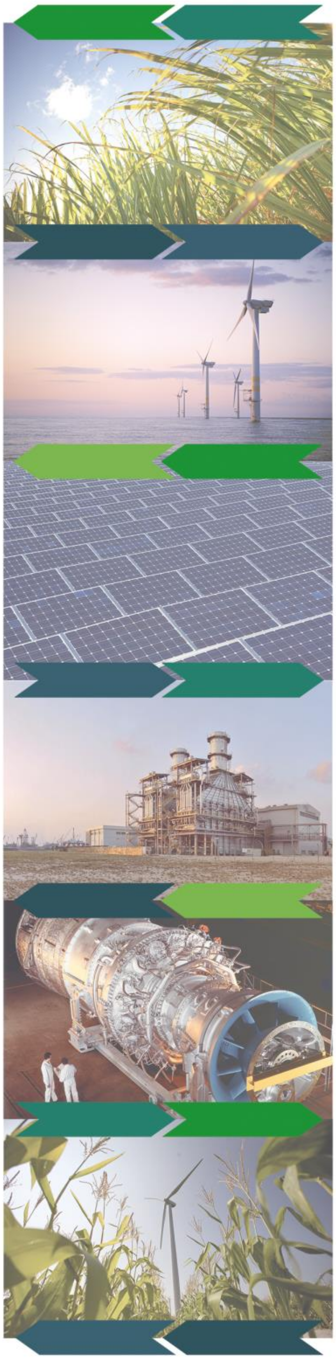
NAVIGATING THE ROADMAP FOR CLEAN, SECURE AND EFFICIENT ENERGY INNOVATION



Final Policy Brief

Decarbonising the EU's Energy System

Policy implications and priorities from modelling in the SET-Nav project

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SET-Nav
Strategic Energy Roadmap

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Executive Summary

What next steps and priorities for the SET Plan?

The European Strategic Energy Technology Plan (SET Plan) aims to accelerate the development and deployment of low-carbon technologies. It seeks to improve new technologies and bring down costs by coordinating national research efforts and helping to finance projects. In this policy brief, we focus on specific energy transition questions addressed by the SET Nav pathways. Through a large-scale modelling effort, we describe key insights based on the SET-Nav main modelling perspectives: demand side, energy supply and infrastructure, and the macroeconomic effects. According to our analysis, the following key priorities for the SET-Plan should be made:

- The diversity of the energy technology portfolio across the full set of priority areas should be increased. At the same time, more consistency is needed, specifically by increasing SET Plan activity in the areas of generation, codification, spillover, and international flows of knowledge in the sustainable transport and energy efficiency areas. Furthermore, market activity and innovation efforts should be aligned, especially in the smart grid and sustainable transport areas.
- Regarding the different sectors, the main priorities from the demand side are decentralised heat supply, heat pumps and implementing corresponding activities. Furthermore, to decarbonise industry, extending the ETS with a minimum price as well as expanding public RD&I funding are important measures. Furthermore, a CO_2 tax as the central element of a broader energy tax reform could provide the incentives needed for fuel switching. Policies to overcome barriers to energy efficiency are also crucial, as is pushing sales of electric vehicles and inducing a modal shift from cars to public transport, car-sharing, cycling and walking.
- In terms of energy infrastructure, electricity network development for integrating new RES generation is a prerequisite, as is preparing grids for the integration of large volumes of Distributed Energy Resources (DER) and for new forms of storage. From the supply perspective, our analysis shows that direct electrification should be favoured wherever reasonable as it is more efficient and leads to fewer requirements on generation infrastructures (e.g., power grid upgrades or conventional generation).
- The final takeaway is that efficient decarbonisation via direct or indirect electrification requires efficient linkages between the energy markets by monitoring close to real-time carbon content of energy carriers.

Navigating critical uncertainties…

Pathways towards a low-carbon future

The EU Energy Roadmap 2050 and various stakeholders' discussions with the European Commission have outlined four main decarbonisation routes for the energy sector. These are Energy Efficiency; Renewable Energy Sources (RES); Nuclear; and Carbon Capture & Storage. The **SET-Nav pathways** assess the *drivers, factors and scenario dimensions* that affect these decarbonisation options.

SET-Nav devised four hypothetical pathways to a clean, secure and efficient energy system – taking different routes. These pathways are shaped by two key uncertainties: the level of cooperation (i.e. cooperation versus entrenchment) and the level of decentralisation (i.e. decentralisation versus path dependency), cf. Figure 1. The modelling assumptions for these pathways were an 85-95% emissions reduction by 2050; 40% as an intermediate reduction target in 2030 and meeting all reduction goals by 2020. The pathways serve two main purposes: first, to determine **main drivers and critical uncertainties** and second, to highlight outcomes and consequences. The former are *modelling parameters,* the latter are *modelling results*. Drivers are policies or intermediate actions, for example. Outcomes consist of costs, the electricity mix or infrastructure developments, among others.

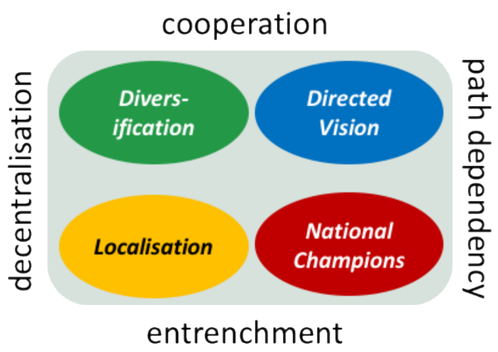

Figure 1: SET-Nav pathway storyline visualisation

The SET-Nav pathways

The **diversification** pathway depicts a decentralised but cooperative world where many new entrants and heterogeneous actors determine the market. Digitalisation, prosumers and high support for coordination as well as regulatory opening characterise this pathway. The **directed vision** pathway goes in a different direction. Although the scenario is still a cooperative one, we see more path dependency and strong EU guidance in determining the shared vision. Large actors are favoured.

The other set of storylines is less cooperative: the **localisation** pathway focuses on the exploitation of local resources. National strategies differ according to country and public resistance leads to lower investment in big new infrastructure but rather favours the emergence of market niches and digitalisation. Finally, the **national champions** pathway minimises transition costs which allows a strong role for incumbent firms and utilities. This transition is highly path dependent and favours large-scale projects. For more details on pathway modelling and analysis, see the SET-Nav Pathways report.[1]

[1] Crespo del Granado et. al. (2019), Comprehensive report "SET-Nav – Comparative assessment and analysis of pathways", SET-Nav project, http://www.set-nav.eu/content/pages/library

Modelling and analysing SET-Nav pathways

In the following sections, we outline the main findings and insights of the SET-Nav pathways. Addressing the multiple dimensions of energy transition entailed using around 15 different energy system models in the SET-Nav project. This unique and large-scale energy modelling exercise consisted of three main parts: 1) demand perspective, 2) supply and infrastructure assessments, and 3) macroeconomic outlooks.

To sum up our analysis, we formulated guiding research questions across modelling teams (demand side, supply side, infrastructure and macroeconomic effects) that are addressed alongside the different dimensions of the SET Plan. That is, we structure the answers according to these dimensions to show which portfolio of measures is necessary to arrive at a low carbon future.

...a roadmap towards a low carbon future

Policy implications from modelling and analysis of energy ***demand sectors***

How do policies complement each other to achieve the EU's 2030 and 2050 targets?

Buildings: Policies to increase the thermal efficiency and energy performance of buildings can lead to substantial reductions in consumption, especially space heating demand. Lower heat demand in combination with low temperature heat distribution systems allows for the **integration of efficient heat pumps**, facilitates the transition to advanced, low-temperature district heating systems and reduces the need for limited biomass resources. Carbon prices on fossil fuels in the heating sector alone are unlikely to provide sufficient incentives to decarbonise the building stock. Further **financial incentives for RES-H/C systems** and renewable support or obligations for renewable heating systems are needed. To increase the share of connected buildings within district heating areas, information and/or district heating regulatory policies (e.g. zoning) will be needed. In particular, the role of **spatial heating and cooling planning** as an integrative policy approach at the local and regional level needs to be strengthened. The affordability of decarbonisation measures, but also of comfortable housing, is a prerequisite to the acceptance and successful implementation of low-carbon policies.

Industry: An effective policy mix should include the following elements. Extending the ETS with a minimum price path (i.e. a floor price) could provide more long-term clarity and the certainty investors need for low-carbon innovations. **Public RD&I funding** can play an important role in accelerating the market introduction of innovative low-carbon processes. A **CO_2 tax** as the central element of a broader energy tax reform could provide the incentives needed for fuel switching. This must avoid any double burden on companies inside the ETS. Policies to **overcome barriers to energy efficiency** (energy management schemes, audits, soft loans, and energy service market) are a prerequisite for other (price-based) policies. Targeted **public procurement** can support the market introduction of low-carbon products by establishing niche markets.

Transport: Sales of electric vehicles have to be pushed, either by stricter fuel efficiency or a CO_2 standard or by putting pressure on the automotive industry to shift to new technologies.

Infrastructure deployment is also needed, as is reducing costs for new technologies while increasing costs for conventional vehicles (i.e. by fuel taxes, subsidies for electric vehicles in early market phases, vehicle registration taxes steered via bonus-malus systems and road charges related to vehicle CO_2 emissions). A **modal shift** from cars to public transport, car-sharing, cycling and walking can be achieved by making cars less attractive. **Possible interactions between sectors** for CO_2 neutral production of alternative fuels. Households with rooftop PV installations should have incentives to buy battery electric vehicles that they charge with self-produced electricity.

For each pathway, what are the important elements, drivers and factors of the energy transition and their cost-effective solutions?

	Diversification	Directed Vision	Localisation	National Champions
Buildings	a mix of decentral heat pumps, biomass boilers and solar thermal systems in combination with IT solutions for smart heating are the cornerstones of CO2 mitigation technologies	same technologies as in diversification, but with less focus on smart heating solutions and less use of decentral heat pumps	it is assumed that due to regulations higher market shares of district heating can be reached. Decentral renewable heating options still play a key role in areas with lower heat density	member states follow very different strategies. It is also assumed that member states with currently high shares of natural gas could opt for green gas solutions to avoid the decommissioning of gas grids
Industry	a stronger fuel switch to biomass, power-to-heat, power-to-gas and radical changes in industrial processes (e.g. switch to hydrogen, low carbon cement sorts) take place	no radical process improvements take place, as companies invest in CCS for major energy-intensive point sources instead of other radical process improvements	a stronger fuel switch to biomass, power-to-heat, power-to-gas and radical changes in industrial processes (e.g. switch to hydrogen, low carbon cement sorts) take place	no radical process improvements take place, as companies invest in CCS for major energy-intensive point sources instead of other radical process improvements.
Transport	transport system as a ‘mobility as a service’ system. Multi-modal information platforms and services, car-sharing and autonomous driving enter into the market early in this pathway and overall efficiency increases	joint decisions on technology across EU countries like overhead-cable infrastructure for trolley trucks and phase-out of pure fossil-fuel based cars, prices for new technologies decline fast. In addition, strong support for improving public transport also for national and international distances supports the modal shift to more efficient modes	car-sharing, public transport, walking and cycling increases. Decentral electricity production including roof-top PV increases incentives for households to buy electric cars. Overall technological learning is slower due to more technological diversity. Therefore, and due to the focus on using local resources, the demand for biofuels is relatively high	The strategy is to stay with internal combustion engine technologies but substituting fossil fuels by biofuels. Technological progress for sustainable biofuel production (incl. 2nd- and 3rd-generation biofuels) and optimal use is made of biomass and existing filling station infrastructure can be maintained

What are the long-term impacts of alternative mitigation options on the economy, the energy sectors and technology development?

Buildings: The phasing-out of natural gas is one of the main challenges for the decarbonisation of the building sector. This transformation will have significant effects on gas network operators and retailers. Only in scenarios with a high amount of green gas generation would the gas grid structure and business models be sustained. Alternatively, district heating could take over the role of natural gas in densely populated areas. The integration of excess heat, large-scale heat pumps and to a limited extent biomass and solar thermal energy into district heating networks would substitute imports of natural gas and create a more regional/local heat supply structure than heat supply from fuel oil and natural gas. The pathway analysis shows that the use of heat pumps is a cornerstone of energy transition in the building sector. But this also requires corresponding activities in the building stock regarding the reduction of temperature levels in the heat distribution systems of buildings. The substitution reduction of direct electric heating systems, which are currently widespread in some countries, and the installation of efficient heat pumps combined with heat storage and demand response schemes can substantially reduce electricity demand in scenarios with a high diffusion of electric heat pumps.

Industry: The pathways show that incremental and BAT (best available techniques) energy efficiency improvements, advanced energy and resource-efficient processes, fuel switching, recycling and re-use, as well as material efficiency and substitution can lead to a significant reduction of industrial CO_2 emissions (-70%). Final energy demand (-25%) in the TRANS-IPT scenario[2] in 2050 compared to 2015 reflects an 83% emissions reduction compared to 1990. However, the remaining energy efficiency potential due to applying the BAT is limited. In addition, fuel switching from fossil fuels such as natural gas to renewable sources is often not possible due to the high temperature levels required in industrial furnaces and the competition with other sectors for biomass. Although incremental improvements of energy efficiency and fuel switching are important pillars of industrial decarbonisation pathways, these two options alone will not suffice to achieve a low-carbon industry sector by 2050.

Deep emission cuts require substantial changes in the iron and steel, cement and chemicals industries (e.g. use of hydrogen), but also need support for RES and energy efficiency in other sectors and companies. Biomass is the most important RES in industry, particularly in the medium term. However, biomass resource potentials and their sustainability are limited. In the long term, RES-based electricity (power-to-heat, power-to-gas) can play a more important role, particularly if electricity generation has very low emission levels. However, electricity is not yet competitive with biomass, even in the most ambitious transition policy scenario, meaning that replacing biomass with electricity would require targeted policies. Improved material efficiency and the circular economy can also have a substantial mitigation potential.

[2] The Transition scenario, including innovative process technologies in industry (TRANS-IPT), describes an industrial decarbonisation pathway aiming to reduce European GHG emissions by 2050 (according to Fraunhofer's FORECAST model).

Transport: The diffusion of zero-emission vehicles such as battery electric cars, fuel cell electric trucks and hybrid trolley trucks generates increasing electricity demand from the transport sector. By contrast, the consumption of fossil fuels decreases markedly over time, while demand for alternative fuels increases. Europe's production of vehicles contributes to GDP growth and employment. Both will be influenced by moving to new zero-emission technologies, depending on how the automotive industry manages the transition and ensures competitiveness. In the case of joint approaches across countries, prices for new technologies will decrease faster due to learning effects and economies of scale. Studies on acceptance, economic, social and ecological impacts and secure supply of scarce resources should be considered when narrowing options down to specific technological solutions.

...a roadmap towards a low carbon future

Policy implications from analyses of ***Supply and Infrastructure*** perspectives

How do policies complement each other to achieve the EU's 2030 and 2050 targets?

The integration of large volumes of Distributed Energy Resources (DER) will result in changes to the flows in distribution grids, potentially leading to the need to undertake relevant upgrades in these grids. Policies to promote the deployment of RES generation should then be complemented with others facilitating the development of the grid infrastructure required to integrate new RES developments. This may also be true for certain storage technologies. Thus, with an appropriate amount of transmission interconnection capacity in place, there may be areas in the European system where large hydro storage capacity could also balance excesses or deficits of electricity in other areas, which may be located far away from these storages

The role of carbon capture and storage (CCS) and nuclear is highly dependent on political decisions. New nuclear power plants are more costly than other generation options.

For each pathway, what are the important elements, drivers and factors of the energy transition and their cost-effective solutions?

In the Diversification and Directed Vision pathways, significant coordination efforts take place at European level. This might lead to large energy exchanges among areas that may differ substantially from traditional ones. Because of this, significant improvements to electricity transmission grids are needed.

In the Localisation and National Champions pathways, transmission network development needs are less pronounced. In Localisation, countries rely primarily on local resources to supply their needs. Thus, energy exchanges among other European regions are limited. In National Champions, traditional incumbents will be in charge of leading the decarbonisation efforts according to national strategies. Here, conventional technologies may play a key role: nuclear generation will still be in place, while relevant amounts of thermal generation will be used in combination with CCS. This will result in energy exchanges across Europe being limited and rather similar to the traditional ones, which explains why accommodating these flows does not require building large amounts of transmission capacity. Given that centralised rather than DER solutions prevail, distribution network development needs should not be great either.

Constructing large new pan-European transmission infrastructure developments, as in the Diversification and Directed Vision calls for three main challenges to be addressed: 1) implementing an appropriate institutional framework to govern the development of the cross-border network; 2) allocating the cost of cross-border network investment projects in an efficient way that is perceived as fair by national authorities; and 3) putting in place the appropriate conditions for these projects to attract funds at a reasonable cost.

Regarding the development of distribution networks in line with the needs of all the pathways, but especially those that rely on DER, namely Localisation, one main need, besides implementing and preserving favourable financing conditions, is to put in place a remuneration scheme for DSOs that takes into account the extra costs that these entities may incur when integrating large amounts of new forms of DER, such as distributed generation and storage. These extra costs not only entail additional network investments, but also the communication infrastructure required to control generation, demand and storage in the DSO grids.

As for the role of CCS, we include it as a technology option at moderate cost in the Directed Vision pathway as part of the optimisation of electricity supply and at higher cost in the National Champions pathways. Our analysis of these pathways shows only a moderate diffusion of CCS, contributing between 8 and 10% of total generation.

In all pathways, renewables play a crucial role in energy supply. The most prominent source in all pathways is wind energy. This prominent role of renewables is a very robust outcome. This result has an important impact on the decarbonisation strategy. In principle, the decarbonised electricity generation can decarbonise other sectors such as heat supply or energy use in the industrial energy supply. The available options are direct use of electricity generation or the utilisation of secondary energy carriers such as hydrogen. Our analysis shows that direct electrification should be favoured wherever reasonable as it is more efficient and leads to fewer requirements on generation infrastructures. The Diversification and Localisation pathways with a very high hydrogen demand end up with a substantial utilisation of the existing renewable generation potential in Europe, which could raise issues of public acceptance. Our analysis shows that the decarbonisation of the energy system via electrification is possible. This will be cheaper if we can strengthen the electricity grid. The Localisation pathway, with a firm restriction on extending electricity grids, shows the highest cost of electricity supply.

What are the long-term impacts of alternative mitigation options on the economy, the energy sectors and technology development?

Not developing transmission networks sufficiently will result in significant increases in the cost of deploying and operating RES generation at European level, since electricity generation excesses and deficits within each area would be balanced locally. This, among other things, would prevent the deployment of large European RES developments, which could negatively affect the development of the RES generation industry in Europe. Local generation and storage would have to be deployed on a huge scale, regardless of its cost.

Additionally, if appropriate distribution network infrastructure is not implemented, the motivation of small consumers to increase efficient energy use and the exploitation of DER in general would be very limited, which would impact the environmental footprint of the energy sector as well as the cost of electricity supply. The development of RES generation technology of a distributed type (like PV) within Europe would be negatively affected. Here, a key takeaway is that efficient decarbonisation via direct or indirect electrification requires efficient linkages between the energy markets reflecting the close to real-time carbon content of energy carriers. In other words, the demand side has to adjust to the short-term nature of the electricity market. This requires flexibility and bivalent generation options in all sectors. A robust example in all pathways is the use of large heat pumps in heat grids with the backing of fuel-based boilers and heat storages as alternative generation options.

Regarding developments in the gas sector, all SET-Nav pathways foresee European natural gas consumption falling by 40-75% to about 125-230 bcm/y by 2050. That is, by 2050 gas demand would decrease from the current approximately 5000 TWh/year (450 bcm/y) to about 1500-2500 TWh/year. When considering domestic European production potential, including from Norway, two of the four pathways may result in the EU being independent of non-European gas imports.

What is the role of innovation in energy transition?

What next steps and priorities for the SET Plan?

The SET Plan comprises portfolios of technologies (the six priority areas) and directed innovation efforts to influence a range of innovation system processes throughout the technology lifecycle from basic research to market deployment. Our analysis of SET Plan activity emphasises the importance of designing, monitoring, and evaluating SET-Plan performance along both these portfolio dimensions. To this end, we developed three normative criteria for tracking progress in the EU's energy research and innovation portfolio: balance, consistency and alignment.[3]

Balance. A balanced SET Plan would place similar relative emphases on different technologies. Our analysis shows that SET Plan activity is currently weighted towards three priority areas: renewable energy, energy efficiency and sustainable transport. Increasing portfolio diversity across the full set of priority areas is an effective means of addressing technology risk and maintaining option value. This is particularly important given the stringency of decarbonisation goals that leave little room for innovation or deployment failure.

Consistency. A consistent SET Plan would place similar relative emphases on different innovation system processes. This is particularly important for less mature technology fields (like CCS or sustainable transport) which rely more heavily on the diversity of processes throughout the innovation system and so are more sensitive to inconsistencies. Our analysis shows that SET Plan activity is least consistent in the generation, codification, spillover, and international flows of knowledge in the sustainable transport and energy efficiency areas. This helps to draw portfolio

[3] These are not covered in any detail in this report, but the supporting analysis can be found in Wilson & Kim (2018) and Kim and Wilson (2017).

managers' attention to areas of possible tension or weakness where innovation efforts could be strengthened to act in concert. This is particularly important given the need for accelerated energy-system transformation in line with the EU's 2030 and 2050 strategic goals.

Alignment. An aligned SET Plan would place similar relative emphases on late-state innovation processes associated with widespread market deployment in line with the EU's strategic goals, particularly decarbonisation. Our analysis finds evidence of misalignment in the smart grid area for which market activity (resulting from regulated smart metre rollouts) has outpaced innovation system activity, with the converse in evidence in the sustainable transport area for which market activity is still limited. Ensuring the alignment of SET Plan activity with medium- to long-term targets and goals is an essential feature of policy learning and adaptive management, and a basis for tracking and improving on innovation system performance. This is particularly important for the SET Plan to deliver on EU policy goals on innovation and energy-system transformation.

Policies and important elements, drivers and factors of the energy transition

A clear finding from our analysis of energy innovation in the SET-Nav pathways is that a diverse mix of policy instruments can help foster collaboration among innovators in the EU's energy innovation system (measured by multi-country patent co-inventions) and this collaborative activity is positively associated with successful innovation outcomes. Policy diversity implies portfolios of regulatory, market-based, innovation, and strategic instruments in line with SET Plan goals. This is consistent with literature that finds that combinations of consistent and stable policy instruments towards long-term targets are important for innovation (Reichardt & Rogge, 2016).

Policy diversity can also better respond to the needs and niches of heterogeneous actors, should innovation activity become more localised and barriers to entry fall, thereby allowing for easier market access for new entrants (including via digital platforms). This is particularly important in the Diversification and Localisation pathways, which see a decentralisation of innovation activity in the EU, and pose greater coordination challenges for effective actor interaction and knowledge exchange.

It is hard to isolate robust effects of future uncertainty in each pathway on energy innovation outcomes due to the complex causal functioning of the innovation system. This means the potential effect of one uncertainty (e.g. the strengthening of RD&I expenditure) may be offset by another uncertainty (e.g. the weakening of policy stability).

The one exception is that in the Diversification and Localisation pathways, the positive and statistically significant relationship between policy diversity and collaborative activity (measured by pan-EU patent co-inventions) signals the importance of policy portfolios tailored to the specific needs of increasingly heterogeneous and localised innovation actors.

...and future destinations

Summary of key findings for the different pathways.

We identified a variety of actions to achieve a decarbonised future taking different pathways. The different pathways are based on storylines of different, largely political decisions regarding the future of the European Union. Depending on political realities, different key research questions will come into focus. Below, a few examples show how they might play out.

Diversification	Directed Vision
- innovation research - developing a variety of new technologies - strong use of local renewable resources with very high hydrogen demand	- more likely to call for ideas on how to expand the grid - manage cross-border flows of electricity in the most cos- efficient manner
Localisation	**National Champions**
- innovative solutions for decentralised energy and the distribution grid - radical changes in industrial processes, stronger switch to biomass, power-to-heat, power-to-gas - strong use of local renewable resources with very high hydrogen demand	- would need decarbonisation solutions for an incumbent energy sector - Green gas solutions - No radical changes in industrial processes and continued use of the internal combustion engine

SET-Nav
Strategic Energy Roadmap

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About the project

SET-Nav aims to support strategic decision-making in Europe's energy sector, enhancing innovation towards a clean, secure and efficient energy system. Our research will enable the European Commission, national governments and regulators to facilitate the development of optimal technology portfolios by market actors. We will comprehensively address critical uncertainties facing technology developers and investors, and derive appropriate policy and market responses. Our findings will support the further development of the SET-Plan and its implementation by continuous stakeholder engagement.

These contributions of the SET-Nav project rest on three pillars: modelling, policy and pathway analysis, and dissemination. The call for proposals sets out a wide range of objectives and analytical challenges that can only be met by developing a broad and technically advanced modelling portfolio. Advancing this portfolio is our first pillar. The EU's energy, innovation and climate challenges define the direction of a future EU energy system, but the specific technology pathways are policy sensitive and need careful comparative evaluation. This is our second pillar. Ensuring that our research is policy-relevant while meeting the needs of diverse actors with their particular perspectives requires continuous engagement with the stakeholder community. This is our third pillar.

Who are we?

The project is coordinated by Technische Universität Wien (TU Wien) and being implemented by a multinational consortium of European organisations, with partners from Austria, Germany, Norway, Greece, France, Switzerland, the United Kingdom, France, Hungary, Spain and Belgium.

The project partners come from both the research and the industrial sectors. They represent the wide range of expertise necessary for the implementation of the project: policy research, energy technology, systems modelling, and simulation.

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