GREEN-PATHS: European Knowledge Hub on Just Transition Pathways

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Introduction

Executive Summary

This review report has the overall goal of summarizing and analysing the results of previous research projects linked to green transitions, with an emphasis on the methodologies and approaches used to assess economic, social, and distributional impacts. It has been written collectively by members of the GreenPaths team, including the University of Siegen, the University of Cantabria, Oxfam Intermon, and the Transnational Institute and was led by the University of Siegen. The work has been achieved through an analysis of previous Horizon 2020 projects linked to green transition, summarizing the results from 18 projects from European Union's Horizon Europe research and innovation programme and presents an analysis of their relevance to GreenPaths. The project summaries focus on the methodologies and results of case studies that form the core of each project. Key conclusions of our summary and review of the 18 Horizon projects include the identification of commonly used general research designs and specific methodologies:

General research designs

- Engagement with stakeholders: Extensive interactions with and involvement of diverse stakeholders, including policymakers, industry experts, academics, and civil society who are relevant to policy formulation, design, implementations and/or are affected by policy outcomes, to gather insights and feedback on policy processes and an understanding of socially acceptable outcomes.
- Transparency and Accessibility: Open modelling and data exchange platforms to ensure transparency and credibility.

Specific methodologies

- Qualitative Methods: Interviews, workshops, surveys, and focus groups provide deep insights into stakeholder experiences and attitudes.
- Integrated Assessment Models (IAMs): IAMs synthesize information from various fields to evaluate social, economic, and environmental impacts comprehensively. They help in policy evaluation, climate change mitigation and adaptation, and long-term planning.

Intended Audience

Apart from the GREENPATHS consortium, this paper is intended for policymakers, researchers, and members of civil society interested in gaining insight into the methodologies used to measure social, economic, and distributional impacts of green transition policies, and a synthesis of results of previous Horizon 2020 projects.

Reading recommendations

After the introduction, this document provides a methodological analysis. It reviews past Horizon 2020 projects, summarizes their case studies results and methodologies, and offers a discussion.

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Approach

We summarize the case studies' results and methodologies of 18 selected Horizon 2020 projects and then present a brief analysis of how their results and methodologies are relevant to GreenPaths. These projects were chosen from European Union's Horizon Europe research and innovation programme because the programme has, through various projects, addressed processes of impact assessment, a crucial element of GreenPaths, especially for the case studies in the upcoming WP 3. The selected projects range from 2015 – 2023 to ensure that they were complete and the results available online, and that they were recent enough to be relevant. The 18 projects were chosen based on their relevance for impact assessment. The projects were identified via the European Commission CORDIS website: https://cordis.europa.eu/

This approach allows us to cover common methodologies used to assess the impacts of green transition policies and assess the results of previous projects linked to green transition.

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1 Horizon Projects Review Report

1.1 Research methodology

This section summarizes the results and methodologies of 18 selected Horizon 2020 projects and subsequently present an analysis of their relevance to GreenPaths. These projects were selected from the European Union's Horizon Europe research and innovation programme because the programme has addressed impact assessment processes, a critical component for GreenPaths, particularly for the case studies in Work Package 3.

The selected projects range from 2015 – 2023 to ensure that they were complete and the results available online, and that they were recent enough to be relevant. The 18 projects were selected based on their pertinence to impact assessment and were identified through the European Commission's CORDIS website: https://cordis.europa.eu/.

Each Horizon project has several deliverables, and each deliverable in the projects under consideration was created in support of the case studies that were conducted in these projects. Therefore, for comprehensive and relevant summaries, we decided to focus on the reviewed projects' case studies' results and methodologies. In the following, each project section consists of an introduction, a description of its work packages, the approach, a description of the case studies and their results, followed by an analysis of the results. Each project description is concluded by a summary of the methodologies used in the case studies.

1. GRETA - GReen Energy Transition Actions

Grant Agreement No. 101022317
Website: https://projectgreta.eu/

The GRETA project worked under the assumption that active citizen participation can help facilitate an effective and just energy transition. This is energy citizenship; the active participation of the public in clean energy transition, becoming key players in the sharing of resources and consumption reduction. Through the adoption of renewable energy, and behavioral changes, the collective effort of citizens within energy systems can lead to the considerable reduction of carbon emissions. The EU-funded GRETA project conducted research on this phenomenon of energy citizenship, developing frameworks and models that reveal factors affecting both collective and individual energy citizenship actions.

The project has five objectives:

(1) to understand who energy citizens are.

(2) to understand the actions and interactions of energy citizens;

(3) develop and test behavioral strategies, models, and frameworks on energy citizenship.

(4) to leverage strategies or methods initially implemented on a local scale and expanding them to broader geographic levels, such as regional, national, and supranational levels.

(5) to improve the policymaking process.

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GRETA studies the social side of the energy transition, understanding how this transition can impact citizens and communities, and how these very citizens can be mobilized to facilitate this transition. The project studies the different social and geographical contexts, as well as the knowledge, technological and financial resources needed to create active energy citizens.

Work Packages

Work Package 1: presents a framework that attempts to evaluate the circumstances under which the formation of energy citizenship might occur in particular contexts. WP 1's overall goal was to increase awareness of energy citizenship inside the EU by describing the various definitions of energy and citizenship, the distinctions between decentralized and centralized energy systems, the different kinds of energy citizens, and the behaviors associated with them.

Work Package 2: Information sensemaking and sharing within, between, and beyond energy communities.

Work Package 3: WP 3's objective is to compile and assess the GRETA case studies to comprehend the structural elements that influence the emergence and development of energy citizenship.

Work Package 4: By creating a strong analytical foundation for the project through the creation of various energy and behavioral models, WP 4 on data processing and explicit modelling will support GRETA's overarching goal.

Work Package 5: WP 5's overarching purpose is to find out how geographic locations relate to the primary drivers of energy citizenship as well as the circumstances in which energy citizenship advances broader decarbonization policy objectives.

Work Package 6: Not available online.

Work Package 7: The plan for communication, dissemination, and exploitation activities of GRETA.

Work Package 8: Project Coordination

Approach

Through several work packages GRETA aims to create Community Transition Pathways (CTPs) and Energy Citizenship Contracts (ECCs) that will lead a decarbonization process that fosters the central and active role of citizens. These tools helped policymakers promote active energy citizenship, starting from the local level. GRETA produced policy recommendations tailored to inform EU policymakers.

Case studies

EU Wide - Electric autonomous and connected mobility network

This case study investigates the rationales of individual citizens to engage with the European Cooperative, Connected and Automated Mobility (CCAM). The engagement of citizens in green energy practices depends on internal (level of agency and emotional state created by external factors such as engagement outcome, and societal pressure) and external (outcomes, whether negative or positive, the dominant social norm, and the nature of the social-relational models) factors.

The results of the case study show that the regulatory frameworks for advanced levels of automation are complex and since many of these rules are integrated into the systems that offer the mobility service,

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the end user of these technologies is not often aware of them. So, to deploy new CCAM-compliant vehicles it is important to create awareness of regulatory matters. The study also finds that engagement with CCAM is strongly impacted by education, age, income level, technical knowledge, and regulatory frameworks. With the above-mentioned factors, new technology itself seems to push for a cultural shift towards community sharing. Therefore, now it is up to policymakers to deliver a policy mix that encourages citizen engagement.

Bologna Pilastro-Roveri, Italy - Renewable energy district

This case study took place in the Pilastro-Roveri district in the northeast of Bologna, where the Green Energy Community project (GECO) has been running since 2019 to design and create a green energy community. The case study is based on two socially economic distinct areas, the Pilastro "Rione" (neighbourhood), and the Roveri area. The case study aimed to identify and describe the behaviour of the local community towards the energy system via a set of activities, such as monthly meetings with local associations, and observing energy participants in local neighbourhoods.

Based on the research methods used, the researchers were able to gather valuable information on energy citizenship in the Pilastro-Roveri district. The findings of the case study show that it is difficult to involve all citizens in energy citizenship, especially those who are economically or socially in fragile positions because the energy issue is not a priority issue for them. Further key findings are:

- Knowledge and information seem to be crucial when it comes to enabling strategies and how to promote a rise in awareness and an increase in energy-efficient actions.
- Economic incentives in particular are viewed as an essential tool to encourage transition-related actions of the population, that would otherwise find them difficult. Citizens would be willing to invest in energy-efficient actions if they received economic support for the installation and/or purchase of tools and materials.
- Finally, these actions must be sustained continuously instead of just a few times at the beginning of the transition process to have real results.

Portugal - Coopérnico - Renewable energy-driven cooperative

This case study focuses on Coopérnico a renewable energy-driven cooperative in Portugal that works on developing and selling renewable electricity. As a cooperative and social enterprise, Coopérnico fosters citizen participation, with consumers also acting as company owners, and it aims to increase even more the number of citizens engaged in energy systems, to enable a socially just energy transition. The objective of the case study was to find factors that encourage already active energy citizens to further their community participation towards a just energy transition.

The results of the case study show:

Cognitive and Attitudinal Predispositions: all stakeholders involved share the vision of a community-led clean energy transition, reducing the carbon footprint with empowered citizens. Regarding economic accomplishments, all other actors see them from the citizens' point of view, whereas the government sees them largely from a grid perspective.

Challenges: all actors face different challenges. The cooperative and its members struggle with operational challenges, while the government and cleantech suppliers grapple with licensing issues and the slow pace at which relevant legal frameworks evolve.

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Social Norms and relationships: While there exist mutually beneficial relationships between the cooperative, its members and the cleantech businesses, they feel unsupported by the government.

Agency to engage: Citing lack of institutional support, the majority of actors acknowledge a need for expertise in technical, financial, legal, and market operations, and they frequently turn to outside sources for help.

Darmstadt, Germany - The Earnest App

The Earnest App case study explored how the use of a sustainability app within a virtual community could foster energy citizenship in Darmstadt, a city in Germany with 160,000 residents. The objective of the case study was to understand what impacted people's energy consumption and mobility behavior in everyday life. The case study's findings offer valuable insights for researchers investigating just energy transition. The use of the app led to an increase in both energy awareness and sustainable mobility of the users. Furthermore, spillover effects were also noticed, as the findings pointed to an increase in sustainable behavior in other areas, such as heating consumption. Finally, the case study makes a highly valuable contribution in highlighting the important role virtual communities can play in facilitating a successful just energy transition, helmed by young citizens.

San Sebastian, Spain - UR BEROA – Energy efficiency-driven cooperative

This case study investigates the workings of a cooperative in Spain, UR BEROA, that provides energy to the Bera Bera neighborhood in San Sebastian, Spain. Apart from introducing cleaner energy sources, the cooperative is also gradually encouraging citizens to embrace decarbonization. The case study aimed to analyze different factors affecting energy citizenship emergence, such as the prevalent social norm to engage, the results arising from engagement, and the measure of agency employed. It also analyzed the interactions between actors through the relational model, the variations in behaviors across actors, and how this affected energy citizenship.

The case study analysis reveals:

- If certain conditions are met, citizens may be motivated to take active participation in energy issues and decision-making processes. This includes a certain level of education and information about the energy system and how citizens can be an active part of it, and financial and other resources that enable citizens to invest their time and energy into setting up energy collectives.
- Further, a collaborative effort, with functional relationships between the different actors are important motivating factors.
- Finally, supportive policy frameworks are essential in paving a path towards active energy citizenship.

Natural gas-free neighborhoods, The Netherlands

This case study investigated the transition towards natural gas-free homes in the Netherlands, studying Dutch neighborhoods to see what factors encourage citizens to replace natural gas with green solutions, such as collective heat networks, or individual heating pumps. The research methods for this case study included semi-structured interviews.

The case study found:

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- Each of the actors plays an important role in facilitating the transition to natural gas-free homes. The Dutch government has the role of central coordinator while municipalities are primarily responsible for guiding homeowners in the transition. Local energy initiatives are there to bridge the gap between homeowners and municipalities, and equipment and installation services are provided by suppliers.
- The principal agents in all this are the homeowners who have the task of replacing natural gas in their homes with sustainable solutions.
- The case study investigates the relationship between these actors and what affects the transition to clean energy. Homeowners are often distrustful of the Dutch government and believe the funding should come from the government. The government, on the other hand, encourages homeowners to invest in alternative solutions independently, which can cause friction between the two actors.

Analysis

The case studies show the challenges and enablers of energy citizenship in different geographic and socio-cultural contexts. Across the 6 case studies, some common points of analysis emerge on energy citizenship:

- The motivation to engage in energy citizenship is dependent on several factors such as education, age, income level, and technical knowledge. Two important factors that come across are knowledge and financial resources. If citizens were made aware of the energy transition and the technical aspects of an energy system, they would be more likely to engage in energy citizenship. Secondly, it is difficult to involve citizens who are in economically or socially fragile positions. These citizens often do not have the time, energy, or resources to engage in participatory processes and some financial support from the government could motivate them to get involved in energy citizenship.
- The government has a crucial role to play in engaging the citizens in the energy transition. It can provide a certain level of knowledge, information and awareness about the energy transition and provide a framework for engaging in energy citizenship. The second most important thing the government can do is provide economic incentives for the citizens to get involved. Offering monetary compensation with economic support for citizens to invest in green technologies or processes, combined with awareness, are important motivating factors for energy citizenship.
- A just transition, based on energy citizenship depends on the active involvement of all key stakeholders. It is not just their individual involvement that matters, but the relationship between actors also plays a crucial role in meaningful energy citizenship. In some instances, in the case studies, citizens were shown to be distrustful of the government, for example in the Netherlands. It is important therefore to foster a trusting relationship between actors as they work collaboratively for a just energy transition.

Methodology

Multinational citizen consultation results database

In support of the case studies and to understand better the rationales behind energy citizenship behaviors and its emergence, the GRETA consortium designed and launched a multinational survey between September and October 2022 that targeted 16 EU Member States including the 10 largest EU countries

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by population. With 10, 000 individual responses the survey had three target audiences, 90% citizens/households, 5% business, and the rest individuals in policymaking (5%).

In addition to the regular questions, the survey also included a vignette framing experiment (all respondent groups) and a choice experiment (only citizen respondents). The former addressed citizen assemblies, their influence on energy and climate policy decisions, and how fair people think their decisions are, as well as how eager they are to accept them. The choice experiment referred to a community energy project planned in the respondents' local community. The varied characteristics included technology (wind or solar), annual dividend, and distance between the project and own home.

Case studies methodology

The case studies employed qualitative methodologies such as:

- Qualitative Interviews
- Stakeholder Workshops and Meetings
- Policy Analysis and Document Review through desk research
- Surveys
- Mixed-method approach combining quantitative pre-and post-surveys with qualitative data from forums, focus groups, and interviews.

These methodologies collectively ensure a comprehensive understanding of the case studies' objectives by integrating qualitative insights with participatory engagement and policy analysis. This combination helps to capture the complex dynamics of energy citizenship, policy impact, and behavioral change.

2. SENTINEL Sustainable Energy Transitions Laboratory

Grant agreement: No 837089
Website: https://sentinel.energy/

SENTINEL aimed to develop an energy system modelling framework that would support Europe's transition to a low-carbon energy system. This transition has many critical technological, societal and geographic aspects that need to be addressed by policymakers. Thus, the SENTINEL framework, designed to support a renewable energy system, would enable decision-makers to address these critical challenges as the EU transitions to decarbonization. This research project is modular in nature, incorporating the different aspects with separate models.

Work Packages

Each work package within this project identifies approaches and models for different dimensions of modelling energy transitions. The first work package analyses the relation between energy modelling and policymaking:

Work Package 1: relation between policy work and energy modelling.

Work Package 2: identifies approaches to social and environmental transition constraints and the development of tools relevant to it.

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Work Package 3: approach to energy demand models and the development of certain models within SENTINEL.

Work Package 4: system design

Work Package 5: identifies economic impact models

Work Package 6: not present on the website

Work Package 7**:** case studies.

Case studies

"Energy transition in Greece towards 2030 & 2050: Critical issues, challenges & research priorities

Greece has been transitioning to a low-carbon economy, with a significant shift planned for phasing out lignite by 2028. This decision has led to extensive modeling, but further work is needed to ensure a just transition that protects vulnerable groups. The SENTINEL project engaged with policymakers and stakeholders through literature reviews, meetings, and a national workshop to gather insights.

Key findings highlight the need for system storage, flexibility, and secure supply in the power sector, alongside necessary infrastructure for demand electrification. The social impact on coal regions requires a new regulatory framework promoting energy citizenship and prosumers' self-consumption models for small-scale renewables. High initial costs of renewable technologies and installation challenges in the heating sector are noted obstacles. Additionally, there is a lack of incentives for energy efficiency and innovative financing schemes.

Hydrogen is identified as a potential alternative to natural gas in industry, while digitalization measures like smart meters can enhance system management and consumer engagement. The environmental impact of battery disposal is a concern from a circular economy perspective. The lignite phase-out could lead to significant job losses, which Just Transition Funds could mitigate by supporting clean energy start-ups. Existing energy models do not fully address all stakeholder concerns, prompting the development of the SENTINEL model to fill these gaps.

"The Nordic Region – a frontrunner of the decarbonised energy system"

The Nordic region is leading the way in carbon neutrality, emphasizing regional cooperation in energy transition. The SENTINEL project explored how its modeling framework can enhance this cooperation through an online workshop with nearly 30 energy experts, divided into six thematic sessions:

1. **Power Sector Transformation:** Challenges include integrating more wind power and utilizing Nordic hydro reservoirs despite their limited capacity. Reinforcement of transmission lines and improved governance are necessary.
2. **Sector Coupling:** Electrification of transport and heat supply requires renewable energy, smart energy systems, and P2X infrastructure. Heavy-duty vehicles' electrification and the socio-economic impact of these technologies need careful consideration.
3. **Industrial Decarbonization and Carbon Capture:** Essential for chemical, steel, and cement industries, with hydrogen playing a varying role across Nordic countries.

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4. **Energy Efficiency and Smart Buildings:** Despite strong building regulations, existing buildings remain energy inefficient. Demand response for EVs and better incentives for energy efficiency are needed.
5. **Environmental Aspects:** Renewable energy can meet total energy needs, but raw material supply for technologies like batteries and fuel cells is a concern. Biomass is favored for heating, but land use and environmental impacts need addressing.
6. **Socio-Economic Aspects:** There is political support for decarbonization, but social aspects require more focus. Policies should ensure a just transition and consider distributional impacts, with increased awareness and education on climate policies.

"The future of the European energy system: Unveiling the blueprint towards a climate-neutral economy"

The European Union has been a leader in the energy transition with ambitious policies to achieve carbon neutrality by 2050. Key initiatives include the Strategy for Energy System Integration and the Circular Economy Action Plan. The SENTINEL project's online workshop, "The Future of the European Energy System," engaged 40 energy experts and included six thematic sessions, yielding several insights:

Transforming the Power Sector: Achieving over 70% renewable energy by 2040 requires decarbonizing fossil fuel-dependent sectors, enhancing flexibility mechanisms, and addressing regional disparities. Social and environmental constraints must be integrated into models.

Sector Coupling: Successful sector coupling for transport and heating necessitates digitization, electric vehicles (EVs), and P2X infrastructure. Upgrading heating systems to smart energy systems is essential.

Decarbonizing Industry: Hydrogen and electrification are crucial for industrial decarbonization. CCS projects in the North Sea and the combination of hydrogen and CCS in heavy industries like cement are vital.

Building Sector: Reducing CO2 emissions by 60% by 2030 in heating and cooling is crucial. Models should include behavioral impacts on energy consumption and multiple scenario analyses.

Environmental Aspects: CCU technology can help meet GHG reduction targets. Extending the lifespan of appliances and machinery supports circular economy goals. Models should link energy systems to Sustainable Development Goals (SDGs).

Socio-Economic Aspects: The transition can create jobs in hydrogen technologies and renewables but may increase unemployment in coal and lignite sectors. Models should consider regional unemployment impacts and the need for substantial funding for a just transition.

The workshop highlighted that energy systems must be analyzed with social, technological, environmental, and economic dimensions in mind. While a regional approach is essential, national contexts with unique challenges and potential are crucial for comprehensive analysis.

Analysis

The case studies, conducted on three levels, national, regional, and continental addressed key issues related to the energy transition to deliver appropriate and effective modelling solutions. Across all three case studies, there emerge some common points of analysis:

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- The researchers found that the existing energy system models could not address all issues raised by the stakeholders, which further encouraged the development of the SENTINEL model. The inclusion of social and environmental constraints should be clearly communicated in models because the energy system cannot be analyzed in a vacuum: it is impacted by social, technological, environmental, and economic changes and all these dimensions must be considered for the analysis of the energy transition.
- Electrification comes across as a key enabler of decarbonization. By electrifying various sectors such as transportation, heating, and industry, it facilitates the reduction of greenhouse gas emissions and contributes to mitigating climate change. However, there are some challenges to it. In order to decommission traditional power plants, electricity transmission lines need to be reinforced. Electrification of the heating sector faces some obstacles such as installation costs, or lack of expertise in designing and installing them.
- Hydrogen is a popular alternative to fossil fuels, especially natural gas. Hydrogen offers a clean energy carrier solution that can help decarbonize sectors of the economy that are difficult to electrify directly, such as heavy industry, long-haul transportation, and heating.
- Decarbonization so far has remained a political issue and its social, distributional impacts have not been fully measured or mitigated. For example, the phase-out of the lignite industry in Greece or the shutting down of coal mines in Europe would mean the loss of thousands of jobs. To counter these impacts, a novel regulatory framework with social innovations on the theme of energy citizenship needs to be developed. Policy interventions are required at various governance levels that directly account for distributional impacts. This can be done by the creation of new jobs in the green or renewables sector, and through the utilization of funds to mitigate the distributional impacts.

Methodology

Energy demand models in SENTINEL

These are the four different sector-specific energy demand models incorporated into SENTINEL:

1. DESSTINEE (Demand for Energy Services, Supply and Transmission in EuropE) is a model of the European energy system in 2050. It was tailored to test the technical requirements for energy generation and transport, and it evaluates the magnitude of the economic challenge in developing the required infrastructure. DESTINEE works with three modules: a scenario generator, a demand profile builder, and an electricity market simulator. It models fuel consumption, energy demand, and related fossil CO2 emissions for several sectors and final uses.
2. DREEM is the Dynamic high-Resolution dEmand-sidE Management (DREEM) model. It is a hybrid bottom-up model that incorporates characteristics of both engineering and statistical models. The model advances the computational capacities of current Building Energy System (BES) models and serves as an entry point in Demand-Side Management (DSM) modelling in the building sector (Stavrakas, and Flamos, 2020).
3. The Battery Electric Vehicle Policy (BEVPO) model designs car traffic and parking density maps based on the time vehicles require to travel between different city zones in a given day. At the heart of the model lies the Markov model that, on a city-wide scale, converts travel time

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measurements into trip activities and destination selections based on the OD travel time matrices.

4. The HEB (High Efficiency Buildings) model investigates the potential of the building sector to reduce emissions by calculating energy demand and CO2 emissions of the residential and tertiary building sector until 2050 under three separate scenarios. The model is unique in its methodology as it takes the performance-oriented approach to buildings energy analysis. While the model has a bottom-up framework, it also incorporates some macroeconomic and socio-demographic data such as population, and floor area per capita.

Economic impact models in SENTINEL

Through the insights gained from literature reviews and the case studies, improvements were made to the economic impact models within SENTINEL, namely, European Electricity Market Model (EMMA), the WEGDYN computable general equilibrium (CGE) model and the Business Strategy Assessment Model (BSAM).

The first model, EMMA, is a techno-economic model that was developed to simulate the power system of north-Western Europe. Under a long list of technical constraints, this model simulates investment in power plants, minimizing total costs. In economic terms, it is a partial equilibrium model that focuses on a specific sector, the wholesale electricity market, emphasizing the supply side dynamics.

WEGDYN is a macroeconomic model which shows the entire economy, categorized into different production sectors and agents and able to configure at the global, regional, and country levels. Specifically, WEGDYN is a computable general equilibrium (CGE) model. WEGDYN takes a top-down approach as it analyzes relative price and quantity effects based on empirical estimations of behavioral responses. WEGDYN is available in versions for Austria (WEGDYN_AT) and a global multi-regional version calibrated to the GTAP Database. It can be used in both static-comparative and recursive-dynamic modes. The energy system representation in WEGDYN is based on the GTAP Power Database, covering various electricity generation technologies. The model's yearly temporal resolution may miss intra-annual specifics, a limitation that can be addressed by linking it to more detailed energy models.

BSAM is a simulation model that shows the Day-Ahead Scheduling (DAS) of wholesale electricity markets in Greece. Among other features, it can generate the electricity mix, the schedule of all resources used, and the profit/loss of each generator.

Other models developed within SENTINEL include:

ATOM: The Agent-based Technology Adoption Model (ATOM) is an agent-based model that uses historical data to simulate the anticipated impact of various policy initiatives on the uptake of technologies designed to enhance demand flexibility. This includes technologies such as small-scale solar PV, smart devices, and electric vehicles. ATOM considers the specific geographical and socioeconomic context and accounts for the uncertainty in consumer behavior and decision-making processes.

ENBIOS: For prospective energy scenario design Administrations use energy system optimization models (ESOMs). While Energy System Optimization Models (ESOMs) play a critical role in steering the energy transition, they generally neglect to consider a pathway's sustainability in terms of resource consumption and environmental impact. It was discovered during the SENTINEL project that decision-

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makers in the energy sector frequently lack knowledge on cumulative environmental impacts such as biodiversity loss, changes in land use, and the depletion of water and minerals. To overcome this gap, the ENBIOS tool examines the configuration and activity data from ESOMs and provides a comprehensive set of indicators for environmental and bioeconomic feasibility.

ENERGYPLAN: EnergyPLAN is a simulation program that runs hourly operations of the country's energy systems, which include transportation, industry, heating, cooling, and power. Analyzing the energy, environmental, and financial effects of different energy solutions is the primary goal of the EnergyPLAN model. Rather than modeling a single "optimal" answer based on predetermined criteria, the main goal is to model a range of choices so that they can be compared with one another. Instead of focusing on a single primary solution, this style allows for the illustration of a palette of choices for the energy system. The model features an easy-to-use interface, is freely distributed, offers a range of training options, and is already available in numerous countries.

EURO-CALLIOPE: It can be used to evaluate issues like how the design of power systems is affected by the growing electrification of transportation and heating, or it can be used to compare various options for distributing infrastructure around the continent in support of an increasingly renewable energy supply. It models the European energy system at high temporal resolution (1-hourly data covering numerous meteorological years) and variable spatial resolution (countries only, sub country regions, or a combination of both).

IMAGE: Subject to resource availability and quality, the model estimates the implications for energy, land, water, and other natural resources. It also identifies socio-economic routes. Future projections account for unintended side effects, including emissions to the air, water, and land; depletion of remaining natural stocks (forests, fossil fuels); and climate change.

QTDIAN – Quantification of Technological DIffusion and sociAl constraiNts. This is a set of tools comprised of both qualitative and quantitative assessments of the socio-technical and political elements of the energy transition that impact the system's general potential, the pace at which energy-related services and technologies spread, and the structure of the energy system of the future.

Case studies methodology

The three case studies used three-tier participatory multi-methods approach.

Literature Review 1. Most recent versions of policy documents 2. Scientific peer-reviewed articles 3. Deliverables from previous EC-funded projects on similar topic 4. Technical reports and position papers
Group sessions 1. 6 physical meetings with 16 key stakeholders (National case study) 2. Online meeting with Nordic Energy Research Council (NERC) representatives (Regional case study) 3. 8 online interviews with key European stakeholders, and an EU-wide online workshop on users' needs (Continental case study)
Interview and workshops 1. 13 online interviews with 20 main stakeholders (National case study) 2. Online workshop with a total of 29 participants (Regional case study) 3. Online workshop with a total of 44 participants (Continental case study)

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3. TIPPING+ - Enabling Positive Tipping Points towards clean-energy transitions in Coal and Carbon Intensive Regions

Grant agreement: No 884565	
Website: https://www.tipping-plus.eu/	

The project focuses on the concept of social-ecological tipping points (SETPs) to examine how social, economic, political, cultural, psychological dimensions and gender affect the clean energy transitions in coal and carbon-intensive regions (CCIRs). The project also identifies tipping interventions designed to prevent disastrous results triggered by crossing irreversible negative thresholds. It also includes a comprehensive analysis of both negative and positive tipping points. Focusing on transition theory, the project evaluates collective narratives and the necessary transformative capacities that create crucial techniques and socio-technical solutions that lead to systemic changes in CCIRS leading to carbon-neutral green energy futures.

Work Packages

Through multiple work packages, the TIPPING+ reviews the latest and most relevant research analyzing the impact of:

Work Package 1: Changes in regional population distribution patterns, the role of migration flows, gender, and age.

Work Package 2: Changes in psychosocial processes and cultural factors

Work Package 3: Policy interventions in transitions and (regional) crises

Work Package 4: Systemic changes in economic and resource systems

Work package 5: gives guidelines on the creation of the case studies based on factors and indicators from WPs 1-4.

Work package 6: about engagement, learning, dissemination, and outreach aimed to coordinate stakeholder consultation, and guarantee that the knowledge generated in the project is policy robust and policy relevant.

Work package 7: on integration, synthesis, and policy vision, carried out knowledge integration to synthesize the findings of WPs 1-6

Case studies

Case study 1: Austria

The Austrian case study explored the possible economic, political and technological tipping interventions that would lead to socio-economic transformation in the basic material industry.

Methodology: To investigate the tipping points in the industry sector in Upper and Lower Austria researchers employed qualitative methods, including interviews, focus groups, and workshops. Additionally, a literature review gave insight into the socio-economic impacts of changes within the industry. The first step was an online stakeholder workshop with representatives from different basic material companies, such as chemical, iron, steel and electricity. The workshop discussion led to the development of alternative transition pathways. Focus group discussions were then held with the

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workshop participants, leading to insight into the impacts, challenges, and opportunities of alternative pathways. Finally, there were seven expert interviews on industrial clusters and political framework conditions.

Results: Based on these qualitative measures, the narratives in this case study are technological. Two narratives have come to the surface which offer the best pathway to reduce GHG emissions in the basic material sector. The first narrative suggests a technology change that allows the use of green hydrogen. Second, the implementation of industrial circularity concepts, enabling a sustainable use of resources. However, to enable the implementation of these technological and conceptual changes, political interventions are needed, especially in the form of financial support. So, overall, a policy mix is required to incentivize industry leaders and reach the tipping point in the basic material industry transformation.

Case study 2: Bosnia and Herzegovina

Bosnia and Herzegovina is a traditionally a coal-intensive country but has decided to completely halt the use of coal by 2030. This important decision highlights the tipping point in moving away from coal use. Bi-H's National Energy Climate Plan (NECP), developed in compliance with EU guidelines, is addressing all important areas to shift away from coal use, including the use of renewables, reduction of GHG emissions, energy efficiency, and innovation. This case study examines the decarbonization efforts of coal region in Tuzla, Bosnia and Herzegovina and a best practice example of Banja Luka, a city that successfully switched to woody biomass for its heating system.

Methodology: To analyze the decarbonization path in Bosnia and Herzegovina, the researchers did a quantitative analysis of public data on economic, political, and cultural trends, finding that fossil fuels, and especially coal, are still crucial to the economy. There was also a review of decarbonization plans and policies in the country. Stakeholder interviews with key actors, such as government officials, and non-governmental representatives, revealed unanimous support for a shift away from coal dependence and efforts to cut down on greenhouse emissions.

Results: The case study results show that it is time for Bosnia and Herzegovina to embrace renewables such as wind and solar. To do that, the transmission and distribution networks should be updated. Finally, a comprehensive regulatory framework is needed to enable a transformation.

Case study 3: Alberta, Canada

The province of Alberta, Canada, has great oil, gas and coal deposit and its productive sectors are heavily dependent on these extractive industries, especially for the export of energy products. This increasing dependency on fossil fuels has destabilized the social, economic and environmental systems of Alberta, with the province reaching a 'tipping point'. This case study investigates existing conditions that keep Alberta dependent on fossil fuels and identifies emerging trends that will either maintain the status quo or push towards clean energy pathways. The study also identifies the four current and emerging actors within Alberta's energy system: the government of Alberta, oil and gas companies, workers of the oil and gas industries, and native people.

Methodology: Using the narrative inquiry methodology, the study takes the idea of human experiences as the point of focus and places them within broader social contexts. The methodology has seven steps, identified by the case study:

Step 1: Identify the phenomenon to be explored.

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Step 2: Select relevant individuals.

Step 3: Collect stories from the individuals: personal and social experiences.

Step 4: retell the story within the broader social, economic, political, and cultural context and identify a theme within the narrative.

Step 5: Collaborate with the participant storytellers in all phases of research.

Step 6: Write a story about the participants' personal and social experiences.

Step 7: Validate the accuracy of the report.

Based on these 7 steps the researchers collected data using official government reports for facts and newspaper articles and social articles and social media to understand the general feelings toward fossil fuels and alternative energy options.

Results: The case study research finds that the mainstream narrative of fossil fuel dependency remains dominant and while energy transition as a concept is becoming more common in Alberta, practically, the strategies used are simply maintaining the status quo. Hydrogen is seen as a possibility for Alberta to transition to a low-carbon economy, but oil and gas remain dominant. The narrative on the economic growth and potential offered by renewables is not yet mainstream and is still seen as high risk with low returns. The key enabler of the tipping point to an energy transition seems to be the government. Offering incentives, grants and investments for alternative energy pathways can help tip Alberta to an energy transition.

Case study 4: Moravian-Silesian Region, Czech Republic

This case study investigates two regions of the Czech Republic: the Moravian-Silesian region as an example of a coal-intensive region currently undergoing transition, and the South-Moravian region as an example of a former coal-intensive region that has managed to successfully transition economically and structurally. Using a multilevel explorative geographical analysis, the study focuses on successful economic transformations and post-mining landscape reviving within these two regions. In doing so, the study evaluates the development of sociostructural forces and processes to identify specific factors that trigger positive tipping points in alternative energy pathways, conspiring different regional and local characteristics.

Methodology: The study uses a mixed-methods approach. At the national/regional level, the researchers used longitudinal statistical data for all Czech districts (NUTS4/LAU1) to collect socio-economic, demographic, environmental and geographical indicators for the period 1990-2021. Using Analysis of Variance (ANOVA), regression modelling and hierarchical cluster analysis, significant relationships between specific indicators, and development trajectories were identified and comparisons between districts were analyzed. At the local level, a multiple-case comparative analysis was conducted of selected ‘good practice’ regeneration projects. For this, project documents and any available literature and media were reviewed, along with expert interviews where possible.

Results: The study finds significant differences between mining, non-mining and post-mining regions. The post-mining regions with declining mining practices experience positive environmental benefits in the form of reduced air pollutants (SO2, CO, and NOx) and an overall improved environment. The coal mining region, on the other hand, still struggled with negative impacts such declining population due

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to out-migration and high unemployment rates. The transformation of coal regions is slowed down by factors such as a high rate of urbanization and population density, a large share of people employed by the industrial sector and low basic or formal education. On the other hand, successful revitalization of post-mining regions depends on the overall costs. Availability of land for sale and development for transformation projects, proximity of such projects to transport means, and availability of financial incentives (from the EU, national or regional funds) are all factors that contribute to successful regeneration projects in post-mining regions. Another key success factor is the involvement of local communities and key stakeholders.

Case study 5: Balearic Islands, Spain

The Balearic region of Spain is made up of four Islands: Mallorca, Menorca, Ibiza, and Formentera. While each island has its local administration, they are governed regionally by the government in Mallorca. The islands are sustained economically primarily by tourism and electricity generation is highly dependent on fossil fuels, with renewable energy sources only accounting for 3% of total electricity generation.

The successful transition of these islands depends on the regional administration's capability to involve citizens in decision-making and considering the distinct geographic, economic, and social characteristics of each island. The Climate Change and Energy Transition Act 2019 aims to do just that. By coordinating collaboration between government levels, energy communities, companies and local associations, the Act aims to decentralize energy production in order to achieve a successful energy transition. The case study will examine this Act as a tipping intervention, analyzing it from a political perspective and identifying the identity-related barriers to the adoption of this new law.

Methodology: A qualitative approach was used in the study. Data was collected from policy documents, statistical sources and approved laws which helped contextualize the study in terms of local, regional, and national energy regulations. Analysis of local newspapers gave the researchers a better idea of the narrative surrounding the Climate Change and Energy Transition Act, in particular, the actors against it and those supporting it and the obstacles in its implementation. Additionally, 9 semi-structured interviews were carried out with key stakeholders of the energy transition to identify the main issues with the implementation of the Act. Finally, two workshops were held with different representatives and stakeholders. The first workshop identified the main problems with implementation and the actors. The second workshop had more detailed discourses on governance and identity issues, the impacts of tourism, alternative energy and economic pathways and the resistance to the implementation of the Climate Change and Energy Transition Act.

Results: The results of the study found that several factors make the Act a positive tipping point. Almost all stakeholders view the transition as extremely beneficial. The local generation of energy means reducing energy imports and creating jobs for locals. Renewables are also economically feasible, compared to the high costs associated with fossil fuel energy generation. Environmentally, the transition offers the chance to greatly reduce GHG emissions. However, there are also some strong obstacles to the implementation of the Act. From a technological perspective, the traditional energy infrastructure is not equipped to generate electricity from renewables. This requires new technological systems. Apart from a technological shift, a systemic social shift is also required, with improved communication between the different stakeholders. Finally, tourism is part of the identity of the Balearic Islands so

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when decarbonization paradigms designed to reduce dependence on tourism are introduced, there is resistance to it from many.

Case study 6: Aragon-Teruel, Spain

Teruel, a province of Spain within the Autonomous Community of Aragón, is a traditional coal and carbon-intensive region. The region is under the Just Transition Agreement for Andorra-Mining Regions which aims to ensure that the closure of the coal mines and the decommissioning of the Andorra thermal power station will create new opportunities for economic, social, and environmental revitalization in the area. This is a pioneer project in Spain, however, the implementation of it has been slow due to bureaucratic issues. Additionally, the region lacks several infrastructures crucial to development and the federal government is slow to follow through on its promise to aid the systemic transition of the region. For the inhabitants as well, the transition has not been easy, as the coal mines and thermal power stations have provided employment and a sense of identity to them. Thus, the case study examines how the people of Andorra-Teruel are adjusting to this transition, and whether they are ready to leave their old identities for new ones associated with decarbonization and the transition.

Results: With the use of interviews and workshops, the case study finds that the people have a sense of nostalgia and frustration with the fact that no concrete projects have been set up to replace the shutting down of the mines and thermal power station. Additionally, some local NGOs and organizations claim that the voices of the local population have not been taken into account, with decisions being made only at the top. There are projects in the pipeline that are expected to boost employment and economic development so if they are executed soon, they could transform the region.

Case study 7: Megalopolis, Greece

Greece's National Energy and Climate Plan (NECP) has a key component: gradually phase out all use of lignite in power generation by 2030. It was a decision that directly affected Megalopolis as it had the only remaining lignite-fueled power plant still in operation, to be discontinued by 2023. To aid the phase-out of lignite, the existing Just Transition Development Plan of lignite areas aimed to construct a gas distribution network in Megalopolis. However, due to the 2022 energy crisis, this plan for Megalopolis's energy transition could cause a negative tipping point, resulting in high energy costs and potential gas shortages for decades to come.

Methodology: The case study investigates how the 2022 energy crisis could change the post-lignite pathway for Megalopolis, suggesting an alternative that does not rely on the use of fossil fuels. The study uses energy modelling tools to analyze different heating investment scenarios. The Dynamic high-Resolution dEmand-sidE Management (DREEM) model is employed to model the residential heating sector of Megalopolis. Additionally, a workshop was conducted with stakeholders in Megalopolis's energy transition, including policymakers, NGOs, energy industry representation, academia, and local authorities.

Results: Based on the case study findings, the following table shows the main enablers and barriers to Megalopolis's transition from natural gas to electrification.

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Table 1. Main enablers and barriers to Megalopolis's transition

Determining factor	Enabler/Barrier	Trend
Natural gas price	Enabler	Upwards and unstable
Gas supply reserves	Enabler	Uncertain with potential downward trend
REPowerEU Plan for reduction of dependency on imported natural gas	Enabler	Upward
Renovation costs	Barrier	Downwards but still expensive
Political commitment for electrification	Enabler/Barrier	-
Funding Mechanisms	Enabler	Upward

Case study 8: Indonesia

Indonesia is one of the largest emitters of greenhouse gases, in part due to its extensive use of coal. And even though the country suffers from climate change impacts, it continues to rely heavily on fossil fuels for its economic growth. Bali province and Banten are two provinces of Indonesia with the several big coal power plants and with the country's increasing reliance on fossil fuels for electricity generation, more are expected to be built in the coming decades.

Methodology: The study identifies the importance of transformative agents' networks as indicators of socio-ecological tipping points in coal-intensive regions. Therefore, the study assesses transformative narratives and potential key stakeholders who could trigger positive tipping points based on their network system. The study uses Q-methodology and social network analysis (SNA) to get empirical evidence for identifying transformative agents, their visions and networks as signs of socio-ecological tipping points towards clean energy systems in Banten and Bali provinces.

Results: The key agents identified by the study are:

- National level: Ministry of Energy and Mineral Resources (MEMR) and the Ministry of National Development Planning (BAPPENAS)
- Local level: BAPPEDA (BAPPENAS' representative at the provincial level), ESDM Banten
- (Banten's Energy Agency), and ESDM Bali (Bali's Energy Agency).
- NGOs as the 'bridge agents' between the government and communities

The study also finds two perspectives on how SETP will be triggered in Banten and Bali province. The first perspective suggests that tipping points and a systemic change towards clean energy can depend highly on efforts of the government and policymakers because they have the financial and natural resources and the influence through policy interventions. The second perspective suggests a more bottom-up approach with coordination between NGOs, local communities, and private companies as crucial to the transition. This view also promotes the diversification of renewable energy in decentralized and remote areas. The study also identifies the barriers to potential positive tipping points:

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- Technological barriers: immature development of batteries
- Social resistance to geothermal and hydropower plants
- Absence of a network that can channel sustainable futures
- Low price of fossil fuel-generated electricity

Case study 9: Sulcis, Italy

Tipping dynamics, psychosocial patterns, and lock-in mechanisms in Sulcis coal and carbon-intensive region, Italy. The Sulcis region of Sardinia is characterized by coal mining. In recent decades, due to energy prices and the global crisis of 2008, the region has experienced a severe industrial decline with corresponding job losses. Environmental assessment reports show that large areas are heavily polluted by industrial activities. The current challenges include the decommissioning of the coal-fired power plant, the switch to renewable energies and the energy supply for industries.

Methodology: Qualitative and quantitative research approaches were combined to identify tipping points in structural change. A longitudinal analysis of newspaper articles published in national, regional and local newspapers between January 2011 and February 2021 was conducted. Interviews were conducted with key informants who were selected because they had an overview of the field from different positions. Furthermore, 26 narrative interviews were conducted with key regional actors and informants representing different perspectives and stakeholders.

Results: Almost half of the newspaper discourse deals with stable and secure energy supply at affordable prices as a decisive factor for the survival or decline of the industry. Coal and coal-fired power generation is legitimized through discourse over time. The energy transition is often seen as instrumental to external interests rather than benefiting locals.
The Sulcis region is perceived by the interviewees as disrespected, economically degraded and dominated.

After a tipping dynamic of destabilization triggered by the decline of coal and carbon-intensive industries, the reconfiguration of positive narratives has been constrained by corridors of possibility (path dependency) and multiple lock-in mechanisms.

Case study 10: Small islands, Carloforte (San Pietro island), South Sardinia

This case study is about the municipality of Carloforte on the island of San Pietro. This island has mainly a maritime economy. The town of Carloforte was the second most important port in Sardinia after Cagliari, from which minerals were shipped from Sulcis. In contrast to Sulcis, there are no alarming unemployment rates on the island. In Carloforte, the same mechanism of community fragmentation occurs by limiting the focus of the energy transition to the household sector. Community resources include a strongly emphasized community identity, a high level of technical education, historical wealth, and a cosmopolitan orientation.

Methodology: The socio-ecological tipping points in relation to common goods are analyzed and tourism is considered as a potential tipping point. Different methods are applied: Press analysis (Sardegna); ethnographic research, participant observation, structured interviews on site and remotely; analysis of secondary sources (local publications and magazines, websites, policy plans).

Results: The interviewees describe an individual involvement in the REACT project, which is led by the municipality and funded by the European Commission. They justify their commitment to switching

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to renewable energy sources as a means of reducing energy consumption and thereby achieving economic savings. In addition, tourism is seen as the only way to bring prosperity to the region from outside. Sustainable practices are within the tourism industry described as a magnet that boosts the economy. This shows an instrumental relationship to sustainable energies and that no comprehensive transformation of the value sphere is taking place.

Case study 11: Upper Silesia Region, Poland

Seeking opportunities to enable positive tipping points in the coal mining region: case of Upper Silesia, Poland. The research focuses on the process of decarbonization in Upper Silesia, with the aim of capturing attitudes towards regional structural change and identifying potential converging interests in the transition. Potential changes in narratives and interventions that could lead to systemic change are also identified. Particular attention was paid to investigating potential tipping points in regional development.

Methodology: The study analyses quantitative data to assess economic, political, and cultural trends. In addition, 54 local development strategies from mining communities in Upper Silesia were systematically analyzed and a dozen in-depth interviews with stakeholders from different interest groups were conducted. The interviews focus on the short- and long-term effects of structural change on the regional and local economy.

Results: Since 2019, the prevailing opinion on decarbonization has changed significantly. Previous negative arguments warning of industry collapse and threats to energy security and regional development are now balanced by arguments in favor of change. Mainstream and alternative narratives are finding consensus on further development paths based on the region's existing competitive advantages. The agreement of the trade unions to a concrete program or the closure of mines was an important intervention. However, a socio-ecological tipping point could not be clearly identified, as the changes observed do not meet all the criteria of such a tipping point. The geopolitical shift triggered by Russia's invasion of Ukraine has strengthened the case for energy security. Most stakeholders therefore see increasing the share of renewables and the use of nuclear energy as the right way to maintain energy security.

Case study 12: Jiu Valley Regions, Romania

Jiu Valley is a mining region in Romania that has been suffering from unemployment, economic downturn and social unrest since the mid-1990s. The mines in Jiu Valley have been closed one by one, without any concrete and long-term plans by the government, and now only two mines remain. This has led to record-high unemployment in the region and is still a serious problem. The World Bank has played an important role in the mining restructuring of Jiu Valley and the Romanian government has aided this restructuring through the “Strategy for the socio-economic Development of the Jiu Valley" which aimed to reduce Jiu Valley’s dependence on mining by creating other sectors and businesses, but social unrest plagued the region as late as 2021.

Methodology: The case study explores the endogenous and exogenous factors impacting the evolution of the mining sector in the Jiu Valey. It also investigates the reasons for the success or failure of policies aiming to generate tipping points in the Jiu Valley. To do so the case study adopted a process tracing approach. On trips to Jiu Valley, the researchers engaged in participatory observation and conducted three-step face-to-face interviews with local and national government officials, with people academics

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or ordinary citizens, including retirees. The interviews were based on an interview guide with pre-set, open-ended, and scale questions, aiming to explore the social, economic, and environmental aspects specific to the region.

Results: The study finds that the citizens and municipalities of the Jiu Valley were concerned about the development of renewable industries as an alternative. Currently, efforts are being made to shift the economic focus of the region away from mining to other sectors, especially tourism. A new mountain resort in Petrila to rival the two existing resorts in Straja and the one in Parâng. Another action taken for the transition is the creation of a school in Jiu Valley, Renew Academy, that will train miners into technicians for the renewables industry. The school would be created using various European funds, such as the Fair Transition Fund, for the training of 800 miners per year for ten years.

Case study 13: Essen and Duisburg, Germany

The case study examines the socio-economic transition processes in Essen and Duisburg as part of the broader structural transformation away from coal in the Ruhr region. It investigates the urban development of the past 30 years, with a particular focus on tipping points where the cities' development dynamics could change.

Methodology: The analysis relies on both qualitative and quantitative data. A comprehensive qualitative analysis of documents and literature was conducted to systematically examine the socio-economic measures implemented since the 1960s to counter the effects of industrial decline and industry cessation. Additionally, local narratives and discourse developments were investigated. Semi-structured interviews with state and local actors were also conducted. Furthermore, quantitative data related to various demographic and economic indicators were analyzed over periods ranging from 20 to 50 years. Finally, the relationship between interventions, quantitative socio-economic data, and narrative developments is explored.

Results: Gradual changes in demographic, economic, and political development are observed in both cities. However, neither city has reached a tipping point of transformation. The socio-economic developments in the cities still exhibit similar trends. The narratives and political visions of the cities suggest that their future trajectories will diverge. While Duisburg adheres to traditional narratives and builds new structures around heavy industry, Essen has formulated an alternative vision for the city's green future. Notably, this shift in narrative in Essen has not yet resulted in significant, measurable changes in socio-economic data.

Case Study 14: Greenland

Two case studies were summarized in this research paper. The first study analyses the positive tipping processes that led to a political initiative to develop hydropower plants in Greenland. Functionally, five cities that have hydropower plants exhibit better living conditions than the ones without. The hydropower plants are perceived as a direct extension of the vision of the Minister of Greenland. The second one investigates the transformative capacity of civilians to stop a mining project. Formally the region in this study is characterized by a pit mine that might be developed extract rare earth minerals and uranium. Unemployment is high in that region. Perceptually rare earth materials can be utilized in the green transition. The authors ask how the bureaucratic institutions and actors influence decision-making for advancement, or lack thereof, of sustainable production and consumption.

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Methodology: The first study analyzed public materials gathered from the government and media content. In addition, qualitative interviews with central political actors and former policymakers were conducted. The second case study conducted a quantitative analysis utilizing register data, performed a literature review and qualitative analysis based on archival and historical data and semi-structured interviews.

Results: Mainstream Narratives

- The mainstream narrative about technology states that hydropower plants provide 60-70% of the country's public energy needs. However, 75% of total energy consumption for electricity and heat is still dependent on imported fossil fuels.
- The mainstream narrative of stakeholders and institutions is that plans to build hydropower plants were introduced in the oil crises. Today, the government owns the national energy company. Other stakeholders are municipalities, local politicians and organizations related to the government. Other institutions and private companies have implemented small-scale technology that provides renewable energy.
- The dominant mainstream ideology in Greenland is economic autonomy. However, the younger population is showing interest in environmental sustainability.
- The mainstream policies in the form of the energy plan from 1985 guided the development of the energy structure. In 2017 an energy plan with a vague goal of utilizing renewables as much as possible by 2030 was implemented.

Alternative Narratives

- From 2010 and onward an alternative pathway about technology follows an on-stream narrative, where both the public and private sector seek other technical solutions for renewables such as solar energy and wind power in small-scale.
- The stakeholders for the alternative pathway include politicians interested in implementing cheaper energy solutions for smaller towns and more hydropower plants where it is financially feasible. The state-owned energy company is interested in implementing renewable energy. Other stakeholders include households, municipal institutions, and companies interested in cheaper and greener energy.
- The guiding ideology behind the development of renewable energy systems is economic development. However, the younger population's ideology is guided by environmental and social sustainability.
- Policy instruments for implementing renewable energy-systems have focused on hydropower solutions. The state-owned energy company has a limited budget for research on other small-scale solutions.
- Other factors leading to alternative pathways include the popularization of Sustainable Development Goals (SDG).

Case Study 15: Lofoten, Norway

Despite being a major oil and gas producing economy, Norway also has an international reputation for being a leader in progressive climate policymaking. As a result, Norway finds itself at a potentially tenuous crossroads. Formally the Lofoten archipelago is characterized by rugged coastlines and high mountains and is located just above the Arctic circle. Functionally the region is rich in hydrocarbon deposits but is also a tourist destination and boasts valuable fisheries. Perceptually actors across the

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region self-identify as Lofotinger. The population is declining and ageing. The authors' overarching research question is: how – over the course of a 20-year period – a seemingly locked-in development pathway towards a petroleum future "tipped over" to an alternative, low-carbon development trajectory?

Methodology: The research analysis presented in this article draws on a qualitative framework and is based on semi-structured interviews, ethnographic methods, qualitative process tracing, discourse analysis, and textual and document analysis gathered through ongoing research undertaken from 2008 to 2022, but which extends further back in time through media and document analysis. The authors also employ qualitative media analysis of local, regional, and national media coverage from 2000-2022.

Results: The results showed that the shift occurred in strategic planning and policymaking for the region from a dominant mainstream narrative in the early 2000s which centered on opening the area to offshore drilling, to a new alternative future narrative centered on decarbonization and circularity that emerged in the late 2010s.

The authors' preliminary results indicate that several soft tipping points have occurred, and that these originated at different scales both within and beyond the region itself. This would tentatively include the 2006 Management plan for the Barents and Lofoten seas, the 2010 Norway-Russia Artic border treaty, the 2011 revised Management plan for the Barents and Lofoten Seas, the change of government in 2013, the oil price decline in 2014, the 2015 Paris Agreement, Parliamentary elections in 2017, and the emergence of the Green Isles Initiative in 2019.

Case Study 16: Svalbard, Norway

The Svalbard area exhibits following characteristics:

- Formally many residents do not have voting rights.
- Functionally the region is dominated by tourism and its Arctic location (permafrost) places limits on renewable energies.
- Perceptually the area has been dominated by adventurers and miners, but mining has been predominantly phased out over previous decades.

For this case study, the research questions are as follows. What precipitated the decision to end reliance on coal? How has the decision to end reliance on coal affected the Svalbard society? And what are the likely trajectories of change from the 2018 decision to phase out coal?

Methodology: The authors reviewed different types of literature. Scientific literature, reports and legal documents, conventional media articles, websites, and social media content. For Lofoten, the literature review is ongoing. Additional interviews with key informants from businesses, government, volunteer organizations, and residents were conducted.

Results: The results show that, in terms of human-natural systems, the Svalbard case is illustrative of the need to consider the combined societal and earth system components of energy transitions and transformations toward sustainability. While emissions remain, the coal worker population has been exchanged for a population working in the hospitality-related industry. New and shorter-term residents have replaced the longer-term former residents. This change in demography is recent, and the transformation of the Svalbard community will continue to unfold. Key enablers of transformation are viable economic alternatives, viable alternative forms of energy generation, and a societal composition

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capable of maintaining these alternatives. Potential barriers are the emissions levels of tourists, researchers, students, and fuel transport to and from Svalbard.

Analysis

The case studies give valuable insights into if, why, and how, a specific SETP occurs in a region, and which effects can be identified and analyzed in the context of sustainability of regional economies. While it is not easy to generalize from the 16 heterogeneous case studies that offer varying geographic, social-psychological, political, and economic contexts, the results do offer some key insights into the occurrence, or non-occurrence, of tipping events. Tipping events can be positive or negative. To have positive tipping events that cause systemic change towards climate-neutrality, certain changes or shifts are required to support the transition process. Some of the common shifts highlighted by the case studies are:

Technological shift – reducing dependence on fossil fuels to incorporate renewables requires a technological shift in the economy. This is because the traditional energy infrastructure is not equipped to generate electricity from renewable energy sources. Some of the problems highlighted in the case studies include updates of transmission and distribution networks and immature batteries. A technological shift would speed up the incorporation of renewables such as hydrogen, which was commonly seen as a suitable alternative to fossil fuels, even in the industrial sector.

Social shift – As the theoretical background mentioned, for a social tipping point to be viewed positively, it must support the improvement of social and individual well-being while also bolstering the sustainability and capacities of natural and social systems, including those related to control, interpersonal relationships, group cohesion and continuity, ownership of technology, mastery, understanding of the world, and future vision. The case studies showed that a social shift was necessary to accommodate the green transition processes. There is resistance to change, and people need to be made aware of what the transition is and how it can benefit them, the citizens, and the businesses. From a social perspective, identities can be a barrier to tipping points. In some case studies the identities of the citizens were tied to the coal mines, thermal power stations, or the tourism industry. These were industries that sustained them and gave them a sense of purpose. So, the green transition threatens not just their livelihoods but also their sense of identity, which is why there can be resistance to it. This is where government intervention comes in.

Government intervention – the importance of the government's role in the green transition cannot be overstated, as the case studies mention government actors, legislators and policymakers, the key enablers of the tipping point to an energy transition. The government can challenge or support narratives of fossil fuel dependency, deciding on the course of action that is to be taken. The government can create awareness among people about the benefits of investing in renewable energy; low prices of energy, in particular, seem to be an important convincing point. The government should also create comprehensive regulatory frameworks for the transition. The most important government or policy intervention, however, as supported by both the literature review and the case studies, is the use of financial incentives to push for the transition. In terms of econometric quantifications, the utilization of EU funds can act as an important tipping intervention in triggering a transformation in CCIRs.

The case studies make an important contribution to the study of tipping points, the enablers, and barriers to them and what their impacts are. Any policymaker or future study would benefit from these insights on how positive tipping points can be triggered to achieve a green transition.

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4. REAL DEAL - Reshaping European Advances towards green Leadership Through Deliberative Approaches and Learning

Grant agreement: No 101037071
Website: https://www.realdeal.eu/

REAL DEAL began in February 2022 and is expected to run until January 2025. The project aims to reform the active participation of stakeholders and citizens around the European Green Deal (EGD).

A transdisciplinary project with researchers of deliberative democracy being brought in from a wide range of fields, REAL DEAL is currently developing innovative tools and formats to reshape deliberative democracy around the EGD. These innovations will then be tested in 13 European countries in a deliberative democratic process involving a just and green transition. REAL DEAL will also investigate pan-European formats such as a pan-European Youth Climate Assembly and digital deliberation formats. The partners of the REAL DEAL project will work together to create a comprehensive protocol for citizens to engage with the objectives of EGD in a meaningful and deliberative way. The partners will develop recommendations on how such a deliberative process can be designed and applied in various contexts such as government institutions and civil society.

The project will consider areas of policy and transformation that are crucial to European decision-makers and citizens. Some of these areas include just transitions in Europe, sustainable consumption and production, sustainable food systems and agriculture, and energy transitions and climate action. This project has certain deliverables and reports available on its website which support the creation of the protocol on how citizens can be encouraged to participate. The following summary of the project is based on these documents.

Work Packages

The project is divided into 7 work packages (WP), during the 3 years of the project implementation (from February 2022 to February 2025).

Work Package 1: State-of-the-art assessment of deliberative and participatory approaches relevant to the European Green Deal. Building on a state-of-the-art assessment and overview of current frameworks and formats for meaningful participatory and deliberative processes in connection with areas covered by the European Green Deal, it will suggest formats, procedures, and techniques most suited for stakeholder and citizen deliberation.

Work Package 2: the organization of The Civil Society Forum for Sustainability. Organized by the SOLIDAR and the European Environmental Bureau (EEB) with the support of SDG Watch Europe and the European Alliance for a Just Transition, the forum brought together civil society organizations and key stakeholders to discuss pressing issues related to EGD and participatory democracy. As a result of this forum, a policy tool was created to aid in the social-ecological transition in the context of the EGD.

Work Package 3: Investigating and validating innovative deliberative formats and tools through innovative test cases. With the help of WP 2 stakeholders, it focuses on implementing creative deliberative activities in 13 countries as well as pan-European formats, such as digital, hybrid, and physical events and processes that are assessed and chosen in WP 1.

This project has received funding from the European Union's Horizon Europe research and innovation programme under the grant agreement No 101112305.

Working Package 4: Perspective for the future. It will assess the conceptual and empirical results of WPs 1, 2 and 3 to design a comprehensive protocol for citizens' deliberation that can applied in multiple contexts.

Work Package 5: Dissemination, outreach, communication, awareness-raising, and capacity building.

Work Package 6: Project management, compliance, and sustainability

Work Package 7: Ethic requirements

Case studies

The case studies from this project are not yet available on the website. So, this section will focus on the outcomes of the main deliverables:

Selection of techniques for citizen deliberation on the EGD

The REAL DEAL consortium assembled a selection of tools, techniques and formats for citizen participation and deliberation in the context of the EGD for operationalization in WP 3. To gather this information a survey and a two-day online workshop were conducted with all consortium members. Based on these assessments the following methods were agreed upon for WP 3:

1. Citizens' Assembly or Citizen Forum

2. 21st Century Town Meeting®

3. Public Hearing

4. Public Participation Network

5. Roundtable or Stakeholder Panel

6. Focus Group

7. Analytic-deliberative Discourse

8. Group Delphi

9. Participatory Modelling

Social-Ecological Transition Policy Tool

The Civil Society Forum for Sustainability was organized by the SOLIDAR and the European Environmental Bureau (EEB) with the support of SDG Watch Europe and the European Alliance for a Just Transition, the forum brought together civil society organizations and key stakeholders to discuss pressing issues related to EGD and participatory democracy. As a result of this forum, a policy tool was created to aid in the social-ecological transition in the context of the EGD.

The objective of this policy tool was to provide examples of the current issues and the potential stakeholders that could be involved so that civil society organizations are empowered to engage with policymakers. It identified the main emerging issues and stakeholders of 3 themes identified in the context of the EGD.

This project has received funding from the European Union's Horizon Europe research and innovation programme under the grant agreement No 101112305.

1. Civic Space and Democracy

The forum participants identified some emerging issues that they felt needed to be addressed in the context of civic space and democracy:

Artificial Intelligence (AI) and Digitalization: concerns were raised about the misuse of AI and digital misinformation campaigns by anti-gender and climate-denial actors.

Climate Crisis: Seeing it as a pressing challenge of our time, the participants discussed narratives surrounding climate action, urging the need for inclusive and transparent narratives.

Right-Wing Populism and State-Authoritarianism: this trend threatens to reduce civil space, negatively impacting democracy and civic participation.

Potential key stakeholders were identified who could push for the narrative of participatory democracy in the context of the EGD: Civil Society Organizations (CSOs), local and regional authorities, journalists and independent media, teachers and educational institutions, and grassroots movements.

These are the stakeholders who could advocate for stronger policies to protect and encourage civic participation, promote the ethical use of AI, and help develop narratives for climate action that are transparent, inclusive, and scientifically accurate.

2. The Green and Social Deal

Far-right activism: the emergence of far-right activism has done a lot to damage the movement for climate action.

The social-climate-democracy 'trilemma': with the far-right narrative slowing down the progress on achieving climate goals, it is important to reconcile climate action, democratic participation, and social justice.

Global climate justice and the responsibility of the EU: while the EU has taken leadership of the global climate action, it still needs to take responsibility for its carbon footprint beyond its borders and its duty toward helping the Global South and areas affected by climate change.

The key stakeholders for these issues are voters, trade unions and the private sector. They can help build a positive narrative on climate action, showcasing how it can benefit citizens and stakeholders. A greener fiscal system that has a redistributive agenda that is based on inclusivity and meaningful citizen participation can be established with the help of these stakeholders. Finally, the EU can decrease its carbon footprint and reorient itself to be a fully circular economy.

3. The Mobilization of Citizens

The key issues identified by the forum participants in the context of citizen mobilization are:

Rise of the right-wing: their narrative pushes against climate action and gender equality and discriminates against minorities and migrants.

Socio-economic deprivations: there is a close link between socio-economic deprivations and democratic engagement. People faced with basic issues such as inadequate housing or low wages are less likely to take part in deliberative processes.

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Youth involvement in democratic processes: the youth are disconnected from the current political representatives, which is an issue for the future of European democracy.

Inclusivity of minority groups: despite the efforts of some civil society organizations, the inclusivity of minority groups remains a challenge as they continue to face security issues.

The stakeholders identified to address these issues are members of the European Parliament (MEPs)/candidates, members of the public, members of marginalized groups, civil society organizations, and local authorities. Together, they can tackle issues of social justice, such as the provision of sustainable green employment, affordable housing and inclusive economic policies. The public can also be encouraged to be more engaged in the decision-making processes at the local, national and EU levels. Open political discussion, both virtual and physical, can promote media literacy.

Methodology

Survey

The consortium members were asked to answer a survey so that their preferences and visions on how to address specific concerns and contexts in deliberative processes in EGD could be collected. This qualitative information was to help develop formats and questions for the empirical testing of participatory deliberative democratic processes in WP 3. The final output of the survey included 12 respondents.

Online workshop

The online workshop was intended to collaboratively explore and propose public engagement and deliberation tools and formats for future consideration and possible operationalization in WP 3, thus assisting the EGD's transition to sustainability.

5. PHOENIX - The rise of citizens' voices for a Greener Europe

Grant Agreement: 101037328
Website: https://phoenix-horizon.eu/

The project aims to develop a process that increases the transformative potential of democratic innovations to address the European Green Deal. These democratic innovations allow citizens to meaningfully participate in decision-making processes. PHOENIX will design and test democratic innovation in 11 case studies, spanning 7 countries at several administrative scales and within various environmental and socio-cultural contexts. The project will also engage in popularizing, scalability, and adaptability of existing methodologies. Given the importance of financial incentives and remunerations in engaging citizens in climate action, the measures of the Just Transition Fund will also come under particular focus. The project currently does not have any deliverables published yet. The project, however, is relevant to GREENPATHS as it addresses a crucial element of just transition: citizen participation.

The PHOENIX project has five main aims:

This project has received funding from the European Union's Horizon Europe research and innovation programme under the grant agreement No 101112305.

- Analyze Democratic Innovations: conduct an in-depth analysis of the 4 types of democratic innovation and how they can be practiced practically.
- Understand the different context: contextualize the effects of the EGD in different territories.
- Develop the PHOENIX Tangram: tailor a system of tools and methodologies, that when combined based on context-related characteristics, leads to the creation new 'Enriched Democratic Innovations' (EDI).
- Test EDIs in real settings: apply the EDI's in 11 case studies to test their adaptability to socio-cultural contexts and administrative levels.
- Promote future implementations: develop an online platform that connects the pilots' implementation so that the methodologies used can be adapted later.

6. COACCH - CO-designing the Assessment of Climate CHange costs

Grant agreement: No. 776479
Website: https://www.coacch.eu/

COACCH is a project designed and executed by 13 leading research institutions in Europe. It aims to increase our understanding of the effects of climate change and the policies that stakeholder communities may directly utilize. The final goal of COACCH is to produce an improved downscaled assessment of the risks and costs associated with climate change in Europe. The aim is for this assessment to be directly available for use to suit the needs of end users from research, business, investment, and the policy-making community. To do so, the project adopts a co-design approach.

The main objectives of this project are:

1. Develop research on complex climate change impact chains by using downscaled climate information and advancing integrated assessment methods and models.
2. Involving stakeholders in the co-design, co-production, and co-dissemination of policy-driven research.
3. Producing knowledge and evidence on climate and socio-economic tipping points
4. Advancing knowledge on economic analysis of climate action in the EU at various scales.
5. Co-disseminating of results with business, industrial, public decision-makers, and research communities.

The COACCH project is structured into 8 work packages:

Work Package 1: Stakeholder Engagement & Co-Deliver: To develop the co-design, co-production and co-dissemination approach for the project.

Work Package 2 – Impact Chains: To produce a downscaled evaluation of the impact, risks and costs associated with climate change in Europe.

Work Package 3 – Tipping Points: To provide an assessment of key climate and socio-economic tipping points in Europe.

Work Package 4– Policy Assessment: To assess policy implications of the climate insights from WPs 2 and 3 and identify mitigation and adaptation strategies in different sectors of Europe.

This project has received funding from the European Union's Horizon Europe research and innovation programme under the grant agreement No 101112305.

Work Package 5 – Synthesis: To synthesize and summarize the major findings of COACCH.

Work Package 6 – Dissemination And Outreach: To carry out external project dissemination, exploitation, and communication activities.

Work Package 7– Coordination: To ensure effective project coordination and management.

Case studies

The case studies in the COACCH project are divided over WPs 2,3 and 4 and, respectively, these are about the assessment of climate change costs and impact, climate and socio-economic tipping points, and policy assessment.

Impact assessment by sector

The COACCH project analyses the impact of climate change on different sectors within Europe.

Impacts on agriculture, forestry, and fisheries: climate change can affect agriculture, forestry and fisheries negatively (extreme heat, lower rainfall) and positively (extended seasons), and these can directly and indirectly affect production, consumption, prices and trade. The case studies find that winter wheat, oil seeds, and sugar crops have a lower impact magnitude compared to impacts on corn. For forests, climate change has reduced rainfall and increased temperature, leading to reduced growth rate and biomass and increasing the likelihood of fires.

Impacts on infrastructure, built environment, and transport: this sector will be severely affected by coastal floods, incurring annual damages worth €13 trillion. River flooding associated risks are expected to increase from €9.5 billion in 2010 to between €70-80 billion in 208, with considerable spatial inequalities.

Impacts on Industry, Energy, Services, and Trade: the researchers find significant evidence that labor productivity is negatively impacted by gradual temperature changes and extreme heat events. Because of future global warming, countries in south Europe such as Greece, Italy, Spain, and Portugal will face the highest productivity declines while colder regions such as Estonia, Finland, northern Italy, and Sweden will see improved labor productivity.

In the case of international supply chain risks under extreme events, the study found that a sector's export value is reduced by around 11 percent due to weather-induced production shocks. These shocks are stronger for countries in the topics and sub tropics as they experience severe weather crises.

Renewable energy generation is also affected by climate change. Under unmitigated climate change, wind power generation will decline, with the highest declines in eastern and western Sweden, and in Andalusia, Spain. Hydropower generation, which generates electricity based on precipitation, temperature and snow accumulation will decline by 4.2% (2050) and 7.3% (2070), respectively.

Tourism is also adversely affected by climate change, facing a greater decline in southern Europe.

Non-market impacts - ecosystems and biodiversity: the models used in this study indicate that by 2050 climate change will have significant effects on biodiversity, more due to nitrogen leaches from fertilizer use than from deforestation. Land cover changes are induced due to climatic changes, with an expected decrease in cropland in areas of South Europe and increase in parts of North Europe.

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Non-market impacts – health: the study has multiple key findings. The urban heat island (UHI) effect means that urban areas are expected to experience more heating in the coming years. With increases in frequency and severity of heat and cold stress, the study finds that the impact of these stresses is heterogeneous across age classes, with older citizens more vulnerable to temperature extremes. In fact, heat waves in Europe will also increase premature mortality over time and if it is not countered with strict mitigation strategies, will get more severe. The spread of tick-borne diseases is another health concern in Europe, and is already increasing in certain parts of Europe, namely in the Czech Republic, Slovakia, and Austria. Environmental changes and climatic events also directly and indirectly impact mental health.

The **cross-sectoral macroeconomic assessment** shows that climate change is deepening inequality. The NUTS2 regions, already with the highest projected GDP growth, the lowest population density, and below-average current mean temperature, will face less GDP loss in 2050 due to climate change. Meanwhile, European countries that currently have the lowest GDP per capita, lowest percentage of residents with tertiary education, lowest life expectancy and higher mean temperature, will experience the highest GDP loss due to climate change.

Tipping point assessment

Climate tipping points economic impacts

The study evaluates the economic impacts of three climatic tipping points, namely global extreme sea-level rise, Alpine glaciers disappearance, and the disappearance of Arctic Summer Sea ice. Severe economic impacts are expected after 2050, with some regions experiencing higher GDP losses, along with sectoral impacts such as agricultural production losses. On the positive side, the melting of the Arctic Summer Sea ice will enhance tourism, offering economic opportunities for local communities.

Socio-economic tipping points implications

Immigration impacts – immigration from African countries to Europe is expected to increase significantly in the 21st century, driven by changes in population and extreme heat events and droughts caused by climate change.

Financial tipping points - Credit ratings, cost of debt and capital are already affected by climate change and may cause the financial markets in high-risk nations to anticipate future risks, thereby leading to a socio-economic tipping point.

Food and water - Land abandonment may occur due to the increasing challenges of food production. Southern parts of Europe, specifically Southern Spain and Italy will see the highest level of land abandonment.

Trade disruptions due to flooding - The study finds that the European road network is quite resilient, and the risk of river flooding may not trigger a socio-economic tipping point.

Collapse of insurance markets for extreme weather risks - When flood insurance adoption declines owing to increased premiums brought on by climate change, poor income, or low desire to pay for insurance, there may be a socioeconomic tipping point. Such a tipping point may occur in Croatia, Bulgaria, Czech Republic, Poland and Portugal.

Macroeconomic analysis of national adaptation strategies

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The case studies on national adaptation strategies in Austria, Spain, and the Netherlands show that adaptation is effective in mitigating the economy-wide and sectoral negative effects of climate change. Flood risk management and adaptation in the forestry and agriculture sectors have direct benefits for the sectors and economy-wide benefits.

Analysis

The overall results of the case studies show that the impact of climate change is heterogeneous across regions, sectors and even age in some cases. Southern Europe and the Southern Hemisphere, with higher populations, above-average mean temperature, and lower overall education, are more vulnerable to the impacts of climate change.

The difference in impacts across sectors and regions underscores the need for diversified and resilient strategies to mitigate climate risks. It also highlights the interconnectedness of climate impacts across sectors.

Low severity of mitigation strategies often means severe consequences for climate change. Overall, this text underscores the urgent need for proactive measures to mitigate and adapt to the impacts of climate change across various sectors. It emphasizes the importance of holistic approaches that consider the interdependencies and complexities of climate impacts, while also highlighting the disproportionate burden borne by certain regions and industries.

Methodology

To assess the costs associated with climate change across different sectors, COACCH used Integrated Assessment Models, using a new set of damage functions for 14 macro-regions across the world, for both global mean temperature increases and for sea level rise. Some models are then used to assess the economic impacts of climate change and mitigation actions.

ICES - ICES (Inter-temporal Computable Equilibrium System) is a top-down multi-sector and multi-country computable general equilibrium (CGE) model for the global economy. Its framework explains how economic activity, energy consumption (including from renewable sources) and greenhouse gas emissions (including non-CO2 from livestock and agriculture) are linked both domestically and internationally.

WITCH (World induced Technical Change) – is an IAM that offers a comprehensive analysis of the energy sector and a game-theoretic setup, provided by a top-down, hard-linked climate-energy-economy dynamic optimization.

IMAGE – an IAM modelling framework, described the relationship between the earth system (climate, land cover, and several important natural cycles) and the human system (energy and land use, in particular). The framework specifically incorporates a number of biophysically modelled effects, such as rising sea levels and the effects of climate change on energy consumption and agriculture, and the water cycle. Various mitigation techniques in energy and land-use systems have been examined using IMAGE.

GLOBIOM is an economic land use model for the EU agriculture and forestry sector. At the national and regional levels, it offers a bio-economic evaluation of the effects of climate change on various sectors with respect to agricultural production, LULUCF, ecosystems, water, land use, bioenergy, trade, and GHG emissions.

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COIN is a computable general equilibrium (CGE) model that spans multiple sectors and regions and focuses on Austria or Europe (global version). It offers an economic evaluation of the effects of climate change in ten climate-sensitive sectors (agricultural, forestry, water, energy, buildings, tourism, transportation, manufacturing, flood risk management, and cities).

CATSIM is a probabilistic modelling framework grounded in risk assessment principles, considering hazard, exposure, and vulnerability factors. It evaluates the advantages of actions taken to mitigate the risks associated with climate change as well as the direct economic effects and macroeconomic ramifications of natural catastrophes.

REMIND-MagPIE - MagPIE connects the production, consumption, pricing, and trade of crops, livestock, pastures, and bioenergy with water availability and land resources. To run for mitigation scenarios, it can be coupled to REMIND, a multi-regional global model that includes the economy, the climate system, and a thorough depiction of the energy industry.

DIVA is an engineering sea-level rise model which conducts a multidimensional evaluation of climate change impacts on coastal areas. The model can incorporate mean sea-level rise, extreme events, low probability/high impact events, and tipping events.

LISFLOOD, FIAT/GLOFRIS develop a risk assessment framework that connects physical models with risk evaluation methods to provide an evaluation of the impacts of river floods on climate change at the basin level.

CMCC Climate models develop climate and weather projections which can identify changes in climate change average conditions, extreme events, and low probability/high impact events at the global and regional levels.

CLIMRISK evaluates the evolving GDP effects of climate change within a local context, utilizing a 50x50 km scale. It considers diverse socio-economic and climate change scenarios at a global level. This is achieved by merging local GDP exposure data with climate forecasts derived from pattern scaling of the MAGICC/SCENGEN climate model.

DIFI (Dynamic Integrated Flood Insurance Model) replicates the effects of climate change scenarios on simplified versions of current European insurance setups designed to manage flood risk.

SFM/FLAM can be used to evaluate the hazards and effects of forest fires in relation to socioeconomic and climate change scenarios. These will be quantified in terms of projected burned areas.

7. PARIS REINFORCE - Delivering on the Paris Agreement: A demand-driven, integrated assessment modelling approach

Grant agreement No. 820846
Website: https://paris-reinforce.eu/

PARIS REINFORCE was created to aid the design of effective climate policies. The project's specific goal is to create a novel, demand-driven, integrated assessment model-oriented framework that will effectively support the research and development of climate policies related to the Paris Agreement and

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related challenges in the European Union, other major emitters, and a subset of less emitting countries. Its main objectives are:

1. To create a novel, demand-driven, integrated assessment model-oriented framework that will effectively support the research and development of climate policies related to the Paris Agreement
2. To increase the transparency of the relevant models, techniques, and tools and to introduce a novel framework for stakeholder engagement (co-design).
3. To introduce innovative policy support frameworks created with the help of established qualitative and quantitative methods.

Work Packages

Work Package 1: Project Management

Work Package 2: Coordinating, harmonizing, and streamlining modelling activities.

Work Package 3: Innovative stakeholder engagement, operation of the Stakeholder Council, promoting inclusion, governance and transparency.

Work Package 4: Robustification and socio-technical analysis toolbox.

Work Package 5: Reinforcing the effective implementation of EU NDC, preparing of future pledges, carrying out sectoral analysis, designing 2050 strategies.

Work Package 6: Assessing the decarbonization potential of all major emitters and other less developed and/or less emitting countries.

Work Package 7: Model inter-comparisons, global stocktake, and scientific assessments.

Case studies

PARIS REINFORCE uses a mix of Impact Assessment models and qualitative and quantitative approaches to create mitigation scenarios at the EU level, non-European national level, and the global level. This section will shortly explain the case studies and their results and will then detail the model and methods that were used in the scenarios.

EU-level mitigation modelling scenarios

The first batch of models' run for the EU level implemented the "Where are We Headed" scenario protocol which investigated what the future holds for the world based on the countries' current climate strategies. The modelling scenarios research revealed that while the EU is now on course to meet its 40% emissions reduction objective, it is still well short of its most recent goal of 55% emissions reductions by 2030. Additionally, the extent of CCS implementation looks linked to more significant reductions in emissions; similarly, transportation electrification appears critical to achieving the greatest possible reduction in emissions by 2050. Although electrification performs substantially better than hydrogen diffusion, CCS appears to play a crucial part in the latter process as well. The detailed sectoral figures show that energy efficiency and fuel switching are the main drivers of the building sector's 30% and 50% CO2 emission reductions in 2030 and 2050, respectively, compared to 1990. In the transportation sector, the decarbonization is predicated on the quick adoption of electric vehicles for passenger cars and hybrid diesel catenary trucks for heavy-duty vehicles. Lastly, the analysis of the

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post-COVID-19 pandemic impact on the EU energy system concludes that, despite significant short-term effects, there will be mitigated consequences in 2030. These findings also support the idea that long-term behavioral changes observed during the pandemic may help to lessen the burden of GHG reduction.

Non-European country mitigation modelling scenarios

The countries covered in these modelling exercises are the USA, Canada, Mexico, China, India, Brazil, Russia, and countries of the Central Asian Caspian region (Azerbaijan, Kazakhstan, Turkmenistan, and Uzbekistan). Using stakeholder workshops the research finds that there are some key barriers to low-carbon pathways. For instance, preliminary conversations with collaborating organizations on the ground in the USA emphasized the significance of equity and employment in the establishment of low-carbon pathways. In China, there is a strong focus on policy design, for example through emissions trading system development. In the Central Asian Caspian region, energy tariffs, water resources, and energy trade were the main focus of stakeholders' workshops. The primary findings drawn from the scenarios modeled in this study include the possibility of decarbonizing national energy systems globally by substituting unrestricted fossil fuels with nuclear, renewable energy, and carbon capture and storage, with energy efficiency being crucial to the functioning of the entire economy.

Global mitigation modelling scenarios

This case study models projections of global energy CO2 emissions up to 2050 based on various Integrated Assessment Models (IAMs). It highlights that emissions are influenced by both current policies and Nationally Determined Contributions (NDCs). Differences in emissions arise due to regions not meeting their NDC targets. Post-2030 efforts significantly impact emissions by 2050, with varied effects depending on the extension method used. Carbon price extensions tend to result in higher emissions compared to emissions intensity extensions. The text applies the Transient Climate Response to Cumulative Carbon Emissions (TCRE) to estimate temperature changes. It notes that NDC-constrained scenarios aim for lower 2100 temperatures compared to current policy-constrained scenarios. Model variations have a larger impact on emissions projections than scenario choices. The study emphasizes the importance of model differences in scenario analysis and mitigation assumptions post-2030. While emissions paths may differ among models, they aim to be compatible with different temperature futures for 2100.

Analysis

Each of the case studies addresses mitigation strategies and their potential impacts, but they do so within different geographic contexts: EU level, non-European countries, and globally.

The EU-level scenario focuses on specific goals and strategies tailored to the region's policies and objectives, such as the 40% and 55% emissions reduction targets. It emphasizes the importance of sector-specific measures like energy efficiency, electrification, and CCS implementation. Additionally, it acknowledges the potential long-term effects of the COVID-19 pandemic on mitigation efforts.

In contrast, the non-European country scenarios highlight the diversity of challenges and approaches across different regions. For example, in the USA, emphasis is placed on equity and employment concerns, while in China, policy design, particularly through emissions trading, is prioritized. The focus in the Central Asian Caspian region is on energy tariffs, water resources, and energy trade. Despite these

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differences, the common theme across all regions is the recognition of the importance of energy efficiency and transitioning away from fossil fuels towards renewable energy and nuclear power.

The global mitigation modelling scenarios provide a broader perspective, emphasizing the interconnectedness of emissions reduction efforts and the significance of international agreements like NDCs. It underscores the role of model variations in predicting emissions trajectories and temperature outcomes, highlighting the need for comprehensive and harmonized approaches to scenario analysis.

Drawing parallels between these texts, it's evident that while mitigation strategies share common themes such as energy efficiency and transitioning to low-carbon energy sources, the specific challenges and approaches vary significantly depending on regional contexts. Additionally, the importance of international cooperation and agreement, as demonstrated by the global modelling scenarios, is crucial for addressing the overarching challenge of climate change effectively.

Methodology

This project includes a total of 22 models that offer various levels of results aggregation (national, regional, and worldwide). There are five models with records at the national and regional level for Europe, nine models covering significant emitting regions outside of Europe, and eight global IAMs containing documentation on the globe as an aggregated region. These models can have different approaches, such as macroeconometric, partial equilibrium, which treat the rest of the economy using inputs from outside sources while providing a detailed description of the markets and activities in particular sectors, or computable general equilibrium (CGE) models provide a more in-depth picture of particular economic sectors while covering the overall economy.

The **national and/or regional** modelling tools for Europe are:

ALADIN - The stock and total energy consumption as well as the CO2 emissions of road vehicles (passenger cars and light- to heavy-duty trucks) in scenarios are projected by this agent-based dynamic simulation model in Europe. Fuel and vehicle markets in road transport evolve as a result of price changes, shifts in consumer preferences, and changes in model availability. Emissions can therefore be computed for various policy situations.

FORECAST - Using a single model run, FORECAST is a bottom-up dynamic simulation tool that projects long-term scenarios for each European country's CO2 emissions and energy demand until 2050. This model also takes socioeconomic factors and technology dynamics into account.

JET - The European Union (EU) uses JET, a scenario-based technology, to generate dynamic, least-cost routes that take into account various technical and environmental limitations. The model facilitates the investigation of various mitigation strategies, such as sector-specific/technology-specific regulations (e.g., subsidies and taxes) and objectives (e.g., annual GHG emissions binding targets and cumulative carbon budgets).

LEAP - An energy-environment modelling tool, an extensive accounting of how energy is used, transformed, and produced in a particular area or economy under a variety of possible assumptions on population, economic development, technology, pricing, etc. forms the basis of LEAP.

NEMESIS - A macroeconomic model, NEMESIS addresses EU climate mitigation measures and emphasizes various economic tools and their economic effects at the EU, national, and sectoral levels.

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A pre-established level of a climate policy instrument or annual GHG emissions limitations can be used by the model to implement mitigation strategies for climate change.

The **national-level** modelling tools for countries outside of Europe are:

CONTO provides information about road transportation as well as the energy needs of households, businesses, and industries in Russia. In reaction to carbon taxes or subsidies for low-carbon fuels and technology, it can represent the mitigation of climate change by altering the relative costs of high- and low-carbon fuels in each sector.

The GCAM family of models examines the behavior and connections between the energy system, agricultural and land use, economy, and climate. It includes the GCAM model with global coverage and its regional variations, GCAM-China, GCAM-USA, and GCAM-SOUSEI. Socioeconomic factors, energy technology features, agriculture technology features, energy resources, and policies are among the set of input assumptions.

MARKAL/TIMES - The energy system optimization model of the MARKAL/TIMES models (MAPLE (for China), MARKAL-India, NATEM, and TIMES-CAC (for Kazakhstan, Uzbekistan, Turkmenistan, and Azerbaijan)) is built on the TIMES modelling framework. They employ bottom-up methodology to provide a detailed description of the energy sectors using a range of specialized technologies characterized by their technical and economic features. They compute an equilibrium that is limited to the energy markets (partial equilibrium).

The modelling tools of the project aggregating results at the global level are:

DICE is a global, optimal growth or welfare optimization IAM that integrates the climate system within the context of economic growth theory. It represents the economic, policy, and scientific elements of climate change and can also be regarded as a member of the CGE family.

ICES and d GEMINI-E3 - are CGE models that are multi-regional general equilibrium models. that was created to analyze market flows both within a single economy and internationally with the rest of the world, as well as to investigate mitigation and adaptation strategies in response to climate change's effects on the economic system.

TIAM - Like the models in the GCAM family, the TIAM model achieves market equilibrium independently in each of its focal sectors, offering a thorough examination of the relationships between environmental effects and specific economic sectors.

MUSE and 42 – these energy system models offer a thorough analysis of the energy sector, including energy technology and related expenses, to help identify the most economical approaches to reducing greenhouse gas emissions or the expenses of different climate policies. Both of these bottom-up models operate under the assumption of a short-term microeconomic equilibrium in the energy system. In addition, MUSE is an agent-based model that incorporates a land use sector.

E3ME – is a macroeconometric model is called E3ME. It is detailed in terms of energy technology and geographic reach, similar to CGE models, but it is different in that it does not make the assumption that producers and consumers will act optimally or that markets will clear and find equilibrium quickly. Rather, by presuming that markets reach equilibrium in the long run, it employs historical data and econometrically determined parameters and relations to dynamically and more accurately model the behavior of the economy.

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8. Open ENTRANCE- Open ENergy TRansition ANalyses for a low-carbon Economy

Grant agreement No. 835896
Website: https://openentrance.eu/

The project aims to develop, use, and disseminate an open, transparent, and integrated modelling platform for assessing low-carbon transition pathways in Europe. The primary objectives of the Open ENTRANCE project are:

- To support the EU's ambition to reduce greenhouse gas emissions and become climate neutral by 2050.
- To provide a comprehensive analysis of the energy transition in Europe, considering technological, economic, and societal aspects.
- To involve a wide range of stakeholders, including policy and decision-makers, energy companies, grid operators, civil society, NGOs, researchers, and other interested actors.

The project emphasizes the importance of open data for energy system modelling to increase transparency about modelling assumptions and results, improve replicability, and enhance public trust.

Work Packages

Work Package 1 - Stakeholder Dialogue: To facilitate understanding among stakeholders and energy modelers, and to disseminate results to policymakers.

Work Package 2 - Communication and Dissemination - To strengthen the policy-science interface and effectively communicate project results.

Work Package 3 - Scenario Building Exercises: To develop low carbon futures for the European energy system and identify necessary data for scenario building.

Work Package 4 - Open Modelling Platform: To provide infrastructure for scenario data exchange and dissemination of results.

Work Package 5 - Suite of Modelling Tools: To develop model linkages and use within the platform.

Work Package 6 - Case Studies: To implement and research themes based on EU Energy Union targets and showcase model linkage.

Work Package 7 - Transition Pathways: To combine scenario analyses, case studies, and macro-economic analyses into policy recommendations.

Work Package 8 - Project Management: To oversee the project's detailed planning, progress, and deliverables.

These work packages collectively aim to improve the understanding of Europe's transition to a low carbon energy system through an open platform of integrated modelling tools and data.

Case studies

This project has received funding from the European Union's Horizon Europe research and innovation programme under the grant agreement No 101112305.

The Open ENTRANCE research project PDF outlines 8 case studies, each focusing on different aspects of energy transition:

Case Study 1: Demand Response - Behavior of Individuals

This study estimates the technical potential for residential household Demand Load Control (DLC) from 2022 to 2050 and evaluates its impact on the European electricity system's cost, operation, and investment needs. It focuses on residential DLC flexibility, excluding industrial and commercial sectors, and considers load shifting without load curtailment.

The results show that implementing DLC results in a decrease in operational costs by 0.45% in a conservative scenario and nearly 2.5% in an optimistic scenario. Likewise, household DLC helps lower both the average marginal costs and their variability. In terms of the impact of residential DLC programs on the long-term investment planning (2020–2060) of the European electricity system., the results find a 0.99% improvement in the total cost of the system.

Case Study 2: Behavior of Communities of Actors

It explores shared energy management in local energy community concepts, considering individual preferences. The quantitative results are scaled to country and European levels5.

The findings illustrate how the existing energy community selects optimal parameters for a potential new member based on the preferences of current members. An environmentally focused community prefers a prosumer with a large PV system, while a profit-driven community favors a consumer with high electricity demand to sell electricity to, thereby generating profits. The decision is also affected by geographical distance and the new prosumer's willingness to pay. In a community with mixed preferences, the needs of both environmentally and profit-oriented prosumers are balanced.

Case Study 3: Need for Flexibility – Storage

This case study examines the interaction between various storage technologies and the transmission grid in delivering the flexibility needed for the electricity system to achieve full decarbonization. The study evaluates the flexibility contributions of decentralized electricity storage within local energy communities (LECs), centralized storage like pumped-storage hydro, utility-scale batteries, and hydrogen storage.

The results show that local energy communities (LECs) in the two studied countries, Norway and Spain, do not heavily invest in energy storage due to limited price variations, resulting in limited flexibility. Instead, they focus on deploying substantial photovoltaic (PV) systems, which produce power during low-price periods, further decreasing prices and increasing the need for flexibility. In Norway, LECs impact renewable energy deployment differently across regions, increasing power exchanges and slightly raising transmission grid use. In Spain, LECs uniformly affect demand and generation patterns, decreasing regional complementarities and moderately reducing transmission grid use.

Case Study 4: Need for Flexibility – Sector Coupling

This case study conducts a sensitivity analysis using openENTRANCE's Techno-Friendly 1.5°C pathway. It evaluates the impact of three critical factors on the development of the pan-European energy system. These factors include the flexibility of electric vehicle charging in individual road transport sectors, the capacity for cross-border electricity trade between national markets, and the prices of

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renewable hydrogen imports from outside Europe for end-use demands that cannot be met by direct use of renewable electricity.

The case study reveals that hydrogen import prices significantly influence the energy system changes in a climate-neutral setup and shape Europe's dependency on energy imports. Low hydrogen prices drive up demand and result in a substantial share of imports from emerging global markets. These prices have the most pronounced effect on regional electricity price distributions, whereas cross-border trade and electric vehicle flexibility have a comparatively minor impact on the extremes of price volatility.

Case Study 5: Decentralization

This case study compares geographic coordination levels for investment decisions, examining regional decisions with local objectives against European coordinated decisions with global targets.

The analysis considers two geographical scales: Europe at the global level and individual countries (or groups of countries) at the local level. The findings indicate that decentralizing decision-making and targets at the national level within Europe tends to significantly increase costs. Conversely, a more effective approach for decentralizing decarbonization efforts in the European electrical system could involve developing country-specific decarbonization targets based on a fully centralized optimization at the European level. This approach would consider the grid's exchange capacity and each country's unique renewable energy potential and generation characteristics.

Case Study 6: Innovative Technologies

Investigates the use of underground rocks for seasonal heat storage in a district in Oslo, Norway, and its impact on the energy system.

The findings indicate that generally, connecting to an existing district heating network is adequate to lower peak electricity demands during winter. However, incorporating seasonal thermal storage enhances the use of waste heat and decreases emissions by replacing other peak units in the district heating network.

Case Study 7: Integration of Electricity and Heating Sector

This case study evaluates the impact of flexibilities from the heating sector on system operation costs and network expansion needs in Denmark.

The results indicate that the flexibility of Danish electrified heat demand has a significant impact on both Danish and European electricity dispatch, although the effect is relatively minor on a continental scale. Demand response may slightly reduce Danish electricity costs by enabling lower-priced imports and higher-priced exports. Heat storage has an even greater impact, reducing domestic operational electricity costs, which are already negative, by 1.3 EUR/MWh compared to a reference scenario. Power-to-heat demand flexibility greatly benefits the operation of the Danish power system, primarily through more efficient cross-border trade.

Case Study 8: The Role of Natural Gas Storage for Flexibility

This case study examines the role of natural gas storage in current and future energy systems in Turkey.

The study demonstrates that employing power-to-gas technology to produce hydrogen and/or synthetic methane, which is then stored in Turkey's underground natural gas storage facilities, can significantly

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enhance the flexibility of Turkish energy supply systems, especially during the transition period leading up to 2050. The analysis focuses on model outputs related to the production and use of natural gas, synthetic methane, and hydrogen, as well as storage activities for each scenario. In all scenarios, natural gas storage contributes additional flexibility to the energy system. The results indicate a declining share of natural gas, primarily due to increased renewable energy capacity, while synthetic gas is projected to be predominantly utilized by the industry in the future. The study anticipates an increase in the required underground gas storage capacity in Turkey, with the model suggesting that future capacity will be adequate.

Analysis

The case analysis reveals some key insights regarding:

The cost-efficient alternatives for energy system development:

- The project analyzed various scenarios for transitioning to a low-carbon energy system in Europe. By considering different technologies, energy sources, and infrastructure investments, it identified cost-effective pathways.
- These alternatives involve a mix of renewable energy sources (such as wind, solar, and hydropower) and improvements in energy efficiency. The goal is to minimize costs while achieving environmental targets.

Macro-Economic Consequences:

- The transition to a low-carbon energy system has significant macro-economic implications. The project assessed how different policy choices impact economic growth, employment, and overall welfare.
- By modelling these consequences, policymakers can make informed decisions that balance environmental goals with economic stability.

Impacts on Different Geographical Levels:

- The project considered impacts at various geographical scales, from local to regional and continental levels.
- It examined how energy transitions affect specific regions, industries, and communities. Understanding these localized impacts is crucial for equitable and effective policy implementation.

Policy Recommendations:

- Based on the findings, the project recommends accelerating the energy transition. This involves scaling up renewable energy deployment; enhancing energy storage and grid infrastructure; and promoting energy efficiency measures.
- According to the findings of the project, policymakers should prioritize these actions to meet climate goals and ensure a sustainable energy future.

Methodology

The methodological approach used in this entrance included:

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- Creation of an open, transparent, and integrated modelling platform for assessing low-carbon transition scenarios in Europe.
- Development of scenarios based on policy exertion, smart society, and technological novelty to achieve climate goals.
- Use of computational general equilibrium models to study the macro-economic consequences of decarbonization.
- Case Studies: Conducting detailed local analyses to validate the robustness of the results and explore impacts on different geographical levels.

To conduct the case studies, specific modelling tools were developed and used by the consortium. These tools include:

GENeSYS-MOD - Based on the Open-Source Energy Modelling System (OSeMOSYS) architecture, the Global Energy System Model (GENeSYS-MOD) is an open-source energy model. It is still a member of the OSeMOSYS family, but it has experienced substantial alterations, augmentations, and additions. To minimize overall system costs, GENeSYS-MOD runs as a linear program with predefined energy demands that the model must satisfy by providing enough capacity. Depending on the research topic and input data, its flexible structure supports a variety of use cases, from household-level studies to global regional aggregations. GENeSYS-MOD can be considered a flow-based cost-optimization model.

REMES - The Norwegian economy is analyzed using the REMES Computable General Equilibrium model, which places particular emphasis on the energy sector, studying the effects of macroeconomic policy on the Norwegian economy. The Norwegian national economy is divided into five areas by the model, and these regions correspond to the five zonal pricing of the Norwegian energy market. It takes into account the demand from consumers, investors, and the government in addition to imports and exports from other countries. It consists of 36 production sectors and 32 goods. Policies are modelled as shocks that impact the economy through subsidies or taxes. Impacts on costs, activity levels, imports, exports, and technological advancements are then assessed.

EMPIRE - The EMPIRE power system model encompasses generation, storage, and increased transmission capacity. It is intended to take into account both short- and long-term dynamics and determine the best capacity investments in light of operational unpredictability.

EXIOMOD is an economic model designed to evaluate the environmental impact of economic activities. As a multisector model, it captures the economic interdependencies between various sectors. It also functions as a global, multi-country model, establishing consistent trade connections between countries at the commodity level. Utilizing national account data, EXIOMOD can generate comprehensive scenarios on the evolution of key economic indicators such as GDP, value-added, turnover, consumption (both intermediate and final), investment, employment, trade (exports and imports), public spending, and taxes. With its environmental extensions, the model links the economic activities of different agents (sectors, consumers) to the utilization of numerous resources (energy, minerals, biomass, land, water) and the production of negative externalities (greenhouse gases, waste).

openTEPES - The Open Generation and Transmission Operation and Expansion Planning Model with Renewable Energy Sources and Energy Storage Systems (openTEPES) identifies investment strategies for new facilities (generators, ESS, and transmission lines) to meet projected demand at the lowest possible cost. Ten-to-twenty-year time spans are the focus of tactical planning within this model and its

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main objective is to evaluate the future generation, storage and network needs. The primary findings serve as a set of recommendations for the generating and transmission networks' future design.

GUSTO - The GUSTO model is an open-source framework designed for optimizing energy technology investments and local technology dispatch. This advanced model operates as a mixed-integer linear program (MILP), facilitating decisions on portfolios of energy technologies. It supports the delivery of various local energy services, such as electricity, heating, and cooling, and incorporates the use of different commodities.

FRESH:COM - The linear optimization model efficiently distributes prosumers' renewable electricity generation from Photovoltaic (PV) systems, complemented by battery energy storage systems (BESSs), among community members. This distribution is based on each member's willingness to pay for emission reduction and for purchasing the community-generated PV electricity. Prosumers thus become active participants in decentralized energy markets, specifically through a peer-to-peer trading mechanism.

Integrate - Integrate is an optimization model designed for planning local energy systems by concurrently considering various energy carriers and technologies. Its primary objective is to optimize infrastructure investments over a multi-decade planning horizon, ensuring that energy is delivered to end users in the required amounts and forms to meet demand in the most cost-effective and environmentally friendly manner. The model provides users with a graphical representation of an energy system (such as a municipality, city, or suburb), highlighting costs, environmental impacts, and the utilization of local energy resources.

EMPSW – This stochastic optimization model is employed for long-term planning of hydrothermal systems. It simulates the northern European power supply market, offering a detailed representation of hydropower and calculating individual water values for each reservoir in Scandinavia. The results demonstrate that the model is highly effective in assessing the flexibility of hydropower in energy systems with a significant proportion of intermittent renewable generation.

MESSAGEix-GLOBIOM - The IIASA IAM framework is comprised of a synergy of five distinct models or modules: the energy model MESSAGEix, the land use model GLOBIOM, the air pollution and GHG model GAINS, the aggregated macro-economic model MACRO, and the simplified climate model MAGICC. Each model specializes in different domains, complementing one another. During a typical scenario development cycle, these models provide inputs to each other and iterate together. Collectively, they form the IIASA IAM framework, also known as MESSAGEix-GLOBIOM.

9. REINVENT - Realising innovation in transitions for decarbonisation

Grant agreement No. 730053
Website: https://www.reinvent-project.eu/about

REINVENT involves multiple European universities and institutes. The project aims to analyze system-wide transformations to support Europe’s decarbonization efforts. It targets the meat/dairy, paper, plastic, and steel industries, which are significant economically but have underexplored low-carbon transitions. The project takes an interdisciplinary approach, studying entire value-chains and

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considering non-technological factors like supply chains, financing, trade, and social impacts. It aims to understand sector-specific transitions and initiatives, acknowledging that government climate policy is just one of many influencing factors. An overall goal of the project is to make future climate policies better aligned with the specific conditions in different sectors.

Work Packages

Work Package 1 - Conceptual Framework: Focuses on developing the theoretical and conceptual foundations for REINVENT, influencing all other WPs.

Work Package 2 - Mapping Decarbonization Innovations: Involves mapping decarbonization innovations and identifying emerging pathways for decarbonization.

Work Package 3 - Non-Technical Drivers of innovation for decarbonization: Studies in-depth cases to understand non-technical drivers of innovation for decarbonization.

Work Package 4 - Impact and Scenarios: Explores cumulative impacts and scenarios consistent with long-term climate objectives.

Work Package 5 - Non-climate Synergies and Trade-offs: Investigates non-climate synergies and trade-offs associated with decarbonization processes.

Work Package 6 - Realizing Decarbonization Pathways: Turns research results into practice, focusing on decarbonization pathways and policy evaluation.

Work Package 7 - Communication & Dissemination: Handles communication and dissemination of research findings to various audiences.

Work Package 8 - Management: Ensures overall management and coherence of the project, integrating work across all WPs.

Case studies

REINVENT analyses 20 in-depth innovation case studies based on intervention in the key sectors at different stages of the value chain. Besides sectoral case studies, the role of finance is addressed as a cross-sectoral aspect.

Steel Sector case studies

1. Castrip

Innovation: Strip casting in steel production

Intervention: Castrip

This case study looks at the strip casting process in steel production which combines casting and rolling for steel production, reducing GHG emissions. The findings show that while the final stages of casting and rolling are not the primary sources of GHG emissions in the steel industry, they still play a crucial role in decarbonization. Their importance will become more evident as primary and secondary steelmaking undergo deep decarbonization through methods like hydrogen direct reduction and low-carbon electricity. Efficient downstream processes will then be essential. The steel industry's dedication to bringing new innovations to market, bolstered by large R&D expenditures, emphasizes the powerful

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incentive offered by possible cost savings through increased efficiency. In the future, rising CO2 costs could serve as an equally strong incentive.

2. HYBRIT

   Innovation: Fossil-free steelmaking through direct reduction of iron ore using hydrogen as reductant (H-DR) and fossil-free mining and pelletisation of iron ore.

   Intervention: The HYBRIT project

   This case study investigates the HYBRIT project which uses hydrogen as a reduction agent in steelmaking, aiming for near-zero GHG emissions2. Key insights from this case study show HYBRIT is one of several initiatives demonstrating the potential for fossil-free steelmaking. Although the concept is not yet fully proven, it challenges the previously dominant belief that carbon emission reductions in the steel industry could only be achieved through CCS. A key factor in HYBRIT's progress is the close collaboration between companies from various sectors, all united by a commitment to societal goals of achieving net-zero emissions. Feasibility assessments of HYBRIT, along with its narrative, rely on political commitment to Sweden's target of net-zero emissions by 2045.

3. Voluntary Certification Schemes

   Innovation: Voluntary low-carbon building standards

   Intervention: BREEAM 2018 New Construction standard (UK)

   This case study investigates the case of Voluntary Certification Schemes in the building sector, focusing on the BREEAM NC 2018 scheme in the UK which evaluates the environmental impact of new commercial buildings. The results show that direct decarbonization is challenging to quantify. At present, there is no available data (to the author) on the extent to which BREEAM-certified buildings outperform non-BREEAM buildings or how much of any potential difference can be attributed to reduced steel usage. Technological advancements in measuring life cycle emissions have prompted BREEAM to include embedded emissions more comprehensively in its standards. Moreover, most interviewees concurred that legislative measures are necessary, as voluntary schemes alone are insufficient to drive widespread change in the sector.

4. MX3D

   Innovation: Wire Arc Additive Manufacturing (WAAM) for Steel

   Intervention: MX3D

   This case study considers the Wire Arc Additive Manufacturing (WAAM) for steel that uses robot technology to build large structures. The intervention, MX3D, was initiated to demonstrate the technical and design capabilities of WAAM steel processing within the construction industry. The results show that decarbonizing steel processing alone will not achieve full decarbonization of the steel sector if primary and secondary steel production still relies on fossil-based reduction agents or electricity from fossil fuels. However, this situation is expected to change, and the relative impact of steel processing on carbon emissions and other Sustainable Development Goals (SDGs) will increase. Policy support is needed to finance innovative construction projects utilizing WAAM. Financing in the

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construction sector should be paired with research projects that assess the total carbon impact throughout the value chain and the service life of WAAM-processed structures.

5. DOCOL Light Steel

   Innovation: Improved process technology and co-design with end users

   Intervention: DOCOL Steel

   DOCOL Light Steel is a case study of using high-strength steels for lightweighting to reduce the amount of material needed. The case study findings show that DOCOL steel boasts greater emission efficiency compared to the global steel average, primarily due to Sweden's exceptionally pure iron ore and low-carbon electricity supply. However, the comprehensive decarbonization of the steel and automotive sectors hinges on fundamental shifts in input fuels.

Plastics Industry case studies

1. Tierra's deterra-jacket

   Innovation: 100% bio-based jacket

   Intervention: Tierra's deterra-jacket

   Tierra represents an innovation in the manufacturing segment of the plastics value chain, exploring the use of bio-based materials to produce a fossil-free outdoor jacket. The Tierra case illustrates that creating fossil-free fabrics is possible within the current textile industry. If a robust outdoor jacket can be produced, it suggests that most other garments can be as well. Many industry players aim for complete circularity and a closed-loop system that eliminates the need for virgin materials. Although this objective is not yet guaranteed, developing fossil-free fabrics is essential for introducing new clothing. However, for immediate decarbonization, these fabrics encounter obstacles related to scalability and cost, making widespread adoption improbable in the short term.

2. Enerkem Rotterdam

   Innovation: Chemical recycling of hydrocarbon wastes (e.g. plastics, biomass)

   Intervention: Enerkem – Waste-to-Chemicals project Rotterdam

   This case study looks at chemical recycling of municipal waste to produce syngas for the chemical sector in the Enerkem plant in Rotterdam. The plant aims to convert municipal solid waste (MSW) into methanol, which can serve as a chemical feedstock or a fuel additive. Despite the fact that MSW gasification has been researched since the 1970s, only a few technologies have achieved success. The main impetus for the Rotterdam facility is the shift towards a circular economy, which is also influencing policy development, and the quest for low-carbon chemical feedstocks as part of the chemical industry's energy transition.

3. Zero-Waste Grocery Stores

   Innovation: Zero-waste grocery stores

   Intervention: Gram (Malmö) and Løs Market (Copenhagen)

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Zero-waste grocery stores represent a social innovation within the plastics sector, offering consumers the opportunity to avoid single-use plastics. The case study showcases the decarbonization potential of social innovations in the retail sector. Zero-waste grocery stores, while likely to remain niche within the retail industry, do not individually contribute substantial carbon and sustainability benefits at the store level, particularly in terms of their impact on the plastic sector alone. Their primary sustainability benefits come from fostering local food networks, organic farming, and vegetarian diets. Moreover, the close association between zero-waste grocery stores and the larger zero-waste movement—including NGOs, activists, and social media influencers—has been pivotal in highlighting the issue of plastic pollution. This connection has been a significant factor in driving high-level policy and corporate attention towards tackling plastic waste.

4. Carbon2Chem

   Innovation: CCU (Carbon Capture and Usage) within the steel and chemical industry Intervention: Carbon2Chem

   Carbon2Chem is an innovation bridging the steel and plastics industries by exploring the use of carbon capture and utilization (CCU) to convert waste gases from steel production into methanol for the chemical sector in North Rhine-Westphalia, Germany. Thus, it offers reduction in the use of fossil raw materials for the chemical industry.

   The case study shows that the anticipated contribution to decarbonization is a reduction of 20 million tons of CO2 per year. While this represents 10% of the annual emissions from industrial processes and manufacturing industries in Germany, it is crucial to note that these emissions will be "re-used" by the chemical sector and may be released later in the value chain if the carbon loop is not closed. Nonetheless, the chemical industry can decrease its reliance on fossil resources, as these are supplied by the steel industry through the Carbon2Chem initiative. Additionally, the case illustrates that political actors can play a key role as intermediaries by supporting the initiation and institutionalization of cross-industrial innovations.

Pulp & Paper Sector case studies

1. Äänekoski Biorefinery

   Innovation: Biorefinery

   Intervention: Äänekoski bioproduct mill

   Äänekoski Biorefinery, the largest pulp mill in Europe, serves as a case study of technical innovation in the resource and production aspects of the paper industry, focusing on fossil-free pulp production. The Äänekoski bioproduct mill exemplifies advancements in biorefinery development.

2. Lime Kiln Conversion

   Innovation: Lime kiln fired with biofuel

   Intervention: New lime kiln at SCA Östrand (Bioloop)

   The Lime Kiln Conversion case study explores the operation of a 100% wood powder-fired lime kiln. The intervention involves the investment in a new wood powder-fired lime kiln at the Östrand kraft pulp mill in Timrå. At Östrand the new wood powder-fired lime kiln has replaced two oil-fired kilns. It

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primarily runs on wood powder derived from ground pellets but also utilizes gases from the mill. This case highlights the significance of the mill's context, including expansion plans, material, and geographical factors such as proximity to pellet supplies, and the influence of existing pathways, like the pellet market for space heating, and trust between stakeholders in selecting technical solutions. The primary motivation was to move away from oil profitably, which aligns with the long-standing corporate strategy for decarbonization. Strategic investment decisions are heavily influenced by overall strategy and future expectations, with the EU-ETS playing a minimal role in this investment's motivation. While this innovation might be adopted by kraft pulp mills globally, it is less applicable to European paper mills, where electrification to replace natural gas used in steam generation for heating and drying is a key option. Investments need to be profitable, driving policy changes in relative fuel and electricity prices to encourage such shifts.

3. DuraSense

   Innovation: Biocomposite

   Intervention: DuraSense

   DuraSense is an innovative biocomposite (composite materials usually consisting of a biobased fibre mixed with a plastic) composed of cellulose fibers, wood particles, and plastic, suitable for various applications. The DuraSense case study sheds light on a number of trends covered in Reinvent, including the move away from fossil fuel-based raw materials and toward biobased ones, the expansion of companies beyond conventional borders, and the significance of value chain collaboration for successful innovation in new fields.

Meat & Dairy Industry case studies

1. FrieslandCampina's Green Schuldschein

   Innovation: Green Bonds

   Intervention: FrieslandCampina Green Schuldschein

   FrieslandCampina's Green Schuldschein investigates the nexus between the finance and dairy industries, focusing on the company's use of green bonds as a financial tool. FrieslandCampina, a Dutch company, is the first non-German issuer of a 'green' Schuldschein, raising €300 million in investment as part of its strategy to diversify funding. Additionally, it is the first "green" debt tool that a dairy firm has issues. Thus, emission cuts within the FrieslandCampina value chain have the potential to have a major impact on the total emissions reduction of the Dutch dairy industry, as the cooperative controls between 75 and 80 percent of the country's dairy market. In terms of overall decarbonization, the results show that the factories of FrieslandCampina are not the main source of the company's emissions. While there has been a decrease in emissions, this is not solely attributable to the Green Schuldschein, awhich was used for refinancing existing projects rather than securing new financing. Farms account for the bulk of the company's emissions but are yet unaddressed. In the financial sector, it is not unusual to refinance current projects rather than starting new ones using "green" financial instruments.

2. Green Protein Alliance

   Innovation: Private governance initiative to promote dietary change

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Intervention: Green Protein Alliance

The Green Protein Alliance is a social initiative in the Netherlands targeting the consumption side of the meat and dairy value chain, advocating for the partial replacement of animal protein with plant protein. This is the first multi-stakeholder cooperation aimed at changing protein consumption toward plant-based products in the Netherlands and among the few globally. This program is a step in establishing the prerequisites for consuming more plant-based protein and, eventually, reaching a more sustainable protein balance. The case study shows that encouraging new industries—like the market for plant-based proteins—has a higher chance of winning over important stakeholders than imposing regulations on already-existing ones.

3. Oatly

Innovation: Oat-based dairy analogues

Intervention: Oatly

The Oatly case deals with the production and consumption of plant milk derived from oats as a substitute for cow's milk. The results show that plant-based milks offer consumers a means to reduce their emissions footprint while maintaining their dietary habits. However, these products must be part of a sustainable food system that significantly reduces animal agriculture. Financial constraints prevent many farmers from transitioning their production independently, necessitating a governed approach to achieve a decarbonized sector. Furthermore, this case study also supports the idea that innovation is not enough to start a low-carbon transition.

4. Cultured Meat

Innovation: Meat analogues

Intervention: Cultured (lab-grown) meat

Cultured Meat explores the potential of lab-grown flesh as a technical innovation for meat substitutes. In terms of decarbonization, the study shows that achieving long-term decarbonization of meat production through cultured meat relies on the decarbonization of primary energy sources. Replacing traditional cattle systems before a widespread transition to renewable electricity could risk increasing GHG emissions. In the current model, the adoption and normalization of cultured meat at Western consumption levels might inadvertently support the growth of intensive livestock practices worldwide, potentially leading to overall increases in GHG emissions, with cultured meat products merely adding to the total.

Finance case studies

1. Fossil-free Churches

Innovation: Divestment

Intervention: Fossil fuel divestment by faith-based actors in the UK, Belgium, and Sweden

Fossil-free Churches examines divestment as a financial instrument to foster decarbonization. Church investments as a whole are not very large. But for a long time, churches have led the charge in filtering out specific investments that they believe conflict with their values, with a history of ethical investment that dates to the 19th century. The case study highlights the use of moral arguments (often rooted in theology) to argue the need for climate action among investors. Because of the governance structure of

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churches, clergy and members have a fair amount of say over the investments made with the funds (endowments, pensions) of the churches. Churches are leading the way in experimenting with engagement and divestment methods with high-carbon firms and sectors.

2. Triodos

Innovation: Ethical banking

Intervention: Triodos Organic Growth Fund

The Triodos case study examines how an ethical bank's Organic Growth Fund serves as a tool for financing green innovations. The Organic Growth Fund is one way the bank finances investments in green sectors, particularly businesses involved in agriculture. Two things currently limit the potential for decarbonization: (1) the ethical banking industry's relatively small scale; and (2) the industry's broader focus, which frequently does not prioritize decarbonization, especially outside the energy sector. The financial crisis, however, has had a good impact on ethical banks and has created opportunities for alternative methods.

Analysis

These case studies represent a mix of technical, social, and economic interventions across various industries, aiming to contribute to the decarbonization of key sectors. Each case study explores innovative approaches to reducing carbon emissions and transforming industry practices towards sustainability. The findings of the case studies can be analyzed as:

- REINVENT focuses on decarbonizing industries like steel, plastic, paper, meat, and dairy, identifying opportunities for reducing emissions that are not yet fully utilized.
- The project highlights the need for innovations to be replicated and integrated into economies, encompassing not only technological breakthroughs but also new sustainable lifestyles.
- It provides insights for policymakers, industry, and the scientific community, offering documentation, policy briefs, and a Decarbonization Portal for deeper engagement.
- REINVENT emphasizes imagining the future of production and consumption, exploring a wide range of decarbonization scenarios, and understanding the dynamics of resistance to change.

Methodology

The REINVENT project employs a multifaceted approach to explore the decarbonization of industry sectors. It integrates extensive research across value chains of steel, plastic, paper, meat, and dairy to identify unrealized opportunities for decarbonization. The project emphasizes the replication and embedding of innovations into economies, not limited to technological breakthroughs but also encompassing new ways of living a zero-emissions life. By scrutinizing a broad ensemble of decarbonization scenarios, including both technological and non-technological solutions, REINVENT develops modelling approaches that account for shifting demand and circular economy trends. It investigates the potential of technological innovations beyond their feasibility, examining their political, financial, and cultural futures. Additionally, the project seeks to understand resistance to change and harness the power of movements to facilitate the transition towards a zero-carbon Europe.

The methodological approach for the case studies incorporated both primary and secondary methods. Primary research was conducted through semi-structured interviews with experts and participation in

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field trips and workshops. Secondary research involved a comprehensive review of scientific literature and grey literature sources.

(1) Expert interviews

Each case study team aimed to conduct 8-10 expert interviews per case. While some case studies exceeded this target, others did not meet it due to various challenges. In some instances, limited access to interview subjects was offset by abundant alternative data sources, such as grey literature, allowing for a thorough analysis. Conversely, some case studies were discontinued or substituted due to insufficient data availability. There were also cases that benefited from conducting more than the targeted number of interviews. Overall, it is assumed that a sufficient number of interviews were conducted to capture all relevant aspects of each case study. In total, 135 interviews were completed across 18 case studies, averaging about 8 interviews per case.

(2) Site visits

The methodological protocol also required each case study to aim for two site visits. These site visits varied depending on the case, including trips to company offices and factories, attending industry conferences and workshops, observing debates, and visiting relevant locations such as regulatory offices or competing production sites. On average, the target of two site visits per case was achieved. However, like the interviews, this average results from some cases exceeding the target and others not meeting it. Various reasons account for this variation. In some instances, site visits were deemed unnecessary because key individuals from the locations had already been interviewed remotely, and an in-person visit was unlikely to provide additional valuable information. In other cases, the cost of site visits outweighed the potential benefits. Conversely, some cases facilitated more than two visits due to conveniently located sites or conferences that would have been attended anyway.

Modelling frameworks

Through the case studies, stakeholder dialogues, joint workshops, the REINVENT project has developed decarbonization pathways for industry. These prospective systems have been assessed with two different modelling frameworks: a top-down integrated assessment model (IMAGE) and a bottom-up regional systems model (WISEE-EDM).

The IMAGE modelling framework is designed to analyze the trajectory of global environmental changes, particularly focusing on climate and land use. Key inputs for this system include assumptions about population growth and economic development. The IMAGE-TIMER model within this framework simulates long-term energy scenarios and climate change mitigation strategies by modelling investments in and utilization of various energy technologies, which are influenced by technological advancements (learning-by-doing) and resource availability. This model relies on macroeconomic scenarios and assumptions regarding technology progression, preferences, and fuel trade restrictions. For food and agriculture, the IMAGE framework integrates projections from the computable general equilibrium MAGNET model. This model, in coordination with the main IMAGE framework, forecasts change in food production and trade for a wide range of crops and animal products.

The WISEE model developed by the Wuppertal Institute is a bottom-up energy system model that focuses on representing production technologies within value chains interconnected through product, energy, and resource flows. It provides a highly detailed depiction of energy system technologies and features a low degree of endogenization, allowing many parameters to be adjusted based on stakeholder

This project has received funding from the European Union's Horizon Europe research and innovation programme under the grant agreement No 101112305.

input. Instead of identifying the optimal pathway to achieve specific targets, the WISEE model emphasizes uncovering existing potential for energy efficiency and GHG mitigation. Additionally, the model includes a comprehensive representation of the manufacturing sector.

10. NAVIGATE Next generation of AdVanced InteGrated Assessment modelling to support climaTE policy making

Grant agreement No. 821124
Website: https://www.navigate-h2020.eu/

The project aims to advance Integrated Assessment Models (IAMs) capability in two directions. First, it will improve the representation of transformative structural and technological change in the economy and different sectors as industry and land-use and analyze changes in lifestyle and consumption and their implications. Secondly, it will depict the distributional implications of climate policies, the impacts of climate change and the benefits of mitigation and adaptation strategies in terms of avoided damages and reduced inequality. The project aims to offer new knowledge to effectively support international climate policy processes like the global stocktake in 2023 and related EU climate policy discussions.

The objectives of the NAVIGATE project are:

- To develop advanced integrated assessment models (IAMs) for supporting climate policy making.
- To describe transformative changes in the economy, technology, and consumer goods and services.
- To assess the distributional impacts of climate change and climate policy.
- To increase the usability, transparency, legitimacy, and uptake of IAM results by engaging with stakeholders and improving communication tools.
- To facilitate capacity building to lower the entry barrier to IAM activities for researchers worldwide.

These objectives aim to address weaknesses in current IAMs and provide new insights for translating long-term climate goals into short-term policy actions.

Work Packages

Work Package 1: Stock taking, stakeholder dialogue and capacity building for developing and using IAMs

Work Package 2: Transformative structural and technological change and climate change mitigation

Work Package 3: Fundamental transformation of consumer services in the context of deep decarbonization

Work Package 4: Spatial and social heterogeneity in integrated assessment modelling

Work Package 5: Impacts, co-benefits and links with other SDGs

Work Package 6: Synthesis, Dissemination and Exploitation of Results

This project has received funding from the European Union's Horizon Europe research and innovation programme under the grant agreement No 101112305.

Case studies

The case studies reveal the following findings:

- The project underscores the urgency of implementing advanced mitigation strategies. It identifies critical areas where policy interventions can lead to significant emissions reductions. For instance, the energy sector can transition to renewable sources, the industry sector can adopt cleaner technologies, and land use can be optimized for carbon sequestration. These actions are essential for achieving the ambitious targets set by the Paris Agreement.
- NAVIGATE's findings reveal that climate mitigation efforts can have positive synergies with other sustainable development goals. For example, transitioning to renewable energy not only reduces greenhouse gas emissions but also improves air quality and public health. Similarly, sustainable land management can enhance food security while also storing carbon.
- The role of individuals and communities is highlighted in the transition to net zero emissions. Changes in consumer behavior, such as reduced energy consumption, increased use of public transportation, and adoption of energy-efficient appliances, can collectively make a substantial impact. The project suggests that policies encouraging these behaviors can be as crucial as technological advancements.
- The findings emphasize the need for deep structural changes within production sectors to limit global warming to 1.5°C. This involves a shift towards high levels of electrification, widespread use of renewable energy sources, and the implementation of carbon capture and storage technologies. The project suggests that these changes require not only technological innovation but also supportive policies and investments.

In summary, the NAVIGATE project calls for immediate and coordinated efforts across various sectors and levels of society to ensure a fair and efficient transition.

Methodology

The NAVIGATE consortium curated a diverse selection of globally renowned cutting-edge instruments to ensure successful implementation of the project. They include:

- sophisticated integrated assessment modelling tools,
- detailed state-of-the-art sector models,
- other tools concerned with input-output modelling, socio-technical transition modelling, stochastic general equilibrium modelling, and country-level downscaling,
- extensive datasets such as the ISIMIP dataset of climate and biophysical impact projections for use as background in the project.

For section we will detail the first three, the IAMs, sector models, and other tools, used in NAVIGATE.

Integrated Assessment Models used in NAVIGATE

REMIND-MAGPIE (PIK) – see COACH methodology section.

MESSAGEIX-GLOBIOM (IIASA) – see OpenENTRANCE methodology section.

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IMAGE – see REINVENT methodology section.

WITCH - see COACH methodology section.

IMACLIM-R WORLD (CIRED) – with global coverage, ~~it~~ integrates sectoral and macroeconomic analysis with a focus on the energy and economic systems. The model's purpose is to investigate long-term scenarios of economic growth and energy transition while accounting for changes in technology, changes in policy, and constraints imposed by the environment. It facilitates the evaluation of the effects of various policy initiatives on emissions, energy consumption, and international economic performance (Ghersi, 2015).

TIAM-UCL – see PARIS REINFORCE methodology section.

The GEM-E3 model is a multi-sectoral dynamic computable general equilibrium model comprehensive of the global economy, which represents multiple regions and sectors linked through bilateral trade. It covers interlinkages between productive sectors, consumption, price formation of commodities, labor and capital, trade, and investment. The model formulates the supply and demand behavior of economic agents, allowing for quantifying the socio-economic impacts of policies under the assumption that the economic system remains in general equilibrium. GEM-E3 includes a detailed representation of energy system and technologies, whilst conventional computable general equilibrium models are based in more restrictive functional forms. This model, however, has also limitations, such as its restricted capacity to deal with new unexpected geopolitical conditions which may affect decarbonization in the EU, and the assumptions on the efficient functioning of the markets (Joint Research Center European Commission , n.d.).

PRIMES (E3M) - It is intended to replicate European energy markets and systems. Electricity, transportation, manufacturing, and residential sectors are just a few of the sectors across which the model accounts for energy supply, demand, prices, and investments. PRIMES enables the examination of the effects on energy consumption, emissions, and economic performance of various energy and environmental policies, technological developments, and market dynamics (PRIMES, n.d.).

E3ME - see PARIS REINFORCE methodology section.

BLUES (Brazilian Land Use and Energy System) (COPPETEC) - focuses on the interaction between land use and energy systems in Brazil. It examines how different laws and technical developments affect the creation of energy, land use, and greenhouse gas emissions. BLUES aids in the investigation of sustainable development scenarios by taking into account the equilibrium between the growth of agriculture, deforestation, the production of bioenergy, and other land use dynamics. The model aids in the design of policy by highlighting the long-term effects of different strategies to accomplishing Brazil's environmental and climate change objectives (BLUES – Brazilian Land Use and Energy System, 2020).

COFFEE (COmputable Framework for Energy and the Environment) (COPPETEC) - Its main objective is to assess how environmental and energy policies affect greenhouse gas emissions, energy output, and economic growth. The model is used to inform policy decisions about energy transitions, climate change mitigation, and sustainable development, particularly in the context of Brazil. Through the integration of intricate models of the energy system, land use, and climatic interactions, COFFEE offers insights into the possible outcomes of different approaches to mitigation and adaptation (COFFEE – COmputable Framework For Energy and the Environment model, 2020).

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TEA (Times Energy Analysis) (COPPETEC) - It makes use of the TIMES (The Integrated MARKAL-EFOM System) framework to model the energy supply and demand in different sectors and regions. It covers land use, buildings, transport, energy, industry and offers global coverage.

IAMC/BRIAM (NCSC) - It studies at how land use, greenhouse gas emissions, and energy production interact in the context of Brazil. BRIAM incorporates comprehensive sectoral models to assess how different policy initiatives and technological advancements affect the objectives of sustainable development.

DICE - see PARIS REINFORCE methodology section.

RESPONSE (CES) - it incorporates comprehensive data on energy production, consumption, technology developments, and policy initiatives to examine scenarios for lowering greenhouse gas emissions and accomplishing sustainability goals.

Sector Models used in NAVIGATE

ALBIO-N (CHALMERS) - It is a detailed physical model that explains the motions of nitrogen and biomass in crop and livestock systems. It is employed to denote dietary shifts away from meat and toward plant-based protein sources. It offers global coverage.

COCHIN-TIMES/ MOCHO-TIMES (CHALMERS) – offering coverage for the US and Denmark, it is a consumer vehicle/mode choice model for transportation. It is utilized to expand the capabilities of IAMs in expressing customer investment decisions in advanced automobiles and determining new transportation services as well as alternate means of transportation.

PRIMES INTERNATIONAL SHIPPING/TREMOV/BUILDINGS (E3M) – see section above. The TREMOV model is the techno-economic model of the transport sector.

GLOTRAM (UCL) – It is the techno-economic model of the global marine shipping system.

AIM (UCL) – It is an integrated assessment model of the global air transportation system.

BRAIN-ENERGY (UCL) – It is an agent-based model (incumbents, new entrants, regulators, government) of the electricity system. It covers Germany, Italy, and the UK.

Other tools

PECE (NCSC) – is an energy system model focusing on China. It is a bottom-up model that selects technologies and minimizes total costs through factors such as availability of energy and service demands in a non-linear optimization framework.

FEMRIO_ EXIOFUTURE/ THEMIS (NTNU)- It is used in demand-side transformation analysis and global evaluation of structural change. It is a multi-regional model and is based on exogenous scenario assumptions about technological advancement and economic growth. It is helpful in estimating the indirect effects of these changes on the environment and society.

MEWA/VESPA (WISE EUROPA) – MEWA offers Global/European coverage while VESPA focuses on the national/regional level. They are both dynamic stochastic general equilibrium model with an extensive representation of emissions, the energy industry, and endogenous technological development.

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SIAMESE (CA)- The purpose of SIAMESE is to downscale the output of the regional IAM energy system to the national and subnational levels. Its findings can be evaluated with bottom-up, sector-based methods for determining national decarbonization pathways.

BLUE (UCL) – it is a a system dynamic model that employs a multi-level approach on sustainability transition to model future energy transitions and the associated changes to technologies, energy use and emissions.

EXPANSE (UNIGE) - It is a bottom-up energy system model that addresses the processes of socio-technical transformation. It is employed to look at the possibilities and methods of capturing socio-technical variables in mitigation pathways.

11. GREEN-WIN - Green growth and win-win solutions for sustainable climate action (GREEN-WIN)

Grant agreement No. 642018
Website: https://www.green-win-project.eu/

The GREEN-WIN project represents a significant international collaboration in transdisciplinary research, adopting a solution-oriented approach to enhance the comprehension of the connections between climate action and sustainability. Its primary aim is to overcome implementation hurdles by employing win-win strategies. The project critically evaluates the efficacy of win-win and specifically green growth strategies in real-world scenarios, while also acknowledging the inevitable trade-offs that may arise. Focused on four key barriers identified by practitioners and policymakers, the project engages in ongoing international dialogue involving stakeholders from various sectors, including policy, research, civil society, and the private sector. Additionally, it employs an open knowledge management and capacity-building strategy to facilitate knowledge dissemination and learning beyond the project's duration.

Work packages:

Work Package 1 - Science & Technology Dialogue and Synthesis

Work Package 1 guides and situates all the other project work-packages in a common dialogic framework. It contributes to a behavioral transition towards climate action by developing a set of transformative narratives on the opportunities of linking climate action and economic development.

Work Package 2- Climate Finance Governance

Work Package 2 explored some of the key financial barriers and opportunities to activate and scale up climate finance. It examines the structural issues underpinning the orientation of public, “institutional” and more traditional forms of market finance. This WP also addresses what factors bias finance towards short-termism. It then considers developments in governance and policy packages that could help reorient finance from less to more sustainable investments.

Work Package 3- Macroeconomic Analysis

Work Package 3 analyses the behavioral transition towards a green economy by providing an assessment of the enabling conditions, dynamics, and macroeconomic impacts of the innovation and diffusion of low-carbon and adaptation technologies.

This project has received funding from the European Union’s Horizon Europe research and innovation programme under the grant agreement No 101112305.

Work Package 4 - Business Models for Local Transformations

Work Package 4 contributes to the behavioral transition towards a green economy by guiding and assisting WP 5-7 in identifying local to regional adaptation and mitigation strategies as well as business models, investment opportunities and incentive structures that support these strategies.

Work Package 5 - Coastal Flood Risk Management

Work Package 5 implemented case studies on coastal flood risk management (CFRM). The objective of the work package is to identify win-win strategies, sustainable business models and enabling environments that contribute to flood risk reduction and link adaptation with sustainable development goals.

Work Package 6 - Transformation in Urban Systems

Work Package 6 analyses and contributes to the behavioral transition by examining urban transformations from an integrated and systemic perspective, relating specific transformations to the sustainable development goals, and assessing the implementation potential of win-win and green growth strategies at local and city levels. This will be investigated in four case studies, namely Istanbul, Shanghai, Barcelona and Venice.

Work Package 7 - Energy Poverty Eradication

The overall goal of Work Package 7is to identify, assess and support exemplary cases of integrated strategies leading to win-win solutions, new business models and enabling environments for sustainable climate action, with a focus at the community level. It provides examples and evidence to support a Global Dialogue on green economy and other GREEN-WIN Work Packages, including insights on how to leverage private investments, support capacity building, knowledge transfer and learning in the area of energy poverty alleviation and resilient livelihoods. The core case studies under WP 7 include India, Indonesia, South Africa.

Work Package 8 – Knowledge Management and Dissemination

Work Package 8 is focused on supporting a behavioral transition towards a green economy and climate resiliency by implementing an open-knowledge system to support interaction and sharing, accelerate learning, and build capacity around the research generated through the GREEN-WIN project.

Case studies

The case studies aimed at identifying win-win strategies, sustainable business models and enabling environments in three action fields of coastal zone flood risk management, urban transformations and energy poverty eradication and resilience.

Coastal Flood Risk Management

The research in WP 5 focuses on coastal flood risk management, addressing the challenges of insufficient investment and the need for innovative financing strategies.

Coastal regions confront escalating flood hazards attributed to rising sea levels, expanding populations, and urban development. However, the deployment of protective measures to adapt to these coastal challenges has been slow-paced, leaving numerous communities exposed and vulnerable. Despite the acknowledgment of coastal adaptation as a governmental obligation, inadequate funding persists, especially in developing countries where tight fiscal limitations and conflicting developmental agendas prevail.

Through case studies and analyses of institutional frameworks in Germany, Australia, the UK, and The Netherlands, several observations and recommendations have been made:

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1. Coastal adaptation investment improves social welfare, especially in economically active or densely populated areas, but high upfront costs pose barriers for local-level entities with limited budgets.
2. Financial constraints can be alleviated by leveraging public resources through mechanisms that connect to project co-benefits, attract co-funding, or enable externalization of costs to private actors. Long-term contracts with the private sector can enhance project efficiency.
3. Projects involving land reclamation or real estate development offer opportunities to generate revenue through land or real estate sales or leases.
4. Nature-based flood defenses can leverage public investments by generating co-benefits such as improved environmental quality, leading to increased recreational opportunities and property values.
5. Long-term contracts with the private sector can improve operational efficiency and reduce costs for the public actor, but they require enhanced procurement and contracting skills.
6. Adjustments in national financial arrangements may be necessary to ensure revenues from co-benefits are reinvested in coastal adaptation. The specifics of these adjustments may vary across countries and regions.

Overall, the research emphasizes the importance of innovative financing mechanisms and institutional arrangements to enhance coastal adaptation efforts and address the growing flood risks faced by coastal areas.

Urban Transformations

In WP 6, urban transformations were assessed by examining the potential of win-win strategies and green business models at the city level and their impact on urban sustainability, integrating these efforts with the Sustainable Development Goals (SDGs). The analysis focused on understanding the enabling environment for these strategies and models, considering dimensions such as vision, cultural-cognitive, policy-regulatory, organizational, and economic factors. A 3-Co helix mechanism (co-creation, co-evolution, and co-governance) was proposed to elucidate the city-green-business transformation process.

Policy recommendations include:

- Empowering value co-creation by recognizing and incorporating emerging socio-economic relations,
- Triggering and sustaining co-evolution by aligning policies with long-term sustainability visions, and
- Facilitating co-governance by engaging with stakeholders and creatively exploring their roles and responsibilities.

Energy Poverty Eradication and Resilient Livelihoods

In WP 7 the focus is on energy poverty eradication and climate-resilient livelihoods in India, Indonesia, and South Africa. The research examines the conditions, constraints, and opportunities for designing and implementing win-win solutions (WWS) and green business models (GBM) to benefit vulnerable populations. Emphasis is placed on “micro win-win solutions” that yield short-term economic, climate, and sustainability gains at the community and household levels.

Findings indicate that WWS and GBMs often emerge in distributed ways but are linked to various capacities, including organizational, cognitive, and collaborative capacities developed through transnational learning networks. These networks facilitate the development of green services, local markets, cooperation, and knowledge transfer.

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Despite identified barriers, several supporting measures can be implemented quickly to accelerate the deployment of win-win solutions in rural and poor contexts.

Recommendations include:

1. Focus on empowering agents and enable them 'to be the solution'
2. Do not expect perfect solutions: focus on capacities for the emergence of solutions rather than anticipate concrete results
3. Innovative financial schemes and incentives
4. Promote new forms of business models which take more responsible forms of ownership, risk and profit sharing
5. Promote co-designed solutions and experimentation at the local level while considering fast-changing market and technological conditions
6. Identify the most conducive regulatory and governance environments at local level

Analysis

This project highlights the challenges of insufficient investment and the need for innovative financing strategies, as well as the importance of balanced results and shared benefits. Limitations and difficulties faced by local entities (e.g. financial) can be solved by cooperation and financial innovation (e.g. co-funding and private funding). Innovative financing mechanisms and institutional arrangements are crucial for the mitigation of climate change effects with more efficient economic management. As usual, cooperation and stakeholder involvement are crucial, in this case inspired by the "3-Co helix mechanism":

- co-creation (recognizing and incorporating emerging socio-economic relations)
- co-evolution (aligning policies with long-term sustainability visions)
- co-governance (engaging with stakeholders and creatively exploring their roles and responsibilities)

This approach emphasizes actions like nurturing social capital, providing regulatory support, and avoiding reactive solutions to ensure the efficacy, resilience, and sustainability of urban transformations. In general, the measures and guidelines suggested share a focus on fostering innovation and collaboration to address challenges effectively. They emphasize empowering individuals and communities, promoting experimentation and adaptation, incentivizing innovation through financial schemes, encouraging responsible business practices, and identifying supportive regulatory and governance frameworks at the local level.

Methodology

Coastal Flood Risk Management

The methods used include document analysis, semi-structured interviews with key stakeholders, and a stakeholder workshop to gather insights into coastal adaptation projects focusing on natural-based flood defenses (NBFDs). These methods facilitated the collection of data and information necessary for describing the cases, understanding mechanisms, motivations, and capturing stakeholder perspectives.

1. Document Analysis and Data Pooling: Researchers analyzed documents such as feasibility studies, reports, and contracts related to the selected cases to gather information on costs, financial arrangements, benefits, and project implementation.
2. Semi-Structured Interviews: Researchers conducted semi-structured interviews with key stakeholders involved in the design and implementation of the cases. These interviews aimed to gather descriptive information on project goals, implementation processes, costs, benefits, and value capture.

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3. Stakeholder Workshop: A stakeholder workshop was organized to gather experiences and perspectives on value capture in coastal adaptation projects. This interactive session likely involved discussions and exchange of views among stakeholders to enrich the understanding of key factors influencing mechanisms and motivations.

Urban Transformations

Each case study utilized a combination of workshops, interviews, surveys, and fieldwork to gather data and insights relevant to their specific research objectives. These methods allowed for a comprehensive understanding of the social-ecological dynamics and potential win-win strategies for sustainable development within each context.

Shanghai Case Study:

- Stakeholder Workshops: Two workshops were held in Shanghai and Oxford, gathering sharing economy practitioners and academics to discuss urban transformation towards sustainability.
- Interviews and Surveys: Over 200 stakeholder interviews, 100 cultural-cognitive surveys, and 700 behavioral surveys were conducted with sharing mobility companies, research communities, and user groups.

Istanbul Case Study:

- Interviews and Surveys: Interviews, participant and non-participant observation, cultural-cognitive, and green-business model surveys were conducted.
- Stakeholder Workshops: Two workshops were organized to identify win-win strategies within seismic-risk driven urban renewal projects.

Barcelona Case Study:

- Stakeholder Workshops: Two workshops were carried out to engage researchers and stakeholders in knowledge co-production and to assess win-win solutions.
- Platform Creation: An open platform was created to support knowledge crowdsourcing and collaboration for win-win solutions.

Venice Case Study:

- Ethnographic Methodology: Ethnographic methodology was employed, including contextual scans, interviews, participant observation, and archival analysis.
- Fieldwork: Fieldwork was conducted in Venice's Lagoon and outside Venice to explore local narratives and mindsets about sustainability.

Energy Poverty Eradication and Resilient Livelihoods

Their research has used a variety of methods besides literature review and analysis of relevant secondary documents; interviews and field trips to the selected locations were carried out in all the selected cases, as well as direct action-research by creating a new green SME to support resilient livelihoods and provide biogas energy in Indonesia. The cases reported here come from distinct poor rural or peri-urban contexts in South Africa, North India, and Indonesia.

Specific research methods:

- Literature Review and Secondary Document Analysis: The research began with a literature review and analysis of relevant secondary documents to establish background knowledge and context.

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- Interviews: Interviews were conducted with stakeholders and community members in all selected cases to gather firsthand insights and perspectives.
- Field Trips: Field trips were organized to selected locations in South Africa, North India, and Indonesia to observe conditions, gather data, and engage with local communities and stakeholders.
- Direct Action-Research: In Indonesia, direct action-research was conducted by creating a new green SME to support resilient livelihoods and provide biogas energy, involving practical implementation and testing of solutions.

Organized Workshops and Field Trips:

South Africa: One workshop in July 2017 with 28 participants, supported by another workshop in 2016 linked to the FLOW project. Field trips to Bergrivier Municipality and the informal settlement of Langrug in Western Cape.

India: Two workshops in April 2016 (71 participants) and April 2017 (38 participants). Field trips to the states of Madhya Pradesh and Bihar.

Indonesia: Three workshops in 2016 (53 participants), May 2017 (52 participants), and 2018 (71 participants). Field trips to Jembrana, Bali, to visit coffee and cacao farmers and their biogas digesters.

Data Collection and Analysis:

Continued Engagement and Interviews: Data was collected through continued engagement and interviews with green entrepreneurs and community members.

Analysis: Data collected was analyzed to specify different economic, climate, and sustainability wins, and then further analyzed based on literature review.

Systems Mapping: Systems mapping of solutions and involved actors was conducted, along with various action-research activities, including the development and testing of micro-technologies for biogas production in Indonesia.

Additional Insights:

Additional insights from GREEN-WIN supporting partners in Mexico and Brazil were collected during three annual Global Dialogue workshop sessions conducted by WP 1.

These comprehensive methods allowed for a thorough investigation and understanding of the diverse contexts and solutions related to sustainable development and green entrepreneurship in rural and peri-urban areas across different regions.

12. JUST2CE – A Just Transition to Circular Economy (JUST2CE)

Grant agreement No. 101003491
Website: https://just2ce.eu/

The JUST2CE project is based on the assumption that a critical evaluation of the Circular Economy (CE) paradigm, its economic, societal, gender, and policy implications, and the outcomes of its implementation, has not yet been conducted. A direct consequence of this gap is the neglect of the political economy and geopolitics of transition in CE studies. European, and more generally global, productive systems are characterized by geographical specialization aimed at maximizing profits along traditionally designed linear supply chains. These often unequal and asymmetric relations might seriously hinder the transition to a CE. To date, no studies have shed light on how such relations should

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be reconfigured to achieve circularity. This represents an urgent and major research gap that will be addressed by this project, which will therefore provide useful insights to policymakers for evaluating the feasibility of the transition to the CE. JUST2CE aims to understand, in a critical and thoughtful way, under which conditions a responsible, inclusive, and socially just transition to a circular economy is possible and desirable, what technical, geopolitical, and social factors can enable or hamper such transformation, and how these aspects can contribute to the development of transitional policy measures.

Work packages:

Work Package 1 – Beyond The Current Ce Models and Practices: The objective of this work package was to review current Circular Economy (CE) applications at micro, meso, and macro levels, taking into account neglected dimensions such as geopolitics, employment, labor relations, and responsibility. The aim was also to map CE initiatives globally. WP 1 delivered three reports on labor, gender, and global environmental justice. Additionally, it developed a global atlas of just CE practices, which collected numerous cases of circular practices in Europe and Africa.

Work Package 2 – Enablers And Barriers to The Transition Towards a Ce: The focus of this work package was to develop a framework called the "technology of humility" for analyzing ten case studies across EU member states and African countries, aiming to understand the implementation of CE practices. WP 2 delivered ten case study reports that highlighted both enablers and barriers to achieving a just CE in Europe and Africa.

Work Package 3 – Towards A Framework for A Responsible Ce: This work package centered around Responsible Research and Innovation (RRI) training. It involved developing an RRI framework for designing CE practices, exploring potential transition scenarios, disseminating information on inclusive and deliberative methods, and creating RRI checkpoints for the Decision Support System (DSS) from WP 4.

Work Package 4 – An Integrated Decision Support System for Responsible Ce Practices: The goal of this work package was to develop an integrated tool that frames the CE paradigm around global environmental justice and gendered innovation. It achieved this by identifying environmental, social, and economic impact hotspots and suggesting ways to improve CE practices.

Work Package 5 – Policy Models for Evaluation and Planning of Ce Practices: The objective of WP 5 was to develop macroeconomic models for studying the effects of adopting CE practices at national and international levels. The aim was to create systemic policy decisions, incentives, and support mechanisms for the development of strategic governance, enabling the transition to a CE.

Work Package 6 – Dissemination And Knowledge Transfer

Work Package 7 – Project Management

Work Package 8 – Ethics Requirements

Case studies

The JUST2CE consortium conducted 10 case studies to explore practices enabling or hindering the transition to a Circular Economy (CE) and identified various unaddressed aspects such as governance, geopolitical factors, and social implications. These cases, conducted between October 2021 and February 2023, involved organizations at different stages of CE transition across Europe and African countries, focusing on diverse value chains, scales, and institutional settings. While the cases varied widely, they revealed a predominant technocentric view of CE, emphasizing industrial development, technological innovation, and economic growth over social and environmental concerns. Social justice was often narrowly equated with job creation, overlooking broader issues like equity, democratic participation, and the rights of marginalized groups.

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Geopolitical and neo-colonial patterns were evident, with waste often being sent to the Global South for recovery, while lacking resources for socially inclusive and sustainable CE initiatives. Western technological solutions dominated, neglecting traditional circular practices and philosophies in the Global South, which offer more culturally and ecologically aligned approaches. The growth-driven CE model observed in the cases could potentially exacerbate environmental impacts and perpetuate inequalities. A shift towards a degrowth-oriented CE, emphasizing sufficiency, redistribution, and localization, is proposed to mitigate these risks. Practical examples showcased alternative, grassroots-driven approaches, such as waste picker cooperatives in Morocco, regenerative agriculture in South Africa, and transition plans towards a fairer circular economy in Taranto, Italy. However, these initiatives remain marginal within the broader context of CE implementation. More support and research are needed to explore convivial, democratic, and bottom-up approaches, particularly in the Global South, to foster a more inclusive and sustainable transition to a circular economy.

Overall, the case studies underscore the necessity of incorporating social justice and political empowerment principles into Circular Economy (CE) initiatives, emphasizing the need for these principles to be more than mere add-ons or superficial considerations, such as mere checkbox exercises or job creation tallies. Instead, social justice concerns should be deeply ingrained in every aspect of circularity projects, policies, or strategies. This includes involving citizens and civil society organizations in the co-creation and co-design process, implementing initiatives democratically and inclusively, and continuously monitoring and evaluating them through participatory means. By prioritizing these principles, it is possible to facilitate a transition to a circular society that is socially equitable and inclusive, thereby mitigating existing socio-ecological disparities and power imbalances.

Analysis

There are a variety of frameworks to deal with climate emergencies and sustainability challenges. All of them have risks of bringing undesired consequences and trade-offs (economic, societal, gender, and policy implications, among others). The existing global economic structure already presents inherent barriers to achieve a fair transition, which are independent of the design of climate policies. Hence, the importance of achieving a responsible, inclusive, and socially just transition, which requires a deep and complex analysis of the reasons that may lead to failures in climate-related policymaking. Reflection requires listing which technical, geopolitical, and social factors can enable or hamper such transformation, and how these aspects can contribute to the development of transitional policy measures.

For the specific case of Circular Economy, challenges related to the diversity of value chains, scales, and institutional settings may arise, along with a technocentric view of this approach, prioritizing industrial development, technological innovation, and economic growth over social and environmental concerns. A key lesson for the design and inspiration of just transition policies is related to the growth-driven CE model observed in the cases, which could potentially exacerbate environmental impacts and perpetuate inequalities. Incorporating social justice and political empowerment principles needs to be done transversally and from the beginning of the intervention.

Methodology

In developing and conducting all 10 case studies, each team adhered to the methodological framework established by the JUST2CE project in November 2021 (*D2.1 Multidimensional Framework for the Case Studies*). This interdisciplinary sustainability framework integrates elements from various fields like feminist ecological economics, political ecology, environmental justice, science & technology studies, and decolonial studies. It aims to provide an ethical, conceptual, theoretical, and methodological lens for analyzing the sustainability implications of the case studies, encompassing issues of power, democracy, inequality, gender, class, race, health, ownership, ecosystems, planetary boundaries, resource limits, science, education, and technology. The framework, diverging from the initially proposed comparative approach, was shaped through workshops and interventions aimed at

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decolonizing the project's methodology, emphasizing reflexivity. This approach aimed to create a shared methodology sensitive to local knowledge and practices, rather than imposing a top-down, standardized vision.

While the consortium outlined a common analytical framework, each partner had the freedom to choose the methodological approach aligning with their expertise. However, to ensure commonality across the case studies, specific steps were identified:

a) Preparing for fieldwork: This involves gaining access to organizations and ensuring safety protocols for researchers and participants, particularly in potentially risky areas.

b) Stakeholders' identification: A systematic process to identify groups and individuals whose interests should be considered during the project.

c) Shaping interview protocol: Designing interviews and focus groups to explore case studies deeply, with emphasis on semi-structured interviews for in-depth accounts.

d) Data gathering & analysis: Piloting interviews, transcribing, and analyzing data through coding to identify emerging themes or issues.

e) Refinement & theoretical reflections: Continual reflection on findings, feedback to participants, and adaptation of the protocol based on new information.

f) Focus group organization & reporting: Using focus groups to share insights and foster community knowledge co-production, followed by comprehensive reporting on the protocol, problems encountered, and recommendations.

This structured approach ensures that the case studies in the JUST2CE project are conducted systematically, ethically, and with attention to local contexts, contributing to a more nuanced understanding of sustainability issues and potential solutions.

13. ASSET - A holistic and Scalable Solution for Research, Innovation, and Education in Energy Transition

Grant agreement No. 837854
Website: https://energytransition.academy/

ASSET has a twofold goal: first, to establish a sustainable and scalable ecosystem that includes all stakeholders in the energy transition and education sectors. This ecosystem will involve a) energy sector companies, b) universities and training institutions, c) authorities and policymakers, and d) society at large.

The objective is to enable a) the continuous creation of research, innovation, and educational (RIE) services from the bottom up and b) capacity pooling.

By "service," they mean any research, innovation, or educational service that can be developed by educational institutions and delivered to energy sector businesses and society. ASSET will also involve actors who can contribute to interdisciplinary research combining social sciences and humanities (SSH) disciplines, reaching out to society to create a new generation of energy-aware citizens who are part of the energy transition mission.

Additionally, ASSET aims to provide the framework and means for the continuous collaborative definition of the knowledge, competencies, and skills required for the energy transition and for continuous resource pooling to efficiently educate and train large numbers of people in diverse and

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interdisciplinary topics, as well as to carry out research and innovation activities. The ASSET approach will be implemented in three phases:

1. Ecosystem set-up: Relevant actors will be engaged to identify knowledge, skill, and competency gaps in the addressed fields to design appropriate RIE services to close these gaps.
2. RIE service development: educational actors, based on the identified knowledge, skill, and competency gaps and the results of ASSET SSH research, will define services (educational and research programs) that meet these needs.
3. Evaluation: ASSET will deliver the developed RIE services to targeted actors across EU universities, energy sector companies, and EU societies. Feedback will be collected to a) refine ASSET offerings and b) define concrete sustainability plans for ASSET.

Work Packages

Work Package 1: ASSET Ecosystem and Networking

Work Package 2: Energy Transition Skills Identification and Societal Challenges

Work Package 3: Energy transition programs preparation

Work Package 4: Programs delivery and piloting

Work Package 5: Dissemination, Communication and Sustainability

Case studies

The main research findings are as follows:

- The future of the energy transition is envisioned as small-scale, decentralized, democratic, inclusive, redistributive, and smart.
- Universities and public agencies are expected to lead and promote this vision.
- Traditional (hard/technological) skills remain important, social sciences and humanities are increasingly valued, and new interdisciplinary dialogues need to be fostered.
- While interdisciplinarity is highly valued, it presents both theoretical and practical challenges.
- Institutions need to learn how social networks function and how trust dynamics operate within their communities.
- Although gender is formally acknowledged as important, it is not effectively addressed as a priority within educational systems.

Analysis

Interdisciplinary approach and mixed methods are useful ways to understand, analyze and address the societal impact of climate policies. The combination of disciplines is necessary to incorporate a holistic view of the transitions at stake (*green/fair/energy*) and to foresee the social impacts of these transformations. Incorporating the educational system in this planning is crucial for the success of the implemented policies.

Methodology

The research was carried out using qualitative techniques. A survey involving stakeholders and experts at a European level was conducted to investigate two main focus areas: a) the policy frameworks of energy transitions, and b) green professions and educational needs. The qualitative method was based on comparative ethnographic accounts developed from case studies of energy transition experiences, the conduction of focus groups, and in-depth open interviews. These research techniques were designed considering the findings of the survey and addressed the following analytical focuses: energy transition "in action and practice"; values, knowledge, ethics, and social legitimation of energy transition.

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14. COMETS - Collective Action Models for the Energy Transition and Social Innovation

Grant agreement No. 837722
Website: http://www.comets-project.eu/

COMETS is a Horizon 2020 project focused on investigating Collective Action Initiatives (CAIs) as key drivers of social innovation in the energy sector. By examining and quantifying CAIs' contributions to the energy transition to renewable sources, COMETS aims to fill knowledge gaps at both national and European levels. The project studies the role of citizen-driven CAIs, such as energy communities and cooperatives, which have not been previously quantified or deeply understood.

The project has two main objectives:

1. To develop robust knowledge on social innovation processes in the energy transition by examining technical, institutional, economic, social, and cultural factors affecting CAIs. COMETS will provide new tools for assessing CAI performance and estimating their contribution to the energy transition.
2. To offer tools and recommendations for improving the start-up, management, and scaling-up of CAI activities. These tools will be co-designed with practitioners to create blueprints for future initiatives.

Work Packages

The COMETS work plan is divided into seven closely interconnected Work Packages (WPs). WP1 and WP7 span the entire project duration.

Work Package 1: Focuses global coordination and ensuring strong interaction among partners.

Work Package 2: Inventory of COMETS investigation

Work Package 3: Survey for COMETS investigation

Work Package 4: Participatory case studies

Work Package 5: Involves the co-design of scenarios and roadmaps for CAI development in the energy sector and includes investigating a few innovative frontier case studies. Active engagement of CAI members occurs in WP 4 and WP 5.

Work Package 6: Dedicated to ensuring the quality and coherence of COMETS methods and results.

Work Package 7: Responsible for implementing the Plan for Dissemination, Communication, and Exploitation (DCEP)

Case Studies

1. Citizen Participation and Engagement:

The level and form of citizen engagement varied across CAIs studied, influenced by factors like cooperative culture and project focus. Leadership participation was crucial, often needing support for training and guidance. Financial participation was common, with strategies involving personal networks, diverse communication channels, and government support. CAIs offered varied opportunities for member participation, often tied to project diversification and community connection. Skills and

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knowledge contribution from members was valued, though accessing expertise remained a challenge. Inclusivity, particularly regarding vulnerable groups and gender balance, was recognized but often lacked systematic approaches.

2. Organization and Governance:

CAIs varied in focus from energy-only cooperatives to those with broader aims. Energy cooperatives typically followed established governance models, while broader CAIs displayed more diverse structures. Collaboration among CAIs within regions was recommended, with support from umbrella organizations. Legal form transformation was considered to widen social engagement and promote renewable energy communities.

3. Market, Business Models, and Funding:

CAIs relied on a mix of public incentives, private finance, and member shares for funding. Public financial incentives and startup grants were common, but mature CAIs faced challenges in accessing continued support. Private financing and bank loans remained difficult to secure, with CAIs often selling shares to fund projects. Competition from commercial actors posed threats, emphasizing the need for innovative financing models and social acceptance.

4. External Actors and Institutions:

Engagement with stakeholders varied, with CAIs balancing independence and cooperation. Regional networks and government support were beneficial, particularly in startup phases. Relationships with private actors and regulatory entities required careful navigation to maintain CAI values and goals.

5. Regulation and Policies:

Regulatory factors influenced CAI development, with enabling factors including supportive laws and financial incentives. Constraints included the phase-out of subsidies and bureaucratic hurdles. Recommendations focused on policy support for citizen participation and access to renewable energy knowledge.

6. Growth and Scaling Up:

CAIs approached growth pragmatically, balancing short-term operations with long-term strategy. Collaboration among CAIs was essential for expansion and diversification, focusing on shared projects and local cooperation. However, barriers like lack of specialized knowledge hindered scaling efforts.

7. Impacts:

Changing policies and social perceptions impacted CAIs, emphasizing the need for evaluation tools to quantify their impact on the energy transition. CAIs were seen as transformative in empowering communities and promoting participatory democracy, but their full impact required clearer assessment methods and increased awareness.

Analysis

This project highlights the importance of taking into account the citizenry into policymaking, by incorporating bottom-up strategies, collective intelligence and solution design beyond the conventional expert and technical know-how. Trusting the effectiveness of CAI initiatives requires investing in methodologies that collect data from a broad population and allow for a complex diagnosis with a wide perspective. The project also describes the advantages of implementing collaborative methodologies to identify best practices and considering the collective decision-making throughout all the research phases (research questions, methods, and interpretation of results).

Methodology

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For the survey analysis:

- The methodology involved two stages: preparing the survey dataset and creating a synthetic dataset for profiling Community Action Initiatives (CAIs).
- Data preparation included assessing quality and coding for consistency.
- Questions were grouped into four dimensions: Dynamics of Creation, Organizational Structure, Financing, and CAIs' Activities, with a focus on citizen participation.
- A detailed analysis refined these dimensions into seven for better synthesis.
- Variables were merged to profile CAIs for in-depth case studies.

For the comparative case studies:

- A Consortium Benchmarking (CB) strategy was used to understand CAIs in different national contexts and engage them in the research process.
- CB focuses on identifying best practices collaboratively.
- All participants are co-researchers, with research being a team effort using various sources.
- The process involves collective decision-making on research questions, methods, and interpretation of results.
- CAIs are actively engaged, fostering shared learning, and coordinated action.
- The procedure includes four phases: preparation, Kick-off, visits, and lessons learned.

15. TRANSrisk - Transitions pathways and risk analysis for climate change mitigation and adaption strategies

Grant agreement No. 642260
Website: https://cordis.europa.eu/project/id/642260

(The project website was not available which limited the information available.)

The project TRANSrisk aims to address the challenges associated with climate change mitigation by creating a novel assessment framework. This framework integrates established models for analyzing the costs of low-carbon pathways with interdisciplinary approaches, including risk assessments.

TRANSrisk has two primary objectives: first, to assess low emission transition pathways that are both technically and economically feasible, as well as socially and environmentally acceptable; second, to bring together quantitative models and qualitative approaches, particularly through participatory consultations with stakeholders. Additionally, the project aims to design a decision support tool to assist policymakers in better understanding uncertainties and risks, enabling them to incorporate risk assessments into more robust policy design. Overall, TRANSrisk seeks to provide comprehensive insights into the costs, benefits, risks, and uncertainties associated with different mitigation pathways to inform effective climate policy decision-making.

For TRANSrisk the project website was not available, therefore the information below has been gathered through the CORDIS website.

Work packages: NOT AVAILABLE

Case studies

The core of the TRANSrisk project is 14 country case studies; each one examines specific technologies in different country contexts. In addition to their value as individual pieces of work, the case studies have fed into TRANSrisk's overall investigation of risk and uncertainty in low carbon transitions. They have also acted as testbeds for the policy development tools and techniques pioneered by the project.

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TRANSrisk deliberately selected a diverse range of case studies from across the world: from Europe and North America to the fast-growing economies of Asia, Africa and South America. Case studies were divided into 'full' and 'limited' categories depending on the resources applied to them. In practice the boundary between the two categories has become somewhat blurred, with several limited studies providing a more detailed study than originally envisaged.

Case study 1 Austria: Decarbonizing the Iron & Steel and Electricity Supply Sector

Austria must reduce emissions substantially after 2030 in order to reach the EU's decarbonization targets by 2050. The iron and steel industry needs to make significant cuts, as does the electricity supply. The goal of this study is to transition these industries to reduced emissions by analyzing transition pathways, risks, and uncertainties and including a wide range of stakeholders.

Methods: A transdisciplinary approach was used. Qualitative methods included bilateral calls, semi-structured interviews, surveys, and workshops. The WEGDYN CGE model was employed to assess the economy-wide effects of these interventions.

Results: Important conclusions showed that implementation risks, with examples including inadequate cross-sectoral policy integration and a weak long-term policy framework are more common than consequential risks. Deep decarbonization scenarios may result in a minor decline in GDP growth and unemployment rates, but these trends usually stabilize with time. Technological lock-ins, disputes over social justice, and unstable grids are further risks.

Case study 2 Canada: Oil Sands

Alberta, Canada is the highest-emitting province, largely due to its oil sands, which contain significant crude bitumen reserves. Because the extraction of oil sands is linked to significant greenhouse gas emissions and environmental effects, the industry is investigating novel solutions to lower emissions. This case study focuses on how Alberta's production of oil sands affects the environment, the economy, and society, considering the concerns of oil developers and First Nations people.

Methods: The study involved developing narrative pathways through two stages: pathway development and risk elicitation. Public sentiment on climate policies and low-carbon futures was gathered from media, government, industry, and NGO sources. Information was also collected from Statistics Canada.

Results: Three low-carbon pathways came to light: one from the provincial government, one founded on the concerns of Indigenous people, and one collaborative approach in line with federal regulations. Economic losses, environmental deterioration, social unrest, and health effects were among the main risks. Lack of Consensus among stakeholders was a significant obstacle. Indigenous communities, most affected by oil sands development, were underrepresented in decision-making processes. A consensus-building framework (CBEP) is recommended by the study to guarantee inclusive policy making that takes Indigenous objectives and knowledge into account.

Case study 3 Chile: Renewable Energy and Energy Poverty

To support global climate efforts and meet the social, environmental, and economic needs of its population, Chile must meet its rising energy consumption. By increasing the efficiency of energy generation and investigating solutions to lower greenhouse gas emissions, the government hopes to improve resource usage.

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Methods: Two models were used in the study: a cost-minimizing electricity model and a dynamic stochastic general equilibrium model that represented Chile's economy with a simplified energy sector.

Results: The results show that a carbon price would have a detrimental effect on households at risk of energy poverty by increasing their energy bills. However, these consequences might be lessened by compensatory measures like electricity bill subsidies. This strategy would mitigate some negative effects while having a minimal fiscal impact, enabling the government to retain a substantial portion of the carbon tax revenue.

Case study 4 China: Green Building

The transition pathway for China focuses on urban residential buildings, a sector with complex energy consumption due to diverse housing types, household demographics, climate variations, and socio-economic factors like the rental market and cultural practices.

Methods: The study employed qualitative methods, including stakeholder analysis (workshops and interviews) and policy document analysis.

Results: The pathway identified highlights the policies in place to support renewable energy in green buildings and boost energy efficiency; these policies are in line with China's urbanization plans and energy policies. The implementation risks that different stakeholder—including government officials, construction companies, locals, and experts—identified differed. Policies, technological innovation, funding, and energy use patterns were shown to be the main sources of risk. The absence of operational guidelines for green buildings and financial incentives for renewable energy were major issues.

Case study 5 Greece: Solar Power, Buildings and Micro-Generation & Storage

This case study investigates policy strategies for meeting near-term energy efficiency targets in Greece.

Methods: This study used a multi-criteria group decision-making methodology and stakeholder engagement to explore policy strategies for meeting near-term energy efficiency targets. Stakeholders from the Ministry of Environment and Energy and other sectors were involved through workshops, interviews, and risk assessments. The study also included quantitative modelling with tools such as TEEM-BSAM, TEEM-ATOM, and TEEM-DREEM to simulate market and policy impacts.

Results:

1. Energy Efficiency in the Near- and Long-term:

- Near-term risks include adverse market conditions, bureaucratic challenges, and misalignment between municipal and central government priorities.
- Long-term risks encompass political inertia, complex regulations, financial constraints, and potential social issues like increased tariff deficits and poverty.
- Portfolio analysis suggests that the current budget and technical constraints make it difficult to meet energy savings targets without additional private sector funding or more robust measures.
- Effective policies identified include financial programs for residential energy upgrades, energy efficiency actions in SMEs, and appointing energy managers in public buildings.

2. Diffusion of PV, Micro-generation, and Storage:

This project has received funding from the European Union's Horizon Europe research and innovation programme under the grant agreement No 101112305.

- R&D is crucial for further PV and storage deployment, though economic barriers remain significant.
- Self-consumption of electricity can reduce peak demand and transmission losses but may increase costs for non-participants.
- Bureaucracy is a significant barrier to building renovation and electricity network modification policies.
- Current Net-Metering schemes drive PV investments, but residential storage support is less effective.
- Increasing self-consumption needs broader system considerations and fair benefit distribution between consumers and energy retailers.

Overall, the study highlights the importance of tailored, inclusive policies and stakeholder engagement to achieve energy efficiency and low-carbon transitions in Greece.

Case study 6 India: Solar & Wind Power

India's electricity sector significantly contributes to national emissions, accounting for 38%. With 70% of electricity generated from fossil fuels, the country aims to reduce its emission intensity by 33-35% below 2005 levels by 2030, as outlined in its Nationally Determined Contribution (NDC) under the Paris Agreement.

Methods: The study used a combination of policy review, modelling (CGE and econometrics), and stakeholder consultations. Policies, plans, and budgets at national and sub-national levels were analyzed. Two scenarios—a baseline and an ambitious one based on government priorities—were constructed. Macroeconomic impacts were assessed using the WEGDYN CGE model and the E3ME econometric model, supplemented by stakeholder consultations with academics, consultants, technology developers, and policymakers.

Results: By 2050, the share of electricity from solid fuels is expected to decrease from 74% in 2011 to around 41%, while solar and wind could rise from 15% to 30%. The transition could lower average electricity generation costs by 0.5% compared to 2011 and reduce CO2 emissions. Successful transition requires embedding renewable energy (RE) technologies socially, which involves aligning the network of actors, governance systems, and minimizing policy conflicts between national and sub-national governments. Policy inconsistencies and inadequate actor networks pose significant barriers.

Case study 7 Indonesia: Transition Pathways Through Biogas Development

Indonesia aims to source 23% of its energy from renewables by 2025 and achieve a 26% reduction in emissions by 2020 compared to business as usual, as per its NDC. However, current GHG emission trends do not align with these targets, necessitating enhanced policy efforts to meet the NDC goals.

Methods: The study began with stakeholder mapping and in-depth fieldwork, including interviews and focus group discussions. Analysis based on the MLP framework considered economic and political aspects of biogas development. Pathways were presented in workshops and policy dialogues with national-level decision-makers, leading to the coproduction of model scenarios input into the E3ME model.

Results: The study generated several biogas development pathways:

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- Business as Usual: Electrification target by 2025 with a 35,000 MW plant development program, lacking specific biomass/biogas targets.
- NDC Scenario: Meeting at least 23% of national energy demand from renewables by 2025.
- General National Energy Plan: Implementing at least 31% new and renewable energy by 2050.
- Biomass Cookstove Target: Deploying 10 million clean cookstoves by 2030.

Case study 8 Kenya: Geothermal Power and Sustainable Charcoal

Kenya aims to become a middle-income country by 2030, pursuing a low-carbon, climate-resilient development pathway. Geothermal energy is central to this vision, while modernizing the cooking sector, which heavily relies on traditional biomass fuels, is also crucial. Urbanization poses a threat to forest resources if charcoal use continues to dominate urban cooking.

Methods: To assess risks and uncertainties in geothermal power generation and sustainable charcoal production, the study examined the technological innovation system, market dynamics, and actors involved. Methods included stakeholder attribute matrices, interviews, focus group discussions (FGDs), and field observations.

Results: The research revealed cautious optimism on the growth of geothermal power and the manufacture of sustainable charcoal. But it's crucial to reduce social and political hazards. The growth of the geothermal business and its technical know-how have been the main priorities, but to guarantee equitable benefits, mounting challenges demand responsible development. To overcome these obstacles coordinated actions are required. To appropriately manage Kenya's natural forest resources, investments in sustainable charcoal strategies are essential.

Case study 9 The Netherlands: Low Emission Transition Pathways in The Livestock Sector

The Dutch livestock sector must transition to a more sustainable model to align with the Paris Agreement's lower emissions goals. As a major source of methane (CH4) emissions, the sector also impacts soil carbon (CO2), fertilizer use (N2O), and water quality due to manure surplus and nutrient run-off. The research aimed to identify key (un)anticipated side-effects (consequential risks) of the transition pathways.

Methods: For qualitative assessments, stakeholder interviews (10) were conducted with experts from research, public, and private sectors. Quantitative impacts were estimated by constructing transition pathways, developing land use change scenarios, and performing off-model quantifications for E3ME and FASST models. An online survey was conducted to rank environmental, social, and economic development priorities.

Results: Literature review and stakeholder interviews highlighted several consequential risks for low-emission transitions in the livestock sector, such as biodiversity, animal welfare, air pollutants (PM, NH3), and soil structure and fertility, among others. according to the results of the (off-) model quantification, all low-emission transition pathways have their unique 'footprint' of combined domestic and foreign implications (or side-effects),

Case study 10 The Netherlands: Solar Energy

Under the 2008 EU Energy and Climate Package, the Netherlands is committed to achieving a 14% share of renewable energy consumption by 2020, but current projections only reach 13%. The new

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government in 2017 aimed for a target of 49% reduction in greenhouse gas emissions by 2030. Achieving this requires a substantial increase in renewable energy technologies, and solar energy has significant potential for expansion. The study looked at economic impacts of expanded solar PV use and system-level constraints to solar PV expansion.

Methods: Detailed face-to-face meetings with Dutch stakeholders (researchers, consumer groups, policymakers, solar PV service providers, grid operators, and industry) identified opportunities and barriers for expanding solar PV in the market. A model-based analysis (using the WEGDYN CGE model) assessed system/sector-level consequences and economy-wide impacts, including welfare gains/losses and GDP changes.

Results: in terms of consequential risk, Significant solar PV (and wind power) penetration requires large storage investments. When intermittent technologies constitute about 30% of total electricity, increased storage capacity is crucial for reducing system balancing costs and enhancing grid stability. Implementation constraints include:

- Unsuitable rooftops for solar PV installation
- Policy uncertainty
- Local resistance to ground-mounted solar parks arises from spatial planning issues.

Early involvement of local communities is recommended from the stakeholders.

Case study 11 Poland: Power Sector

The Polish power sector is at a crucial juncture, needing to choose between various emission reduction pathways. A decarbonization pathway would help Poland contribute to global GHG reduction efforts but would necessitate significant structural changes, particularly affecting the coal mining sector, which employs over 100,000 workers.

Methods: The study aimed to support decision-making by evaluating the consequences of different pathways in two steps:

- Economic Analysis using the MOEM Model for optimal electricity generation mix, and for macroeconomic dynamic general equilibrium.
- Risk Analysis through the Calliope Model and stakeholder interviews and workshops.

Results: the economic analysis shows that the most cost-effective pathway for a threefold CO2 reduction involves replacing coal with a mix of wind, nuclear, natural gas, biogas, and biomass. Without emission constraints, a moderate decline in coal use, primarily post-2030, is least costly. The risk analysis shows that clear governmental goals are crucial for business sector transformation, and countries not at the technological frontier risk wasting R&D efforts if they continue investing in traditional energy technologies like coal.

Case study 12 Spain: Renewable Energy

Since 2017, Spain has renewed its commitment to the Paris Agreement goals and the EU's target of a 40% reduction in GHG emissions by 2030. The new Ministry for Ecological Transition, established in 2018, underscores Spain's decarbonization priorities.

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Methods: The Global Change Assessment Model (GCAM) was used to assess risks and uncertainties in global mitigation portfolios. The qualitative analysis included stakeholder engagement through in-depth interviews and surveys.

Results: Key findings from the research highlight the need for a just energy and climate-neutral transition pathway in Spain with stakeholder involvement in an iterative process and Sector-specific policy mixes.

Case study 13 Sweden: Decarbonization of Road Freight

This study examines the uncertainties and risks associated with different technical options for decarbonizing road freight in Sweden. Sweden's strong CO2 mitigation targets, history of innovation in alternative fuels, and focus on new technologies like electric road systems make it an ideal case for analysis. With significant local bio-resources and global truck manufacturers like Volvo and Scania, Sweden is positioned for a swift transition, reflecting the broader challenges of reducing reliance on fossil fuels in road freight transport.

Methods: The study employed a multi-method approach, integrating qualitative and quantitative data, with workshops and stakeholder engagement and macro-economic impacts were analyzed using the E3ME model.

Results: There is no single solution for achieving long-term CO2 reduction targets, and a robust strategy is needed that incentivizes road biofuels and then shifting to road transport electrification. Global technological developments and Swedish truck manufacturers must prioritize electrification. Additionally, public-private partnerships are essential for large-scale deployment of electrification infrastructure.

Case study 14 Switzerland: Nuclear Exit

Switzerland aims to replace nuclear power with renewable energy as part of its Energy Strategy 2050 (ES2050). This transition poses potential risks to the country's reliable electricity supply. Various combinations of domestic and imported wind and solar power are viable and supported by most Swiss citizens.

Methods: Four research methods inform the four options pathways explored: energy system modelling, Q-methodology, a choice experiment, and a stakeholder workshop.

Results: Switzerland can phase out nuclear power without facing significant intermittency issues if it diversifies beyond PV, leveraging hydropower to compensate for variability, especially in winter when PV output is low. Wind power from the North Sea is particularly suitable due to its stability and higher winter output. To mitigate outage risks, redundancy in transmission corridors, high-quality equipment, and robust procedures are necessary, with Swiss hydropower providing a short-term buffer. Finally, survey results show a strong preference for solar power, and to a lesser extent wind power, particularly in industrial and commercial areas.

Case study 15 United Kingdom: Nuclear Expansion Versus Nuclear Phase Out

This study evaluates the risks and uncertainties of using new nuclear power to reduce CO2 emissions in the UK, assessing suitability of nuclear power options in the UK in the short and long term, and socio-economic, environmental costs/benefits.

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Methods: the methods include stakeholder workshops, one on one interviews, and focus groups. The E3ME model was used to test the techno-economic feasibility of nuclear expansion versus phase-out scenarios.

Results: the case study explored two extreme pathways. The pathway of nuclear expansion posed significant risks include large state funding, high nuclear costs, slow progress, and regulatory issues from Brexit. The no nuclear option posed the problem of high costs of large-scale renewable deployment and interconnection.

Analysis

The case studies revealed a wide array of economic, social, political, and environmental factors, leading to varying patterns of risks, opportunities, and challenges for low-carbon technologies, associated policies, and behavioral changes. While each case study identified a diverse set of risks, some common risks were identified across many or all case studies, including:

- Investment risks, which elevate financing costs for low-carbon technologies.
- Cost barriers and lack of acceptance from end users.
- Governance issues, such as inadequate cooperation between government levels and low confidence in government support schemes.
- Public resistance and entrenched social practices.
- Support for existing technologies that hinder transition efforts.
- Failure to identify and mitigate both environmental and social negative co-effects.

Different mitigation pathways are to be chosen after the convenient consideration of their corresponding costs, benefits, risks, and uncertainties. Risks are to be addressed in a complex way: there are a variety of uncertainties and trade-offs, hence, focusing just on the economic technical or end-user barriers may bring ineffective policies.

16. DEEDS - DialoguE on European Decarbonisation Strategies

Grant agreement No. 776646
Website: https://cordis.europa.eu/project/id/776646

The DEEDS project aims to foster dialogue and develop strategies for a carbon-free Europe by 2050. The project focuses on creating a comprehensive knowledge base and synthesizing decarbonization pathways for key sectors such as energy production, industry, mobility, agriculture, and cities. It will also produce policy briefs and a business guide for decarbonization.

Key activities include:

- Developing six Decarbonization Pathways documents for major sectors of the European economy.
- Organizing stakeholder dialogues for policy co-creation with policymakers, businesses, NGOs, and other stakeholders.
- Producing six policy briefs with recommendations and a Business Guide for decarbonization in Europe.

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DEEDS supports the European Decarbonisation Pathway Initiative (EDPI) and its High-level Panel by providing a flexible interface for addressing specific inquiries. The project aims to align and coordinate research and innovation across Europe through targeted workshops, resulting in a Research Agenda for Decarbonization Pathways.

The project collaborates with European networks to engage stakeholders and disseminate outcomes. It employs a comprehensive communication strategy using traditional and social media to enhance information flow and facilitate evidence-based dialogue between science, business, policy, and civil society on decarbonizing Europe's economy.

Work Packages: NOT AVAILABLE

Case studies

a. Survey

The majority of respondents supported most of the overall Research and Innovation (R&I) priorities for decarbonization sectors proposed in the HLP report, with agreement rates between 45% and 83%, and over 70% for most priorities. However, they were less supportive of prioritizing R&I activities related to Bioenergy with Carbon Capture and Storage (BECCS) and public-private partnerships. Concerns were raised about the feasibility of the HLP strategy and the lack of international cooperation. Respondents called for more integrated and system-level R&I strategies, emphasizing electrification, behavior change measures to reduce consumption, and public communication about the transition. Support for all Super-Labs ideas ranged from 60%-77%, with suggestions for additional themes related to transport, tourism, low-productivity agricultural areas, and carbon-intensive regions. Ideal Super-Lab locations included Germany, France, Poland, Spain, and the UK. Sector-specific feedback showed the highest support for the energy and power sector, followed by industry and transportation. Respondents believed the HLP R&I priorities could enhance EU competitiveness, achieve significant emission reductions, and meet target deadlines, especially in power sector actions, urban zero-carbon mobility, circular economy, smart cities, and cross-sectoral partnerships, while BECCS, digitalization for energy, and public-private partnerships received the lowest support.

b. Business guide to decarbonization in Europe

Key Policy Recommendations:

In order to uphold the commitment to achieve EU climate neutrality by 2050 as outlined in the Green Deal, policymakers must devise bold and comprehensive strategies. Collaboration with European stakeholders is crucial to expedite the transition to a decarbonized economy across all sectors. Here are the priority areas demanding ambitious policy initiatives:

High-Level European Policy Framework:

- Establish EU-wide decarbonization targets aligned with limiting global temperature rise to 1.5°C and achieving carbon neutrality by 2050.
- Integrate the objective of climate neutrality into all European policies and legislation.
- Promote a robust industrial policy rooted in circular economy principles, with the European Green Deal serving as the cornerstone for a new growth strategy.
- Foster the widespread adoption of deep decarbonization efforts among businesses, enhancing cost efficiencies and resource utilization.
- Create a regulatory environment conducive to directing investments towards decarbonization and transitioning to a sustainable financial system.
- Implement coherent policies and cross-sectoral approaches alongside efficient review and enforcement mechanisms.

Economic Tools and Instruments:

This project has received funding from the European Union's Horizon Europe research and innovation programme under the grant agreement No 101112305.

- Align the EU Emissions Trading System (ETS) with the trajectory towards net-zero emissions, ensuring a meaningful carbon price across the EU economy.
- Reform the EU energy taxation system to align with energy and climate objectives, embracing the "polluter pays" principle.
- Enact legislation mandating the disclosure of climate-related financial risks, following recommendations from the Task Force on Climate-related Disclosures.
- Introduce sector-specific financial incentives, including tax reductions for low-carbon energy sources and phasing out subsidies for fossil fuels.
- Simplify EU funding programs dedicated to decarbonization, making them more accessible and attractive to various sectors and companies.
- Channel European funding towards investments in existing low-carbon technologies and solutions, mitigating market risks and facilitating decarbonization investments by EU businesses and public banks.
- Invest in infrastructure development, including energy grids, storage capacities, and carbon removal technologies to enable the generation and dissemination of low-carbon technologies.
- Develop policy and finance instruments to support a just transition, ensuring adequate support and employment opportunities in high-carbon regions and sectors.

Education and Awareness:

- Strengthen awareness campaigns on climate emergencies, providing information on climate risks, policies, and legislation to companies and investors.
- Facilitate education and skill development for transitioning to low-carbon industries, particularly in regions facing rapid industrial shifts.
- Encourage a societal shift towards low-carbon choices through targeted awareness programs.

c. Policy briefs

The Policy Briefs deliver recommendations on the cost effectiveness of actions and measures, and on preferences across all actor groups. The set of policy briefs cover the full range of the decarbonization challenges and are Energy Supply; Transport; Industry; Agriculture & Land-use; Cities; Social Innovation & Lifestyles; Economic Implications. The Policy briefs are inherently interdisciplinary and cover economic, technological and societal drivers of the decarbonization as well as its trade-offs.

1. Research and Innovation for Decarbonizing the Transport Sector

Overview: Decarbonizing transport necessitates a holistic approach and comprehension of inter-sectoral dynamics.

Key Considerations: Strong policy interventions and standardizations are imperative, alongside infrastructure support. Embracing e-mobility for road transport and exploring alternative fuels for aviation and shipping are critical. Digitalization enables Mobility-as-a-Service and enhances demand understanding. Urgent actions are needed, particularly in the crucial decade of 2020-2030, to prepare for the 2050 decarbonization transition.

2. Social Innovation and Lifestyle Change for a Decarbonized Europe

Overview: Social innovation and lifestyle adjustments offer significant CO2 reduction potential.

Key Considerations: These changes are integral to systemic decarbonization and innovation adoption. Missions in Horizon Europe focus on societal transformation and climate-neutral cities. Social innovation fosters fairness in the energy transition, promoting job creation and capacity building. Research should target effective lifestyle programs and stimulate social innovation initiatives, addressing existing knowledge gaps.

3. Economic Implications of the Low-carbon Transition

This project has received funding from the European Union's Horizon Europe research and innovation programme under the grant agreement No 101112305.

Overview: Decarbonization carries substantial macroeconomic implications requiring targeted R&I.

Key Considerations: Research should focus on macroeconomic and financial challenges, taxation strategies, and mobilizing financing capital. Restructuring short-term trading and ensuring policy-responsive capital markets are crucial. Understanding industrial policy synergies with Sustainable Development Goals is imperative.

4. Research and Innovation to Decarbonize European Cities

Overview: City decarbonization demands a systemic approach and stakeholder collaboration.

Key Considerations: Mapping city climate actions, considering socio-economic impacts, and implementing low-carbon technologies are essential. Strong city governance and clear zero-carbon targets are necessary for transitioning. Developing a platform for sharing data and best practices will accelerate city decarbonization.

5. Research and Innovation for Decarbonizing the Agriculture and Land-Use Sector

Overview: Agriculture and land-use play a pivotal role in climate mitigation.

Key Considerations: R&I should focus on reducing livestock emissions, promoting plant-based diets, and mitigating food waste. Understanding the sustainability impacts of bioenergy feedstocks and leveraging Earth Observation data are critical for efficient land use.

6. Research and Innovation Needs for Clean Energy Supply

Overview: Coordinated R&I is vital for advancing clean energy technologies.

Key Considerations: Addressing digitalization challenges and adopting systemic approaches are crucial for energy transformation.

7. Research and Innovation for Decarbonizing the EU Industrial Sector

Overview: R&I support is crucial for market deployment of energy-efficient solutions and deep electrification.

Key Considerations: Long-term research should align industrial transition with circular economy principles. Zero-carbon breakthrough technologies are essential for strategic positioning in global markets.

Analysis

Stakeholder involvement takes place in this project in the form of ‘dialogues’. A sectorial approach allows for taking into account different challenges and different issues and recommendations by organizing sectorial workshops. Again, the co-creation of policies requires the collaboration of policymakers, businesses, NGOs, and other stakeholders. As a result of this collaboration, a coordinated research and innovation strategy can be implemented through initiatives like the Research Agenda for Decarbonisation Pathways.

A key output of the project was the Business Guide, which implies considering a multi-stakeholder strategy with no prioritization of governmental strategies. Along with the Business Guide, the Policy briefs are inherently interdisciplinary and cover economic, technological and societal drivers of the decarbonization as well as its trade-offs. All these actions contribute to an evidence-based dialogue between science, business, policy, and civil society. According to the project results, policymakers must devise bold and comprehensive strategies, based on the combination of a high-level European policy framework, economic tools and instruments, and education and awareness actions. The economic, technological and societal drivers of the decarbonisation as well as its trade-offs are to be considered within a holistic approach and that allows for the comprehension of inter-sectoral dynamics.

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Methodology

a. Workshops

Seven workshops have been organized, bringing together representatives from policymaking, science, industry, and civil society across seven critical sectors of the European economy:

1. Industry: "Business for an EU Low Carbon Economy – Solutions and Policies"
2. Energy: "Decarbonizing the Energy Sector through Research & Innovation"
3. Social Innovation: "Social Innovation and Lifestyle Change for the Decarbonization of Europe"
4. Mobility: "Research & Innovation for Unlocking the Decarbonization of Transport"
5. Cities: "Priority Actions to Achieve Zero-Carbon Cities"
6. Finance: "Finance and New Business Models for Decarbonization"
7. Agriculture: "Pathways for Decarbonized Agriculture and Food Systems"

Each workshop was guided by a discussion document summarizing the relevant chapters of the Final Report of the High-Level Panel (HLP) of the European Decarbonisation Pathways Initiative (EDPI). These documents were divided into three sections:

- Part A: Highlighted the most pressing issues in current research.
- Part B: Presented possible Research & Innovation (R&I) recommendations to address these issues.
- Part C: Proposed questions for stakeholders to discuss the chapter and the topic in general.

These discussion documents served as the foundation for dialogues with experts, whose insights will help co-design policies and business strategies, identify knowledge gaps, and facilitate feedback loops.

b. Survey

On the other hand, an online survey was created to gather feedback on the report's key messages from experts, businesses, and stakeholders involved in EU decarbonization. The survey ran from March to June 2019 and received responses from 189 participants. Most respondents were from academic or research organizations, with significant experience in the energy and power sectors. Geographically, the majority had professional experience in Germany, the UK, France, and Italy. Over a third of the participants had previously received Horizon 2020 funding, indicating familiarity with European R&I programs. About half of the respondents were aware of the HLP report, but fewer than 15% had read it before completing the survey.

17. CD-LINKS - Linking Climate and Development Policies - Leveraging International Networks and Knowledge Sharing

Grant agreement No. 642147
Website: https://www.cd-links.org/

Understanding the interplay between climate change policies and sustainable development is crucial for effectively implementing both the Paris Agreement and the Sustainable Development Goals (SDGs). This is particularly pertinent for policymakers in G20 nations and beyond, as it encompasses objectives such as eradicating energy poverty, enhancing well-being, improving air quality, preserving biodiversity, and ensuring food and water security. Thoughtfully crafted climate mitigation policies have the potential to yield significant co-benefits across various development priorities. However, inadequate management of mitigation efforts can result in trade-offs. Therefore, maximizing synergies and minimizing trade-offs necessitates integrated strategies based on innovative technological and socio-economic pathways. The CD-LINKS project has united an international team of interdisciplinary

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researchers with expertise at both global and national levels. Utilizing cutting-edge scientific models, the project aimed to achieve several key objectives:

- Enhance understanding of the connections between climate policies and diverse sustainable development goals.
- Expand the evidence base regarding policy effectiveness through the analysis of past and ongoing policy experiences.
- Develop globally consistent, national low-carbon development pathways for the next generation.
- Establish a research network and capacity-building platform to facilitate knowledge exchange among institutions across the EU and other countries, including Brazil, China, India, Japan, Russia, and the United States.

Work Packages

Work Package 1: Empirical assessment of the effectiveness of past and existing policies

Work Package 2: Assessment of international country pledges, national action plans and development policies

Work Package 3: Coherent national and global low-carbon development pathways

Work Package 4: Climate change as part of the broader development agenda – Systematic assessment of synergies and trade-offs between multiple policy objectives

Work Package 5: Future policies and related implementation challenges and opportunities

Work Package 6: Capacity building, dissemination, and stakeholder engagement

Case studies

The project has achieved significant milestones, including the establishment of globally consistent national low-carbon development pathways and the creation of a robust research network and capacity-building platform to facilitate knowledge exchange among institutions. Additionally, it has enhanced understanding of the connections between climate change policies and various sustainable development objectives, thereby enriching the existing evidence base on policy effectiveness. Particularly noteworthy are the insights generated regarding policy designs that effectively address mitigation trade-offs across different sectors, stakeholders, and goals.

The analysis indicates that each section of the good practice policy menu is addressed by at least one country. Notably, energy efficiency boasts over 80% coverage in each relevant sector, alongside renewables in the electricity and transport sectors (100% and at least 69%, respectively), and forestry (88%). Across all G20 nations, support policies for renewable electricity production and minimum energy/emissions standards for light-duty vehicles or passenger cars are in place. Similarly, GHG emissions reduction targets are adopted by all G20 countries, encompassing those outlined in the Intended Nationally Determined Contributions (INDCs). While over 80% of countries have climate change strategies, only 63% possess coordinating bodies to support their implementation.

Conversely, policy areas with less coverage across G20 members include changing activity, industrial non-energy, and renewables in the residential sector (non-solar PV). Moreover, overarching policies such as offsetting mechanisms, fossil fuel subsidies removal, and energy and other taxes are implemented by less than 70% of countries in all sectors. Transitioning to low-carbon pathways necessitates comprehensive climate mitigation actions across all relevant sectors, addressing existing GHG emissions sources. Therefore, it's imperative for climate mitigation policies to span the entire good practice policy menu in every country, particularly in sectors contributing to GHG emissions.

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Failing to establish policies in these areas not only impedes emission reduction but also overlooks potential co-benefits arising from decarbonization efforts. Mitigation co-benefits from renewables in the residential sector include increased asset value of buildings, job creation, enhanced energy security, and mitigation of urban heat island effects.

Analysis

Both the Paris Agreement and the Sustainable Development Goals (SDGs) require a holistic and ambitious approach, since they embrace a wide range of topics and areas to be incorporated in the design of policies. Moreover, the resulting policy frameworks are to be inspired by integrated strategies based on innovative technological and socio-economic pathways. These frameworks can be enhanced by efforts aimed at conducting networked and collaborative research and pursuing globally consistent national low-carbon development pathways. Initiatives like global modelling, the combination of expert opinions and literature research, and a capacity-building platform to facilitate knowledge exchange among institutions, were used in this case to contribute to this roadmap. Due to the urgent nature of climate emergencies, enriching the existing evidence base on policy effectiveness may contribute to achieving ever more impactful interventions. For instance, policymaking strategies that already foresee potential risks and trade-offs avoid subsequent additional ‘palliative’ policy interventions.

Methodology

While all policies within the good practice policy menu hold significance, certain policies are anticipated to yield a greater impact than others, varying on a country-specific basis. In this study, the most influential policies for reducing greenhouse gas (GHG) emissions in each of the G20 countries were identified. These policies were singled out to evaluate their effects and relay the findings to the global modelling teams of the CD-LINKS project, who utilize them as foundational elements for regional long-term scenarios.

The identification of these high-impact policies relied on a combination of expert opinions and literature research. The experts engaged in this process included the authors of the report, experts from CD-LINKS country teams focused on their respective countries, and other country-specific experts not affiliated with CD-LINKS partner institutes (refer to the 'Acknowledgments' section for further details). The aim was to identify at least one significant policy from each sector where feasible.

Initially, a roster of pertinent climate and energy policies for each country was compiled, drawing from sources such as literature reviews and the Climate Policy Database. Subsequently, these policies were categorized as either implemented or planned, based on the existence of supporting policies and the likelihood of implementation. Here, planned policies denote aspirational targets outlined in strategic documents or policies under consideration for adoption, often extending beyond 2020 or lacking effective policy instruments. These policies offer insights into how Intended Nationally Determined Contributions (INDCs) might be actualized should current policies prove inadequate.

The list of implemented policies was then circulated to country experts for evaluation, with the objective of identifying a top 10 (actual number varied by country) of policies exerting the most significant impact on GHG emissions. In instances where country experts were unavailable for review, literature sources such as biennial update reports and other UNFCCC documents quantifying GHG emissions using 'existing measures' scenarios were utilized.

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18. ENGAGE - Exploring National and Global Actions to reduce Greenhouse gas Emissions

Grant agreement No. 821471
Website: https://engage-climate.org/

ENGAGE is a consortium of international and multidisciplinary leading research groups that aims to co-produce knowledge for designing cost-effective, technologically sound, socially and politically feasible pathways that can meet the objectives of the Paris Agreement. ENGAGE will also quantify avoided climate change impacts at the regional and national levels and identify concrete policy portfolios that maximize co-benefits and minimize trade-offs.

ENGAGE has five main objectives:

1. Build a legitimate, transparent, and iterative knowledge co-production process rooted in stakeholder dialogue.
2. Conceptualize and operationalize multidimensional feasibility of decarbonization policies and pathways.
3. Quantify national impacts of climate change and identify decarbonization policies that maximize co-benefits and minimize trade-offs.
4. Develop a new generation of decarbonization pathways which represent multidimensional feasibility and reflect all characteristics of the Paris Agreement
5. Inform and contribute to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

Case studies

The ENGAGE project employed integrated assessment models (IAM) to identify pathways that explicitly limit peak temperature according to the Paris Agreement, addressing technical, social, and political challenges.

Meeting the Peak Temperature Constraint: Institutional Capacity and International Support

ENGAGE's stakeholder process involved societal partners to develop new scenarios considering feasibility constraints. The findings revealed that traditional emissions pathways, which focus on end-of-century average temperatures, lead to hazardous mid-century peak-temperature overshoots with greater climate impacts and tipping point risks. Short-term emission reduction investments lead to long-term economic gains, resulting in higher end-of-century GDP in scenarios that avoid temperature overshot.

Project coordinator emphasized that high institutional capacity in regions like the EU, Japan, and the United States is crucial for rapid mitigation. He stressed the importance of international aid for capacity building and knowledge transfer to achieve ambitious decarbonization.

A Comprehensive Toolkit for Climate Stakeholders

ENGAGE developed several tools to aid decision-making, including:

- The Scenario Explorer with all project scenarios.
- The Multidimensional Feasibility Visualization Tool to evaluate decarbonization pathways.
- Dividing the Carbon Cake, which depicts allocation rules and regional emissions to keep global temperature rise below 2 °C.

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The Climate Solutions Explorer, featuring 'avoided climate impacts' for successful global warming mitigation to 1.5 °C, and the Impacts Explorer National Dashboards, showing mitigation benefits for nearly 200 countries and 10 global macro-regions.

Informed Climate Policymaking

ENGAGE contributed significantly to policymaking, informing the IPCC Sixth Assessment Report and producing eight policy briefs compiled in the ENGAGE Summary for Policymakers report. National policy scenarios were developed to align national climate policies with global goals. The Climate Policy Database, covering 6,028 policies across 198 countries, was also established. ENGAGE has provided the necessary data-driven tools for effective policymaking and decision-making, leaving it to governments and stakeholders to realize their potential in limiting peak temperature in line with the Paris Agreement.

Analysis

The design of cost-effective, technologically sound, socially and politically feasible ("multidimensional feasibility") pathways requires the active collaboration of a global and multidisciplinary network of actors. Knowledge-based policies have more chances of effectiveness and allow for the timely prevention of undesired consequences.

In this project, the methodological diversification and stakeholder involvement are also considered, by incorporating a "stakeholder dialogue process" (consisting of workshops, surveys, and frequent interactions and feedback among scientists, policymakers, civil society, the private sector, and other key stakeholders). The multidimensional challenge of policymaking aimed at countering the effects of climate change is reflected in this project by considering a set of various areas to be addressed: biodiversity, food security, poverty, water resources, air quality, health, and employment.

Institutional capacity and international support are two key factors to face an unexpected challenge: traditional emissions pathways focused on end-of-century average temperatures result in perilous mid-century peak-temperature overshoots, while investing in short-term emission reduction yields long-term economic benefits. The development of tools and an informed climate policymaking are also valuable aspects to be considered, especially to align national policy scenarios and policies with global goals.

Methodology

Knowledge co-production was facilitated through an ongoing stakeholder dialogue process, which encompassed workshops, surveys, and frequent interactions and feedback among scientists, policymakers, civil society, the private sector, and other key stakeholders. ENGAGE was inclusive of major emitters and selected developing countries, ensuring the credibility and legitimacy of the scientific and policy insights.

ENGAGE also addressed a historical shortcoming of IAM (Integrated Assessment Model)-based pathways—namely, the insufficient attention given to social, political, and certain technological constraints and enablers of mitigation efforts—by developing and operationalizing the concept of multidimensional feasibility of decarbonization policies and pathways. To achieve this, ENGAGE employed empirical analysis, stakeholder dialogue, and conceptual insights from the social sciences to create a tool that was subsequently used to assess and enhance the feasibility of decarbonization pathways.

The ENGAGE project set the goal of establishing new standards of transparency by systematically combining three efforts in its approach of documenting models, (i) using a harmonized model documentation framework, and making (ii) critical model input data, and (iii) pathway results publicly available. Building upon the existing wiki-based model documentation developed in the FP7 project ADVANCE, hosted by PBL on behalf of the modelling community, ENGAGE has strived to document all global and national IAMs involved in the project using this harmonised documentation framework.

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ENGAGE quantified the impacts avoided through climate change mitigation by analysing the exposure and associated costs for individual sectors and regions at different levels and timing of global peak temperature. Particular emphasis was placed on quantifying the benefits (or trade-offs) of climate policies on biodiversity, food security, poverty, water resources, air quality, health, and employment, especially for vulnerable populations.

Conclusion: takeaways and outlook

The summaries of the previous and two ongoing Horizon projects provide several key insights regarding their approach and the methodologies they use for impact assessment. The aim of the GreenPaths project, specifically the case studies in the upcoming WP 3, is to assess the social, economic, and environmental impacts of green transition policies and actions. This deliverable, therefore, offers important information on methods and approaches that can be used in the case studies in WP 3. While each project is unique, it is possible to identify some common themes on general research designs and specific methodologies.

General research designs

The review and comparison of research designs applied by the projects under considerations suggests that the core of the projects is often stakeholder engagement, utilizing an inclusive approach: One critical aspect of most projects was the engagement of diverse stakeholders, including policymakers, industry experts, academics, and civil society. Through co-creation workshops and stakeholder meetings, the projects gathered insights and feedback to ensure that the project activities, such as socio-economic and ecologic modelling, as well as formulating policy recommendations, were plausible, robust, relevant, and socially acceptable. By involving stakeholders such as academia, industry, policymakers, civil society, and end-users, the Horizon projects could draw on a broad base of knowledge and experience. This collaborative approach enhances the quality and robustness of research and innovation activities, leading to more comprehensive and effective solutions.

For instance, several projects on energy transition (GRETA, SENTINEL, ASSET, OpenENTRANCE, COMETS, TRANKSrisk) engaged with stakeholders from the energy sector, environmental organizations, local communities, and government agencies to ensure that the project addressed the technical, environmental, social, and regulatory dimensions of the issue. This collaborative effort can lead to innovative solutions that are more likely to be adopted and implemented successfully.

Secondly, the projects emphasized transparency and accessibility in all their activities. This is why the modelling and data exchange platforms are open and easily accessible to any user through the project websites. Open modelling and data exchange platforms promote transparency by making data, models, and methodologies publicly accessible. This openness allows other researchers to verify the results, reproduce studies, and build upon previous work, thereby enhancing the credibility and reliability of research findings. The open modelling and data exchange platforms of NAVIGATE, Open ENTRANCE, PARIS REINFORCE can be used by and other researchers, including GreenPaths researchers for their case studies in WP 3.

Specific methodologies

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The methodologies employed by ongoing and recently concluded Horizon projects can be broadly associated with two categories: First are a variety of qualitative methods and the second are Integrated Assessment models.

The qualitative approaches include methods such as semi-structured interviews, workshops, and focus group discussions. These methods offer deep insights into the experiences, attitudes, and motivations of various stakeholders, facilitating a comprehensive understanding of the complexities of the systems that are scrutinised. For instance, in the ASSET project, interviews with industry leaders in the energy sector helped uncover the economic and operational impacts of transitioning to sustainable practices. Similarly, interviews in GRETA's Natural gas-free neighbourhoods case study in Netherlands identified barriers to transition towards natural gas-free homes in the Netherlands. Another example is the stakeholder engagement workshops in the TIPPING+ case study 1 in Austria, which led to the collaborative development of alternative transition pathways. Finally, focus groups were identified and brought together by the REAL DEAL as one of the tools for citizen participation and deliberation in the context of the European Green Deal (EGD).

The second main methodology is the use of Integrated Assessment models (IAMs). IAMs are complex tools that use quantitative and qualitative tools and processes to synthesize information from multiple fields. This approach allows to examine intricate problems, especially those pertaining to social, economic, and environmental systems. They are especially valuable in impact assessment, as they provide a comprehensive framework for evaluating the potential outcomes of policies and changes across multiple dimensions. The use of various IAMs in the Horizon projects has shown that IAMs offer several advantages for impact assessment, and that they can be useful tools for GreenPaths or any researcher interested in green transition and impact assessment. The following lays out the key strengths of IAM approaches:

Comprehensive Analysis and Interdisciplinary Approach

One of the primary strengths of IAMs is their ability to integrate diverse types of knowledge into a single analytical framework. Green transition is inherently interdisciplinary, requiring insights from fields such as economics, environmental sciences, sociology, and political science. IAMs facilitate the synthesis of these insights, enabling a holistic understanding of complex problems. By capturing the interactions between different systems, IAMs provide a comprehensive analysis that is crucial for effective impact assessment. For example, COIN is a computable general equilibrium (CGE) model that was utilized in the COACCH project. COIN spans multiple sectors and offers an economic evaluation of the effects of climate change in ten climate-sensitive sectors (agricultural, forestry, water, energy, buildings, tourism, transportation, manufacturing, flood risk management, cities). Similarly, ICES (Inter-temporal Computable Equilibrium System), developed in the COACCH and PARIS REINFORCE projects, offers a framework that can link economic activity, energy consumption (including from renewable sources) and greenhouse gas emissions. The GCAM family of models, developed and applied in the PARIS REINFORCE and TRANSrisk (Case study 12 Spain: Renewable Energy) projects examines the behaviour and connections between the energy system, agricultural and land use, economy, and climate. These models can also accommodate socioeconomic factors, energy technology features, agriculture technology features, energy resources, and policies. IAMs, therefore, allow for a detailed understanding of how changes in one domain can affect others, providing a accurate picture of the potential consequences of different policy choices.

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Policy Evaluation

IAMs can help assess future policies by simulating the effects of different possible policy options and strategies, allowing researchers to compare synthetic outcomes and identify the most effective and efficient options. By modelling the economic costs and environmental benefits of various approaches, IAMs can help policymakers identify the strategies that provide the greatest benefit at the lowest cost. This is particularly important in the context of limited resources and the need for efficient allocation. In ALADIN, emissions can be computed for various policy situations in Europe, based on factors such as price changes and shifts in consumer preferences. DICE, a welfare optimization tool developed in the PARIS REINFORCE and NAVIGATE projects, can represent the policy elements of climate change. REMES studies the effects of hypothetical macroeconomic policies on the Norwegian economy. These policies are modelled as shocks that impact the economy through subsidies or taxes.

Climate Change Mitigation and Adaptation

IAMs are especially valuable in the analysis of determinants, effects, and policy responses to climate change, when they are used to assess both mitigation and adaptation strategies. Climate change is a complex and long-term problem that requires coordinated action across multiple sectors and scales. IAMs provide a framework for understanding the potential impacts of climate change and evaluating the effectiveness of different responses. For example, the JET model (see PARIS REINFORCE) is used to facilitate the investigation of various mitigation strategies, such as sector-specific/technology-specific regulations (e.g., subsidies and taxes) and objectives (e.g., annual GHG emissions binding targets and cumulative carbon budgets). The macroeconomic model NEMESIS can use pre-established levels of a climate policy instrument or annual GHG emissions limitations to suggest mitigation strategies. CONTO, a model for road transport and energy needs, can represent the mitigation of climate change by altering the relative costs of high- and low-carbon fuels in each sector. The IMAGE modelling framework simulates long-term energy scenarios and climate change mitigation strategies by modelling investments in and utilization of various energy technologies, which are influenced by technological advancements and resource availability.

Similarly, IAMs can be used to evaluate adaptation strategies, such as infrastructure investments or changes in land use planning. By modelling the potential impacts of different adaptation measures, IAMs can help researchers identify the most effective ways to reduce vulnerability and enhance resilience to climate change. Both, ICES and GEMINI-E3, investigate mitigation and adaptation strategies in response to climate change's effects on the economic system.

Long-term Planning

IAMs are essential for long-term planning, providing insights into the long-term consequences of current actions. This is particularly important for issues like climate change, where the effects of actions taken today will be felt for decades or even centuries. By modelling the long-term impacts of different policies and strategies, IAMs help policymakers design interventions that are effective in the long run. E3ME is a macro-economic model that presumes that markets reach equilibrium in the long run, employing historical data and econometrically determined parameters and relations to model the behaviour of the European economy dynamically and more accurately than other models could.

Challenges and Limitations of IAMs

This project has received funding from the European Union's Horizon Europe research and innovation programme under the grant agreement No 101112305.

While IAMs can offer many advantages, they do have limitations, as shown by the previous Horizon projects. While they are complex tools that can be adjusted to wide range of contexts, they come, as any empirical model does, with a certain level of uncertainty. Secondly, IAMs depend on a wide range of assumptions and inputs, many of which are uncertain or subject to change. This can affect the reliability of the model outputs and the conclusions drawn from them. Finally, IAMs can be resource-intensive and require significant expertise to develop and use.

This summary and review of ongoing and recently concluded Horizon projects sheds light on the recent impact assessment and green transition analysis tools and how these have been used in recent research.

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