Open ENTRANCE Synthesis and recommendations

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Contents

List of acronyms used in this document

BAU	Business As Usual
CET	Clean Energy Transition
CGE	Computational General Equilibrium model
EERA	European Energy Research Alliance
EV	Electrical Vehicle
GDP	Gross Domestic Product
GHG	Green House Gasses
IT	Information Technology
KPI	Key Performance Index
LEC	Local Energy Community
NECP	National Energy and Climate Plan
NUTS	Nomenclature of Territorial Units for Statistics
RES	Renewable Energy Sources
PV	Photo Voltaic
SDG	UN's Sustainable Development Goals
V4	The four Visegrad countries, Czechia, Hungary, Poland and Slovakia
VRE	Variable Renewable Energy

Executive Summary

The H2020 Open ENTRANCE project (open ENergy TRansition ANalyses for a low-Carbon Economy), running between 2019 and 2023, aimed to develop, use, and disseminate an open, transparent, and integrated modelling platform for assessing low-carbon transition scenarios in Europe. The project was successful in reaching these objectives.

The Open Platform helped identify the most cost-efficient alternatives for development of the energy system to reach pre-defined climate goals, to determine the macro-economic consequences and the distributional effects of the alternatives, and to explore impacts and options on different geographical levels. The Platform is open and can be used by any interested actor.

The Platform hosts a description and input and output data of the scenarios developed during the project. These give a common framework to conduct studies with consistent and open assumptions, contributing to their impact through the replicability of the results and the clear assumptions in the scenarios. The four scenarios are defined on three characteristics (policy exertion, smart society, and technological novelty) and share ambitious climate goals of limiting global warming to either 1.5 or 2 degrees.

The analysis of the development of the energy system under these scenarios shows that the present European policy is not sufficient to provide the region's contribution required to limit the temperature increase to 1.5 or 2 degrees. To reach such a target, massive investment is necessary in the power sector as well as for the decarbonisation of other sectors before 2035. Efficiency gains from electrification of the transport and the heating sector will have a major role, while hydrogen will also be important for the decarbonisation of specific applications (e.g. air transport, steel production).

The transition can be achieved with little impact on the GDP. This is due to the fact that the impact of increased energy efficiency is able to counter the effect of the cap on emissions and of the feedback effects from climate change.

Eight case studies are demonstrating the potential of the Platform for detailed local analyses, delivering results on different topics or various geographic scopes, and allowing to validate the robustness of the results.

The results from the project, The Open Platform and the analyses results demonstrate their value by being used by 16 other projects on the end of the project. Maintenance will be necessary to preserve continued positive impact of the Platform.

Based on the project results, we recommend an increase in the speed of the energy transition to be back on track to meet the objectives of limiting temperature increase. This means a more rapid electrification of the transport sector, the installation of heat pumps in buildings, and investments in large amounts of renewable energy. The cost of inaction is larger than the cost of the transition.

1. Introduction

EU has ambition to reduce greenhouse gas emissions to the point of becoming climate neutral by 2050. Preventing the negative and irreversible effects of climate change is challenging and could be implemented in many ways. It will require technological, behavioural, and organisational changes in the economy and society and numerous decisions are needed to guide the transformation. Understanding the connection between decision and impact will be imperative in this process. The ambition of Open ENTRANCE is to provide new knowledge and methodologies that lead to informed science-based input to those decisions.

The H2020 project Open ENTRANCE (open ENergy TRansition ANalyses for a low-Carbon Economy) (2019-2023) aimed to develop, use and disseminate an open, transparent, and integrated modelling platform for assessing low-carbon transition scenarios in Europe. The modelling platform can be used to shed light on the implications and economic costs associated to the different energy scenarios that Europe could take towards its climate goals. With this scientific basis, Open ENTRANCE aims at helping social, economic, and political actors to make informed decisions.

This Open Platform is a lasting key result in Open ENTRANCE and:

- Supports stakeholders to identify the most cost-efficient alternatives to transition towards a 'low carbon' energy system in Europe by carrying out scientific calculations and assessments.
- Can be used to explore impacts of significant changes in framework conditions for the European energy system, e.g., cessation of import of Russian gas.
- Enables analyses of macro-economic consequences of the energy transition.
- Allows consistent analyses across different topics or spatial resolutions by linking different models for analysis of the transition, e.g., energy system models and macro-economic models as well as pan-European models and national and local models.
- Is openly available to use by any interested user, targeting mainly researchers and modellers.
- Provides open data per Member State relevant for energy transition modelling analyses, e.g., energy, economic and human behavioural data.

Since the start of the Open ENTRANCE project in 2019, both the global and the local European situation have changed significantly. The United Kingdom leaving the European Union, the energy crisis, the Russian war on Ukraine and the increased polarisation on the global arena have changed the possible futures of Europe. The methodology developed in Open ENTRANCE is generic and can easily be adapted to these known changes as well as future changes. For example, the Open ENTRANCE scenarios can be updated based on revised data and re-run with the suite of models that are available in The Open Platform. The functionality in the platform allows new scenarios to be compared to scenarios that are already included in the platform or to replace existing scenarios that are outdated because of old input data or important functionality improvements in the Open ENTRANCE modelling suite.

The structure of this report is as follows: Section 2.1 describes The Open Platform, and Section 2.2 defines and describes consistent scenarios for the transition of the European energy system with the aim of limiting the global temperature increase to 1.5 degrees. 4 macro-economic studies can be used to assess the regional economic impacts of the transition as demonstrated in Section 2.3, and drivers and barriers to the energy transition are discussed in section 2.4. The main findings from the case studies are discussed in Section 2.5, and application of the full chain of models from high level energy models to neighbourhoods are exemplified in 2.6. Section 3 and 4 summarises the policy recommendations and proposed future work respectively.

The deliverables that are referred in the document are listed in Appendix 1 and can also be downloaded from the Open ENTRANCE Zenodo repository[1].

[1] https://zenodo.org/communities/openentrance/

2. Open ENTRANCE main results

This chapter summarises the main results from Open ENTRANCE. Figure 1 illustrates how the project worked in interaction with policymakers to develop analytic results about how to most cost-efficiently decarbonise the European energy system.

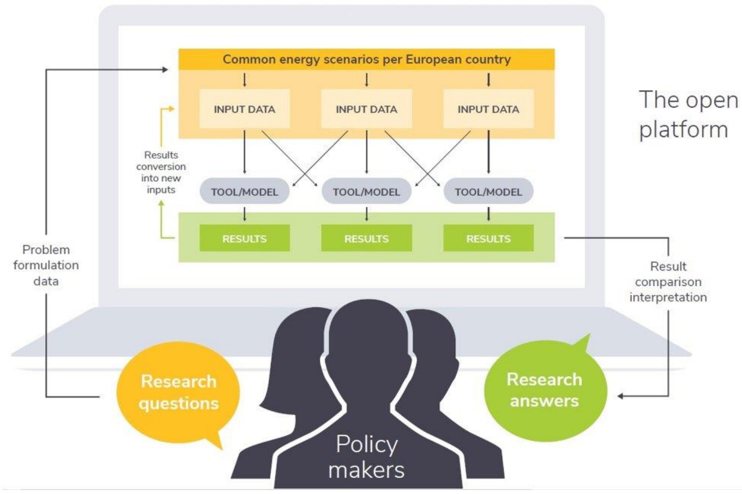

Figure 1 Open ENTRANCE concept for a policy relevant involvement

2.1 The Open energy system modelling Platform

Open ENTRANCE has contributed to structure and align European clean energy transition modelling through the development of an open platform with the following main components: open data for energy system modelling, a suite of linked and open models, a data format and a nomenclature for linking models and open tools for scenario development and comparison.

Open data for energy system modelling is important to increase transparency about modelling assumptions and results, improve replicability and enhance public trust. The Open Platform developed during the Open ENTRANCE project allows to gather and publish these assumptions and contributes to these objectives. It also allows the creation of common scenarios to increase the consistency of results across models with different scopes and validate models with similar scope.

The Open Platform also enables easier access to the open modelling tools used in the project.[2] Those models have both complementarity and redundancy in their scopes and objectives. They include

[2] Open models can be found at: https://openenergymodels.net/models/

energy system models, power system models, macro-economic models and local energy system models dedicated to one or more energy carriers. Non-open models can also be used in relation to the platform as was the case with one of the models used in development of case study 4.

The necessity for models to share data on an open platform led to the development of a common nomenclature, setting conventions that can be used across models and be useful beyond this project. The Open Platform also gives tools to easily visualise, compare and analyse results and scenarios, as well as the possibility to download data. Several avenues exist to improve the platform further by adding features and increasing ease of use. Those ideas for future potential improvements of The Open Platform are described in D4.5. The cases studies allowed a variety of people to use the platform and framework to address analyses involving the use of different tools. The lessons learnt from this are discussed in D6.3, which also provides a tutorial for using the platform and conduct further case studies.

This result already demonstrates its huge potential value in 16 projects (see Appendix 2) that are using or are planning to use one or more of the capabilities provided by The Open Platform. One example of an application of results outside of the Open ENTRANCE project can be seen at DIW Berlin. There, specific metrics of the energy transition are compared to plans and projections, as well as available Open ENTRANCE results. This has currently only been done for France. An extract from this work is presented in Figure 2 The actual installation of renewable capacity in France is compared to the targets set in national regulation and to the Open ENTRANCE scenarios, demonstrating how Open ENTRANCE results can help policymakers and the general public follow the energy transition's progress. The area in grey represents the range of installed PV in the Open ENTRANCE scenarios in different years, while the actual installation of PV is represented by orange bars. Projections of trends and national plans are also included.

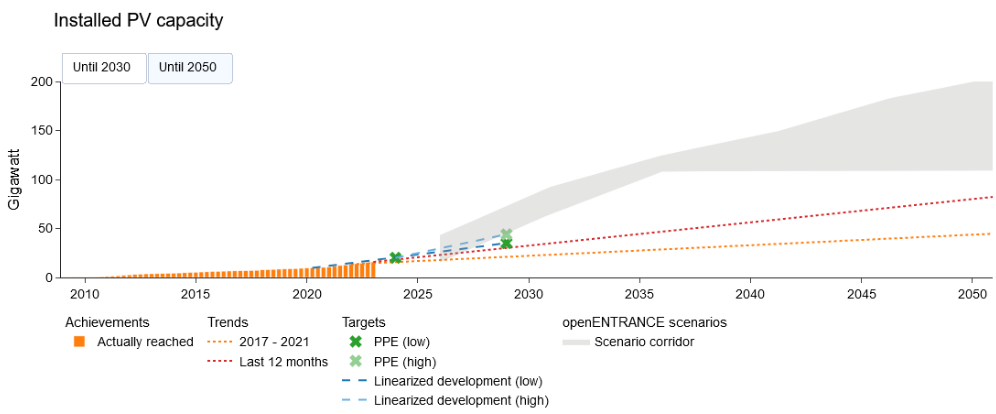

Figure 2 Illustration from the Open Energy Tracker using Open ENTRANCE results https://openenergytracker.org/en/

2.2 Scenarios for decarbonisation of the European energy system

This section presents an overview of the scenarios for decarbonisation of the European energy system. More details can be found in the deliverables D3.2 "Quantitative Scenarios for Low Carbon Futures of the European Energy System on Country, Region and Local Level" and D7.1 "Storylines for Low Carbon Futures of the European Energy System exchange format and template".

Open ENTRANCE has aimed for the objective of the Paris agreement stating that the global warming shall be limited to well below 2 °C; investigating what is needed to reach this goal for different possible futures. As will be shown in later sections, the 1.5 °C target requires tougher action than FIT for 55 and the European ambition for climate neutrality in 2050. This approach brings new knowledge about the policy actions needed and the emission goals required. It puts the possible actions into a frame defining time and cost for implementation in the different scenarios. It is an approach that makes it possible to compare and evaluate the robustness of different scenarios and thereby create new knowledge about the best approaches to succeed with the CET.

The project outlined four scenarios based on drivers and barriers in the energy system, see Figure 3. The names and main characteristics of the Open ENTRANCE scenarios are:

<u>Societal commitment (Reach 1.5 °C)</u>
High societal engagement and awareness of the importance to become a low-carbon society characterises this scenario. Individuals, communities, and the overall public attitude support strong policy measures to accelerate the energy transition.
<u>Directed Transition (Reach 1.5 °C)</u>
Carbon-mitigating energy technologies are further developed but require strong policy incentives for their uptake and refinement. This scenario is driven by a strong centralised vision from the policy side realised by directly incentivised partnerships with industry and technology developers.

<u>Techno-Friendly (Reach 1.5 °C)</u>
Acceptance and societal understanding of the needed clean energy results in little resistance to adopting new technologies and large-scale infrastructure projects. Grassroots initiatives and industry taking action to deliver novel technology in a market-based solution driven by the consumer attitude.

<u>Gradual Development (Reach 2 °C)</u>
With a continuation of current policies and developments, significantly higher efforts are needed even to reach the 2 °C objective. This scenario entails ingredients of 'a little of each' of the other scenarios and represents a business-as-usual approach but still under an ambitious climate target.

The systematic development of the scenarios is described in D7.1 and illustrated in Figure 3. The scenarios have been aligned with existing global scenarios e.g., those considered for the MESSAGEix-GLOBIOM model. Within each Open ENTRANCE scenario, results are consistently calculated to minimise the cost of reaching the emission goals.

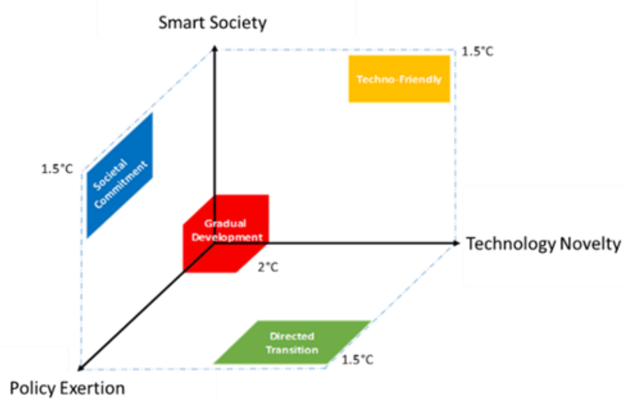

Figure 3 Illustration of the Open ENTRANCE scenarios. From D3.1, Fig. 2-1.

Figure 4 shows the changes in terms of primary energy that are necessary to achieve the transition in Europe. The results clearly indicate the need for, approximately, a 50% reduction in primary energy consumption across scenarios compared to 2018 levels. This reduction comes from general efficiency gains due to the electrification of industry and transport, but also from a stronger sector coupling, whereby a more cost-efficient energy system can be obtained if considering transport, energy storage and electric infrastructure together. Importantly, fossil fuels must be phased out by 2040 to stay in line with the objective of 1.5°.

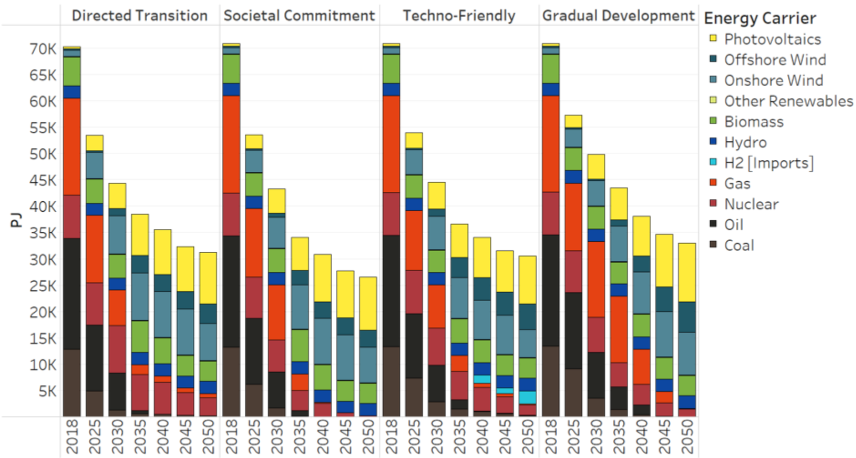

Figure 4 Primary energy resulting from GENeSYS-MOD modelling across study horizon and in the different scenarios. From[3] slide 7.

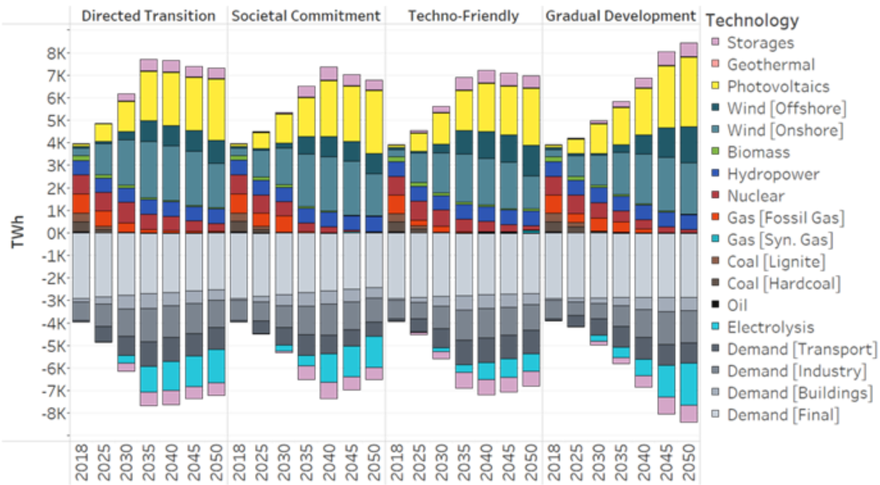

Figure 5 Production and use of electricity resulting from GENeSYS-MOD modelling across study horizon and in the different scenarios. From[3] Slide 9.

Figure 4 illustrates the changes in both the production and use of electricity. On the demand side, the electrification of industry, transport, and buildings accounts for more than half of the doubling of the demand in 2050. The rest of the increase is due to the production of green hydrogen by electrolysis. On the production side, the phase-out of fossil generation is compensated by large investments in

[3] https://openentrance.eu/wp-content/uploads/Decarbonisation-scenarios-European-countries.pdf

wind and solar. Most of these investments should be anticipated and realised early, such that the capacity is installed by 2035 for the 1.5° target to be achieved.

In addition to this transition in generation capacity, the transmission capacity between European countries will also need to be strengthened, with an increase of 60% from 2018 levels by 2050. In addition, these investments should be mostly happening before 2035 according to the 1.5° scenario, underlining the urgency with which the build-out has to happen.

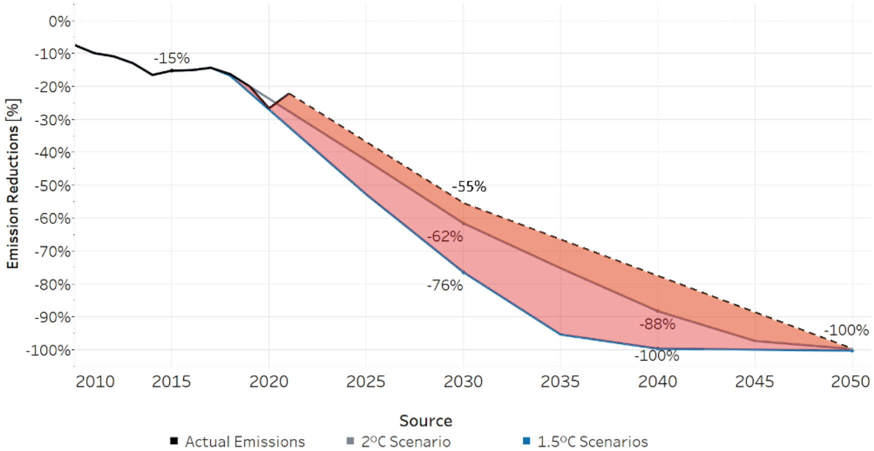

Figure 6 Comparison of current emission reduction trajectory and trajectory necessary to be in line with 1.5° and 2° targets. From[3] slide11

Massive emission reductions are necessary to achieve the 1.5° target. Already by 2030, emissions should be reduced by 76% from 1990 levels to be in line with the objective, and the reduction should reach 100% in 2040. This is far from the current emission reduction trajectory and major actions are required. The current trajectory is also insufficient even for the reduced ambition of 2°. Further delays in the transition only increase the rate of investment that will be necessary at a later stage not to exceed the carbon budgets allowing to stay within 1.5° or 2° and reduce chances of success.

This means a complete phase-out of coal by 2035-2040, oil by 2040-2045 and gas by 2045-2050. It requires active efforts to start reducing their use already now. The solutions to replace their contributions to the energy system exist and must be promoted. Electric Vehicles must go from accounting for 1% of the vehicle fleet in 2022 to 50% in 2030[3]. Heat pumps must go from 14% in 2022 to 55%[3] in 2030. And, as already illustrated, electricity generation from renewables needs to roughly double by 2040.

Hydrogen will have a role to play in this future energy system as an enabler of the decarbonisation of hard to abate sectors. The overall efficiency makes it less suitable for residential heating and cars, where more efficient alternatives exist. Its energy density and potential as a long-term storage solution makes it suitable for applications such as air transport, freight, or specific industries.[4]

Achieving the 1.5° scenario will cost on average 5% more (about 580 billion euros) than the 2° scenario. But it will also prevent 14.5Gt of CO_2 emissions which would, if emitted, engender welfare losses of over 2.5 trillion euros, greatly surpassing the additional cost of reaching 1.5°.

The most important findings in the work with the scenario analyses are:

- Rapid changes are needed to fulfil the goals: RES investment, storage investment, infrastructure investment, increase in energy efficiency and establishing a hydrogen value chain.
- Hydrogen and synthetic methane play a minor role in the power sector but are important for decarbonising other sectors.
- The results show that an optimal use of resources will create regions with net exports and regions with net imports. This opens the need to care about fair transitions for areas with lower RES potential, e.g., Germany becomes a large importer of renewables from both southern and northern regions.

An important policy-relevant result from the project is the ability to use the consistency component from the top-down analysis in the regional and national analyses. The Open ENTRANCE project demonstrates a methodology for creating greater consistency between the policy goals of the EU and their realisation through the national energy and climate plans.

2.3 Macro-economic consequences of the decarbonisation of the energy system

Two computational general equilibrium models were used in this comparative study. Both models are macro-economic models but with different underlying assumptions and equations. This provides a valuable opportunity to compare the results of both and to learn from any differences. The macro-economic addition demonstrates an added value of the platform to provide and verify answers using different types of models. For both models, the Open ENTRANCE scenarios are compared to a business-as-usual scenario, where minimal carbon reduction measures are implemented. A short overview of the results is given below, and further details can be found in D7.2 "Macro-economic impacts of low-carbon transition".

[4] https://openentrance.eu/wp-content/uploads/Decarbonisation-scenarios-European-countries.pdf

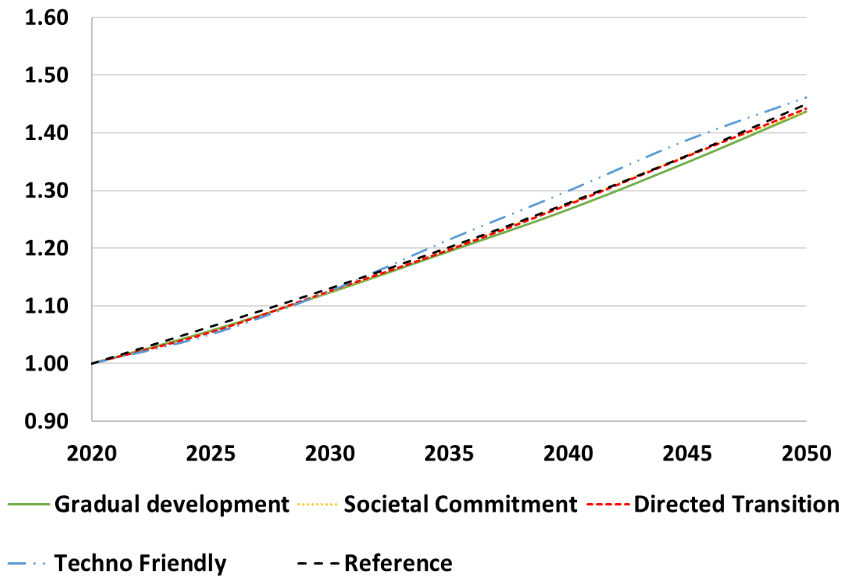

Figure 7 Evolution of GDP in different scenario. From D7.2 Fig. 31

The evolution of the GDP is very similar in the Open ENTRANCE scenarios compared to the business-as-usual scenario, as illustrated by Figure 6. One of the biggest drivers behind GDP is improved factor productivity, which is assumed to improve equally for all scenarios. GDP increases towards 2050 in all scenarios, but is, in general, slightly below that for the business-as-usual scenario because of the small reduction in production in many sectors required to comply with the carbon cap. However, the positive impact that the reduction of emissions in the Open ENTRANCE scenarios would have on health and the productivity of certain sectors, like crops production, is not accounted for in the macroeconomic analyses. The Techno-Friendly scenario stands out with a higher GDP due to the higher energy efficiency assumed in this scenario. The main drivers for the increase in GDP are the assumed increase in population, productivity, and energy efficiency. Some factors have to a lesser extent a decreasing effect on the GDP, like the cap on carbon. However, the feedback effects from climate change, e.g. reduced labour productivity from higher temperatures, would be less prominent with the reduction in emissions achieved in the Open ENTRANCE scenarios. Certain aspects show no or little effect on GDP: the electricity mix, the shift in household spending, the shift from industry to service, and the shift in energy inputs in industries.

While the results show that the decarbonization scenarios have moderate effects on GDP; decarbonization scenarios rather result in sectoral shifts. The Open ENTRANCE scenarios show a large increase in activity in the hydrogen sector, (renewable) electricity sector(s), and the service sector but a reduction in the production of goods. The service sector increases and compensates for the reduction in demand for newly produced goods, because of the shift to a circular economy which replaces the old business model of owning a product.

Looking at individual countries allows us to highlight the difference in the impact of the transition on economies with quite different starting points. For example, comparing Sweden and Romania shows that both countries see an increase in the share of services in the economy. However, while decarbonising the economy to achieve an early reduction target, Romania can start with the relatively "easy" decarbonisation process of the power sector, while Sweden, having an already low-carbon power sector, must seek more difficult sources of emission reductions, which also have a bigger impact on employment.

2.4 Drivers and barriers of the decarbonization process

Drivers and barriers of decarbonization exist at different levels in the society. Open ENTRANCE started with identifying and discussing the potential barriers related to the behaviour of individuals. In Figure 8 below, one can observe the strength of individual willingness to act. The scenario Social-Commitment assumes that citizens are supportive and aligned with the policy to achieve decarbonisation. This scenario is reaching lower emission levels faster than the Techno-Friendly scenario.

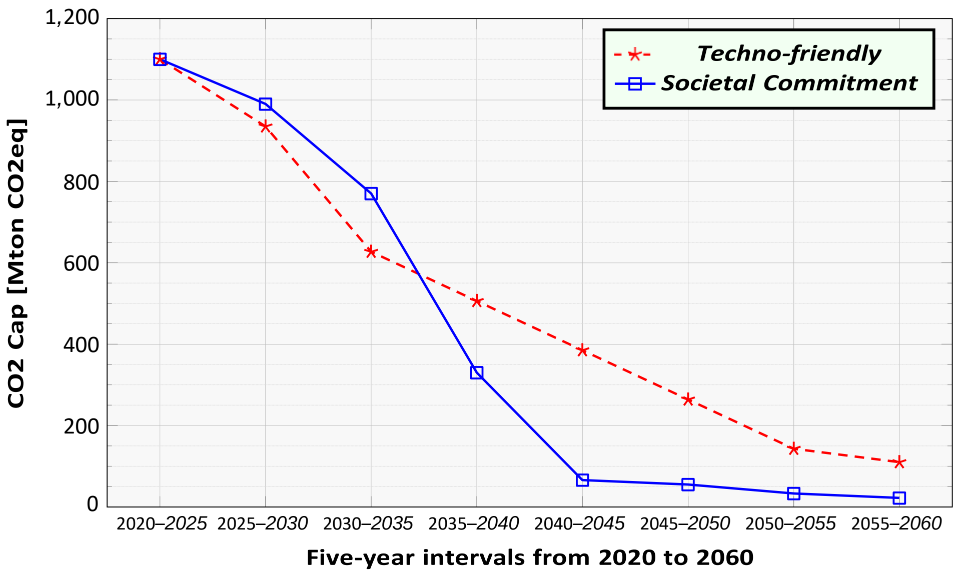

Figure 8 Comparison of the evolution of the CO_2 Cap between the Societal Commitment and Techno-Friendly pathways. From D7.3 Fig. 4.

Another dimension that is investigated is the welfare-related aspects. Under the assumptions of a fair and just energy transition, it is important to have the tools to analyse and understand the impact of global least-cost solutions on individual countries and economic sectors involved in the energy transition. As an example of how the transition can provide different burdens and opportunities, one can look at fossil coal and Poland. Poland produces 40% of the coal used in Europe and has a 74% share of fossil fuels in the power sector. This means that not only must power generation in Poland undergo a huge transition but that, simultaneously, the value of coal exported from Poland decreases. From a different perspective, countries such as Turkey, Spain and Denmark will increase their installed capacity of renewables with a factor of 7, 5 and 6 respectively. The reason is the potential these and other countries have regarding new renewable energy resources. It represents both an opportunity and a challenge because expanding the renewable generation in these countries that much is not impact-free. In guiding the transition, it is imperative to consider the aspects of burden sharing in support achieving a joint effort rather than implementing a nation-wise competitive approach. Figure 9 below shows that, with a joint effort, the changes in GDP across countries will be smaller.

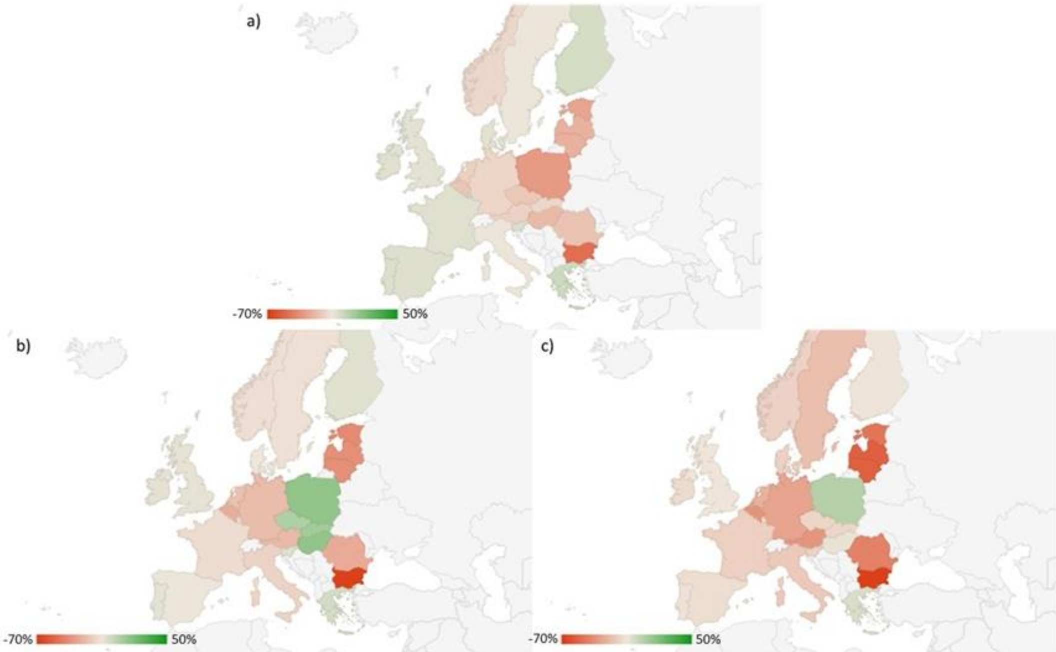

Figure 9 Country specific GDP deviation compared to BAU in 2050 in case of a) decarbonisation under cooperation, b) decarbonisation with V4 calling off the agreements and c) decarbonisation with V4 countries calling off the agreements but subject to tariffs for exports. From D7.3 Fig. 45.

In this work, the Business As Usual (BAU) is aligned with the EU reference scenario[5] so that the GDP development in both matches. The consequences for the system of a more nationalistic approach are simulated by making changes to the group of countries Czechia, Hungary, Poland and Slovakia, also known as the Visegrad countries or V4. Case a) is joint undertaking of the transition. Case b) is the situation where a group of countries leave the climate agreements and increases their competitiveness compared to EU both energy and export wise, hence their GDP is growing. In case c) the countries that are leaving are taxed for exports to other EU countries so that case a) and case c) have similar export values from V4. In this case, the GDP in the V4 countries decreases. However, the fact that there are more expensive goods from the V4 countries available reduces growth in most of Europe as well.

2.5 Case studies

The scenario results computed in Open ENTRANCE are based on the use of aggregated models with one node per country, as well as simplified modelling for some sectors, in particular electricity, and limited representation of variability and uncertainty of renewables. As such, they do not provide details of the clean transition for a nation or region. Therefore, a set of methodologies for analysing regions or parts of the system in greater detail and enabling a more realistic representation of local transition possibilities, has been developed and made available in the Open ENTRANCE platform. This section demonstrates how scenarios can create a consistent framework for performing local analyses. These local analyses were conducted as case studies and are described in D6.2. Simultaneously, the work conducted within the case studies demonstrates the applicability and functionality of The Open Platform.

The case studies have a narrower focus on various aspects. Here is a brief description of each case study:

- **Case study 1** is dedicated to Demand-Response from household consumers. It evaluates the flexibility potential resulting from load control applied to the main household uses such as heating, cooling, washing, refrigeration, electric vehicles charging, and studies its impacts on the integrated European electricity system cost, operation and investment needs.
- **Case study 2** is dedicated to the behaviour of communities of actors. It studies the shared energy management affecting different local energy community concepts, considering the individual preferences of the actors involved. Based on comprehensive modelling, the quantitative results have been up scaled at country and European level.

[5] Pantelis Capros, A De Vita, N Tasios, P Siskos, M Kannavou, A Petropoulos, S Evan- gelopoulou, M Zampara, D Papadopoulos, P Fragkos, N Kouvaritakis, L H¨oglund-Isaksson, W Winiwarter, P Purohit, A Gomez-Sanabria, S Frank, N Forsell, M Gusti, P Havl´ık, M Obersteiner, H. P Witzke, and M Kesting. EU Reference Scenario 2016 - Energy, transport and GHG emissions Trends to 2050. Technical report, European Commission, Brussels, Belgium, 2016.

- **Case study 3** is dedicated to the analysis of the balance of flexibility to be provided across storage and transmission technologies. It analyses how the use of flexible hydropower, transmission, and, more generally, of different kinds of storage (pumped-hydro, batteries, gas….) can tackle some of the main challenges of the energy transition.
- **Case study 4** is dedicated to cross-sector integration, with a specific focus on the flexibilities provided by electric vehicles to the electricity system. It also evaluates the impact of import hydrogen prices on the integrated system.
- **Case study 5** compares different levels of geographic coordination for investment decisions, both at regional and European level, focusing on the topic of decentralisation. In particular, regional decisions made with local objectives were compared with European coordinated decisions made with global targets.
- **Case study 6** analyses the deployment of an innovative technology based on the use of underground rocks for seasonal storage of heat from summer to winter in a district in Oslo, Norway. The analyses show the impact of this on the energy system in the district.
- **Case study 7** evaluates the impact of flexibility from electrified heating on the Danish power system.
- **Case study 8** investigates the role of natural gas storage in the current and the future energy system in Turkey and how it can contribute to decarbonisation.
- **Case study 9** analyses the effects of different types of barriers, from political to technological, on the energy mix, on the sectoral activities, and on the economic growth of the European countries.

The detailed findings of each case study can be found in D6.2. The main findings can be summarised as follows:

- **Flexibility:** Given the European targets for the integration of a high level of renewable technologies, the share of PV and wind power will rise to become dominant. This, because of the variable characteristics of these technologies, will lead to a far greater need for flexibility to ensure that the power system remains stable. Many solutions exist, some of which were evaluated in Open ENTRANCE:
    - The flexibility from residential demand response (load control), including main residential uses like heating, or electric vehicle charging; We determined a realistic but pessimistic (accounting for willingness to participate based on 2018 figures) flexibility potential of demand response of around 50GW, and showed that it could contribute to a reduction of the operation costs, as well as a reduction of the photovoltaic production curtailment , and decreasing the needs for investment in storage.
    - The flexibility from innovative technologies such as the seasonal storage of heat is able to reduce the peak demand in winter, and thus the emissions and costs related to heating, at relatively low costs. This was demonstrated in local case studies both in Norway and in Denmark

- **Local communities:**
    - We evaluated the potential for the deployment of local energy communities in Europe (around 10 million) when these are able to self-consume local PV generation up to 70%
    - We then demonstrated that in countries with large decentralised renewable generation potential, the deployment of Local Energy Communities (LECs) could lead to a decrease in prices, but an increase in the spread between peak and off-peak prices.
- **Hydrogen:**
    - A variation in the prices of hydrogen imports could result in large changes in the energy system with huge impacts on the electricity demand.
    - Regarding the transition to green gases, blending of green hydrogen with natural gas within the existing natural gas infrastructure seems to be promising for the Turkish system, coupled with the extension of existing storages.
- **Importance of modelling the interactions between sectors:** we showed that system development choices and the resulting electricity prices are strongly influenced by the multi-fuel flexibility. It is, then, very important to be aware of the interdependences among the different flexibility measures that are modelled.

2.6 Local studies

In addition to the case studies, partners have conducted further studies within a country along different levels of spatial granularity using The Open Platform infrastructure. Indeed, one of the advantages of The Open Platform and the scenarios defined there, is the consistency it allows between studies that have the same spatial granularity levels, but also among those with different granularity levels resulting from the spatial up-/downscaling. Referring to the latter, algorithms and models have been developed disaggregating country results down over the various NUTS levels to the smallest administrative unit level and even beyond to the building and end user level. Thus, with this kind of consistent and coherent "last mile" analysis, a contribution is made in Open ENTRANCE to make energy policy decision-making much more tangible in very small administrative units such as municipalities, neighbourhoods, buildings and, ultimately, at the individual end user level.

Exemplarily, two consecutive studies at neighbourhood and multi-apartment building level in Vienna, Austria, are mentioned here using the Open ENTRANCE framework and relevant data sets when modelling the decommissioning of the natural gas grid in a neighbourhood in Vienna (used as a heating grid) and identifying alternatives (like district heating and/or electrification), instead of feeding in "green" gas in the future.[6] Among other data from The Open Platform, the study uses emission prices from the Open ENTRANCE scenarios. It finds out that possible stranded assets must

[6] https://doi.org/10.1016/j.energy.2021.121805

not play a decisive role in the investment decisions for alternatives and that the local multi-energy system can be deeply decarbonised without relying on the existing gas distribution infrastructure.

A further study, which builds directly on the neighbourhood study cited above, examined the cost-optimal and socially balanced subsidization strategy for a multi-apartment building to trigger investments in a sustainable heat supply (in the case of decommissioning of gas grid supply) in line with the Open ENTRANCE scenario settings. In the analysis, a public authority incentivises the replacement of the initial gas-based heating system along with building renovation measures (accompanied with reduced head demand) with monetary support to the property owner (e.g. investment grant) and the tenants (e.g. rent adjustment).[7] The results show that a fair and equitable switch to a sustainable heating system is possible. Moreover, it is demonstrated that allocating the costs of inaction among the public authority, the property owner and the tenants is an important lever and can reduce the required subsidy payment.

In conclusion, it can be stated that the use and value of The Open Platform has been demonstrated in the case studies described in section 2.5 and 2.6. Still, the most important argument underlining the value and importance of this Open ENTRANCE results is that 16 associated projects started using the platform even before the project had officially ended. It is of great value that The Open Platform will stay open and accessible for the next 5 years as part of the afterwork of the project, but the value that can be harvested will be much greater if the platform can continue evolving and improving. We believe that the legacy will be expanded in new HEU projects such as OpenMod4Africa, led by SINTEF, and the EERA ambition of a centre of excellence on Energy Transition Modelling (EERA CoE-EMT) led by the Netherlands Organisation for Applied Scientific Research (TNO), Although different activities are ready to take over the legacy from Open ENTRANCE, The Open Platform is still in a vulnerable situation, needing resources to define and manage the long-term strategic development of the platform.

[7] https://doi.org/10.1016/j.enbuild.2022.112013

3. Policy recommendations

This chapter summarises the policy recommendations from Open ENTRANCE based on the state-of-the-art research performed in the project and in line with the scope illustrated in Figure 1.

1) The Open ENTRANCE results show that the current development and policies are insufficient to limit the global warming to 1.5 or 2 degrees. This emphasises the urgency for decisive policy actions to become realigned with the climate ambitions and the Paris agreement. Several decarbonisation measures are robust across scenarios and should be implemented as soon as possible. E.g.,
   - The deployment of EVs should be at least 50% of the car fleet in 2030 compared to 1% in 2021[8]. Present regulation requires all new passenger cars to be fossil fuel-free in 2035, which is not enough to achieve this target.
   - The deployment of heat pumps should cover 50% of the demand for heat in 2030 compared to 14% today. The EU has an objective of installing 10 million heat pumps by 2027 and expects 30 million more heat pumps in 2030 than in 2020 thanks to the phase-out of stand-alone boilers by 2030[9]. Tracking the progress made towards this objective is important to ensure it is fulfilled.
   - The deployment of wind and solar capacities must also rapidly increase to reach productions of around 4000TWh/y and 2000 TWh/y respectively (see Figure 5) compared to 2022 values of 489 TWh[10] wind and 162,5 TWh[11] solar.
2) The costs for taking urgent climate action will be lower than the climate-induced costs Europe will suffer later if it does not act. Making the necessary investments for going from an objective of 2 to 1.5 degrees avoids damages from climate change worth 5 times the investment. This fact needs to be highlighted in communications with the public and Member States to reinforce the acceptance of climate actions and underline their urgency.
3) Consider motivating the public to request less products and more services since a business sector with a larger share of services and a lower share of manufacturing industries emits less GHG gases but maintains economic activity. However, since some industries are decommissioned, politicians must be prepared to support people and regions decreasing their income. Furthermore, it must be a real reduction in request for products and not a move of production to other parts of the world.

[8] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Passenger_cars_in_the_EU#An_almost_9_.25_increase_in_EU-registered_passenger_cars_since_2016

[9] https://energy.ec.europa.eu/topics/energy-efficiency/heat-pumps_en
[10] Wind energy in Europe: 2022 Statistics and the outlook for 2023-2027 | WindEurope
[11] European Electricity Review 2023 | Ember (ember-climate.org)

4) As soon as possible and in line with the REPowerEU strategy, prepare for an extensive production and use of hydrogen in 2030-2035 by among other, incentivising a hydrogen value chain. Hydrogen will have a significant role in the energy system already from 2030-2035 with a particular role in the transport sector and for the decarbonisation of other specific applications such as the production of steel.
5) The policy makers must push the development of flexibility measures:
   a. All alternative measures must be studied combined and in a consistent manner since they significantly impact each other.
   b. Even a small amount of demand response reduces peak prices, decreases curtailment of PV and the need for batteries. Hence, residential demand response should be incentivised.
   c. Flexible seasonal storage of heat can reduce the peak power demand in winter and thus the emissions and costs related to heating. The possibility for incentivising such technologies (underground storage of heat and heat storage in district heating systems) should be considered.
6) Incentivise Local energy communities (LECs) wherever beneficial for the regional system may contribute to reducing peak power prices. Such communities show a consumption of self-produced PV power of up to 70%. According to the Open ENTRANCE calculations, there is, in theory, potential for more than 10 million LECs in Europe. However, since the LECs' impacts on the energy system are very region-dependent, regional assessments must be conducted. Given the large amounts of local, intermittent, generation available within LECS in some region, their deployment may not necessarily involve the reduction of the amount of flexibility mobilized through other means, it could be the other way around.
7) Do not allow possible stranded assets to play a decisive role. Analyses in an urban neighbourhood in Vienna, Austria, show that deep decarbonisation of a multi-energy carrier system is possible, and it is possible even by decommissioning the local natural gas distribution grid. Hence, at a local level, it is recommended to explore the full range of feasible options.
8) Establish and maintain an open energy system modelling Platform including both state-of the-art models as well as complete and consistent data sets for the energy and power system in Europe. There will be a continuous need for analyses of the development of the energy system and the sectoral systems (like the power system) in the coming years and decades. A platform with open models and the corresponding consistent and open data sets enables regions in Europe or Member States to conduct studies to understand the development of their region. One such example is the work done at DIW Berlin on the progress of France towards its decarbonisation goals (see Section 2.1, Figure 2). The Open ENTRANCE modelling platform has proved to have the capacity to take on such a role. It helps create trust among actors, which is very relevant to conduct comparative studies and verify results computed following the open approach. The Open ENTRANCE Platform could also be used

to developed National Energy and Climate Plans (NECPs). In this case, such plans would be consistent at the pan-European level and across Member States.

4. Recommendations for improving The Open Platform

This chapter is mainly for the energy system modelling research community as it contains specific references to model names. Still there are relevant recommendations, as in the first section below, that should be considered also at the policy level.

The Open ENTRANCE platform should be further improved and adapted to increase its impact and value. Therefore, further application of the Open ENTRANCE results is highly recommended. As the transition moves along, considering some new aspects will be needed in the modelling of energy systems. These include expanding the nomenclature, updating The Open Platform and the model suite connected to it, and, last not least, integrating new models addressing more closely the energy security and social aspects of the transition, the European critical raw materials act, the new market designs and business models in the power markets, etc. The list is long, and the work described here involves only the most important gaps that were found in Open ENTRANCE. The recommendations for further development of the Platform (can be used more generally related to energy system model development) comes in addition to the Platform innovation report.

Recommendations for maintenance of The Open Platform

It will be necessary to maintain the Platform, otherwise it will be outdated in few years. Main recommendations are:

- There should be a community or an identified entity responsible for maintenance and possible further development of The Open Platform. The web page must be hosted, the nomenclature needs to be further developed if new models are going to be connected etc. Someone should have authority and budget to do it.

- All the data – and in particular the scenario data – are very useful for education (Master and PhD Thesis) and research, and for authorities in different countries as well as for industry. Many activities for future studies, investment assessments, etc., start with scenario analyses of the future. GENeSYS-MOD and the data sets can save many actors a lot of work, whether they choose to use the scenarios directly or want to adjust some input parameters in them. However, in few years, the data sets will be outdated due to the need to make new assumptions regarding main input parameters. Hence, it is very important that the data sets are maintained. It could be done by the community/entity (see bullet above) or in a follow-up project.

Recommendations for improving The Open Platform

Model functionality improvement

- Increase the temporal resolution of the energy system model. The energy system model GENeSYS-MOD is presently using representative time slots for analysing cost-efficient investments in the future energy system. With only a few hundred time slots per year, the outcome related to the need for flexibility and storage may underestimate the need for new capacities. An energy system model with hourly resolution and acceptable run time would increase the value of the analyses.
- Improve the robustness of the analyses by including stochasticity in the energy system investment analyses. Open ENTRANCE has shown how the models need to capture the variability of VRE to make optimal decisions on capacity investments in generation, infrastructure, and flexibility. Without this ability, the true cost of the transition cannot be captured, and the energy security of the system will be overestimated. Therefore, the development of tools that better capture VRE variability and power capacity and storage needs should be a priority. One way to achieve this in the Open ENTRANCE Platform is by linking GENeSYS-MOD and a stochastic power system model with high temporal resolution.
- Include adjusted weather data due to climate change. The Open ENTRANCE Platform does not include weather data that are adjusted due to the expected climate change. The weather resources may significantly change over the next decades, and this should be incorporated in the models.
- Include material scarcity in the investment models. When the whole world decarbonises its economy, lots of materials will be needed for building wind and solar power production, batteries, electric vehicles, etc. A material scarcity is expected. Minimisation of use of different types of materials should be included in the investment models.
- Include minimisation of land use and impact on biodiversity in the investment models. The energy system model The Open Platform uses finds the cost-minimal investments in new production and transmission capacities that cover an exogenous demand given a climate target. However, new energy production and transmission will require use of land which should be minimised according to the UN's Sustainable Development Goal no 15. Hence, minimisation of land use and impact on biodiversity should be included in GENeSYS-MOD and other investment models on the Platform like openTEPES and EMPIRE.
- An improved scientific approach for calculation of the future energy demand. The future energy demand is an input to several of the investment models in the Platform like GENeSYS-MOD, EMPIRE and openTEPES. The determination of the demand is in most cases based on simple calculations. A model for the assessment of the long-term development of the demand, both the overall volume and the profile, that accurately reflects daily, weekly, and seasonal variability would increase the quality of the energy transition analyses.

Other

- Improve consistency in results by improving the linkages among the models. Open ENTRANCE has soft-linked models to gain extended insight into several aspects of the transition of the energy system towards a low-carbon future, e.g., the soft-linking of GENeSYS-MOD and REMES or EXIOMOD with the aim of understanding the macro-economic consequences of the energy transition. Most of the linkages implemented in the project are the so-called soft-linkages, i.e, output from one model has been used as input to another. Only in a few cases has there been a loop with feedback from the second model back to the first. Running linked models in a sequence until they achieve convergence would improve the consistency of the results. What is more, implementing more ambitious, innovative, linkages among models should help in computing higher quality, consistent, results across the models.
- Improved methodology for dealing with uncertainties and developing more robust results. Uncertainty is dealt with in Open ENTRANCE by running 4 scenarios, by conducting sensitivity analyses and by (to some degree) including stochasticity in some of the models. However, applying a methodology that allows considering a broad range of variation of the input parameters and the combination of the variation of several input parameters would have increased the robustness of the results.
- Improve the efficiency and lower the cost of future analyses by further developing the systematic framework available in The Open Platform for running analyses with the open modelling suite. This can be achieved by adding scripting capabilities to the data platform and writing brief introductions of how to run different types of analyses on the Platform. Two valuable outcomes from this improvement are the possibility to build more coordinated and comparable NECP's, and the possibility to define model based KPI's for following the realization of the energy transition. The latter will make it possible to get early warnings and intervene with the right policy actions. More information about the suggested development of the IT infrastructure of the Platform can be found in D4.5.

Appendix 1: Open Entrance deliverables referred in the final report.

D3.1, "Quantitative Scenarios for Low Carbon Futures of the pan-European Energy System", 2020.05.30

D3.2, "Quantitative Scenarios for Low Carbon Futures of the European Energy System on Country, Region and Local Level", 2022.04.30

D4.5, "Platform innovation recommendations", 2023.01.30

D6.2, "Case study results", 2023.01.30

D6.3, "Best practice for performing case studies for the European energy system in transition", 2023.06.30

D7.1, "Storylines for Low Carbon Futures of the European Energy System", 2019.11.30

D7.2, "Macro-economic impacts of low-carbon transition", 2022.10.31

D7.3, "Policy Measures that Address Barriers and Market Failures in the Low-carbon Transition, 2023.01.30

Appendix 2 – Projects using or planning of using The Open Platform (non- exhaustive)

Project	Type of project	Status project	Reuse from Open ENTRANCE
ECEMF	H2020	Ongoing	Data format and nomenclature
Plan4res	H2020	Completed	Scenarios
SUPEERA	H2020	Ongoing	Scenarios and GENeSYS-MOD
TRANSFORMAR	H2020	Ongoing	Scenarios
NTRANS	FME a)	Ongoing	Scenarios, linked tools: REMES, EMPIRE and GENeSYS-MOD
Nordic Energy Outlook	Nordic Energy Research	Ongoing	Scenarios and GENeSYS-MOD
Ocean Grid	Grønn Plattform NFR b)	Ongoing	Scenarios and GENeSYS-MOD
HydroConnect	KPS c) NFR	Ongoing	Data format and nomenclature
HydrogenPathways	NFR	Ongoing	GENeSYS-MOD, REMES, EMPIRE, linked models
CleanExport	KPS NFR	Ongoing	GENeSYS-MOD
Data Cellar	Horizon Europe	Ongoing	nomenclature, scenarios, other data from data platform (inputs and results of case studies)
OpenMod4Africa	HEU proposal	Proposal accepted for GAP	The Open Platform
ManOEUvRE	CETP project	Proposal accepted	GENeSYS-MOD, scenario data
InterPlay	FME proposal	Propsal development	GENeSYS-MOD; EMPIRE, scenario data

iDesignRES	Horizon Europe	Start fall 2023	Scenario Explorer, nomenclature, GENeSYS-MOD, scenarios
Open Energy Tracker	Project DIW Berlin	Ongoing	Scenarios

a) FME - Centre for environmental friendly energy research
b) NFR - Norwegian Research Council
c) KPS - Knowledge Building Research project
d) Clean Energy Transistion Partnership