used in quantifying the scenarios.

A conceptual illustration of the platform to be used for the openENTRANCE pathway implementation is shown in Figure 5.2. The platform displays[9] results of analyses (models) as well as contains data from multiple scenarios. Through this web-based online platform, researchers and stakeholders are able to share tools, scenarios, datasets and results.

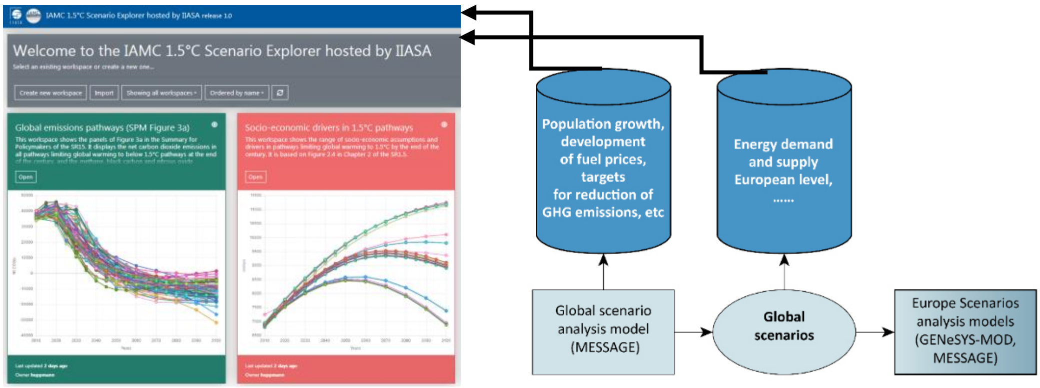


Figure 5.2: openENTRANCE platform, models interaction and data sharing for analysing pathways

[9] https://data.ene.iiasa.ac.at/iamc-1.5c-explorer/#/login?redirect=%2Fworkspaces

As stated in preceding chapters, the starting point of the pathways implementation process is the definition and characterization of a set of pathways. Numerous aspects, drivers, and possible developments of a pathway must be interpreted and parametrized for the different models used within the openENTRANCE project. To start the analysis (quantification) of the pathways, the MESSAGE-GLOBIUM model creates overarching global development trends of macroeconomic factors in the energy system. Then, these are used by GENeSYS-MOD model and, coupled with the initial settings, will quantify the respective storylines and pathways on a technology-rich level.

During this process, all model calculation results are uploaded to the platform where a central data repository is located. The idea is that all models and case studies within one pathway are consistent and coherent (e.g. harmonized input data). Information that is required by one model might either directly be taken from the pathway definition or might be generated by another model. In both cases, this data is accessible via the platform. Over an iterative process, this data will again be used by certain models to build upon the outcomes of other models. This assures that all openENTRANCE models and analyses use with the pathways data in a consistent way.

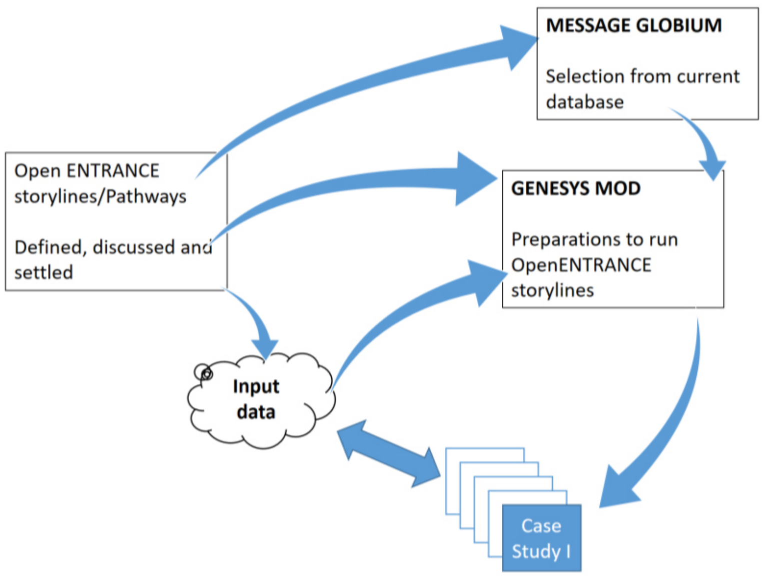


Figure 5.2: Overall process envisioned to implement, analyse and use the openENTRANCE pathways

5.2 Using the openENTRANCE platform

As mentioned, the general purpose of the platform is to provide a central location where all quantified information regarding the openENTRANCE pathways and case studies is accessible. The platform will constantly be updated with output from the different models that are used in the implementation process. This entails the following parts (see schematic in Fig. 5.2):

1. Data directly derived from the pathway definition
   The storylines described in Chapter 4 of this document define driving forces for the low-carbon transformation of the European energy system. These drivers might be of technological, socio-economical, or political nature. In the process of interpreting the pathways modelling wise (i.e. parametrization), they will be quantified and subsequently used by the different models. Examples are learning curves for technologies, willingness of the society to enable low-carbon solutions or the rate at which carbon pricing is implemented.

2. MESSAGE-GLOBIUM
   The first set of model calculations will be performed by MESSAGE-GLOBIUM, an integrated assessment model that combines an energy model with a land use model. It optimizes the energy system to satisfy energy demand at lowest cost and is coupled with a module which provides estimates of the macro-economic demand response implied by the configuration of the energy system. As a result, for the purpose of the openENTRANCE project, the model returns data on demand, price, and emission development for Europe based on a global or world perspective. Demands are sectoral and by energy carrier and have to be disaggregated onto the different countries which will be performed considering the current state of the energy system coupled with the pathway characteristics.

3. GENeSYS-MOD
   The data provided by the pathway definition and MESSAGE-GLOBIUM will then be used by GENeSYS-MOD, a techno-economic bottom-up energy system model. GENeSYS-MOD takes price, demand, and potentially emission development results from MESSAGE-GLOBIUM and combines this data with the general storyline parameters to compute the pathways of the European energy system. In more detail, it provides investment decisions and quantities for all technologies, energy flows and emissions for the electricity sector, low- and high-temperature heat, and fright- and passenger-transportation. While, usually, prices and demand data are exogenous inputs for GENeSYS-MOD this will be in harmony with the MESSAGE-GLOBIUM outputs, which ensures much more robust and coherent results.

4. openENTRANCE Case studies
   The case studies perform analyses with their respective models and use relevant data from the sources above. The case studies perform regional or sectoral analysis within their scope defined in the openENTRANCE project. The output of these analyses is then stored in the platform. The case studies analysis will be based partly on the results of the GENeSYS-MOD and MESSAGE-GLOBIOUM storyline results and partly on the overall pathway definition. In other words, the pathways results will set the scene to understand their effects on sector specific studies and examples.

Hence, in summary, the following procedure and data is envisioned in implementing, analysing and using the pathways:

- Pathway definition: general technological, socio-economical, and political indicators
- MESSAGE-GLOBIUM: price and demand development and other global inputs and perspectives
- GENeSYS-MOD: investments, energy flows, and emissions
- Case studies: regional and sectoral scope

In this process, all models create much more outputs than described here. Therefore, this data is used for consistency checking across all model calculations to ensure consistent and coherent pathway development. In addition, all results from all models will be stored on the platform and can be accessed either for further calculations or to analyse the results. Also openly available to other projects and interested modellers.

5.3 Conclusions and next steps for openENTRANCE storylines

In this document, we have engaged into a creative process to define a new set of storylines that can help map future developments of the European energy transition. Understanding experiences on previous studies on defining storylines and scenario building exercises illustrate that the openENTRANCE storylines propose an innovative perspective on how to design pathways. This endeavour and creative process to create the openENTRANCE storylines involved many active consortium discussions and consultations with experts. Various consortium meetings contributed to collect feedback from various partners as well as via a stakeholder workshop organized in Brussels on September 2019. The workshop presented two earlier propositions on the openENTRANCE storylines, which was subsequently re-discussed and assessed within the project to later frame the storylines ones proposed in this document (Figure 5.3). It is quite certain that once the analysis and quantification of the storylines is performed, further fine-tuning of the storylines will take place as we learned about the results and the factors that drove each decarbonisation pathway.

In this regard, later in the project, once the quantification of the pathways and lessons learned from the openENTRANCE case studies are summarized, new ideas and questions will arise on combining these storyline dimensions. Also, the openENTRANCE cases studies, via the platform and other methodological approaches, will bring a new level of understanding on linking energy system models with different capabilities and covering a variety of energy sectors. This unique pluri-modelling experience accompanied with open data (via the platform) will address some of the research frontiers in energy systems modelling: harmonizing data, opening black boxes, interdisciplinary research and linking (combining) models [29]. From this point, there will be the opportunity to reflect and analyse[10] a possible fifth storyline: “Paris+Vision” (Figure 5.6). A storyline that combines the lessons learned of all the other storylines into a storyline in which the most effective policy, technological, and societal options jointly deliver a robust EU decarbonisation strategy and set the example to the rest of the world (Paris+ Vision also reaches a 1.5 degree Celsius target).

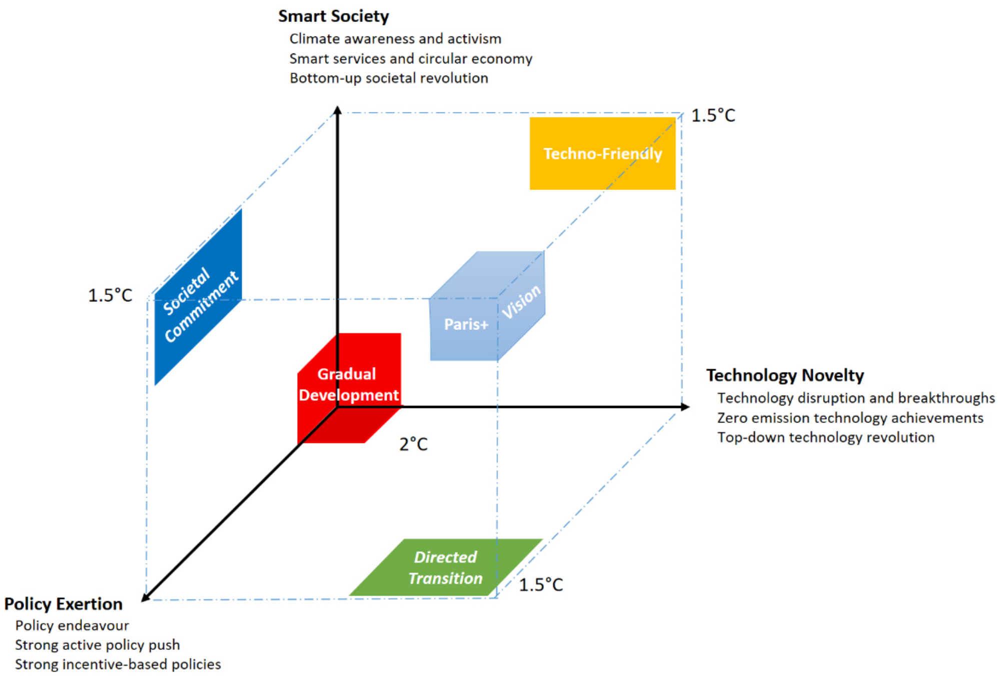


Figure 5.3: Idea of analysing and defining a fifth storyline in the project: “Paris+ Vision”.

[10] As part of the work plan in openENTRANCE, the fifth pathway might be analyzed as part of Task 7.6 in WP7

In summary, the openENTRANCE storylines to some degree relate to existing energy scenario work and policy making in Europe. As we analyze the storylines and their corresponding pathways, we will be in line and argue along with existing work, strategies and corresponding policy documents (besides many others e.g. *European Long-term Strategy Options*). This is important for using openENTRANCE results and recommendations that are in line with current policy making discussions. Moreover, policy makers expect to work out the relation between existing work and openENTRANCE outcomes. In addition, these storylines must be flexible enough to incorporate upcoming energy and climate policy related discussions and initiates on European and global level in the years to come.

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