SPES Sustainability performances, evidence & scenarios

D10.1

Sustainable Energy Futures: Transition Scenarios and Instruments in Selected Case Study Regions

October 2024

Funded by European Union's Horizon Europe Programme under Grant Agreement No. 101094551

Authors

Gregor Zens – researcher of the SPES Project, International Institute for Applied Systems Analysis (IIASA)

Roman Hoffmann – researcher of the SPES Project, International Institute for Applied Systems Analysis (IIASA)

Marjorie Alain – researcher of the SPES Project, Partnership for Economic Policy (PEP)

Camille Belmin – researcher of the SPES Project, International Institute for Applied Systems Analysis (IIASA)

Contributors and peer reviewers:

Mario Biggeri, University of Florence; Tiziano Distefano, University of Florence; Albert Ferrari, European University Institute; Martin Henseler, Partnership for Economic Policy (PEP); Leonardo Paoli, University of Florence.

Acknowledgements:

The authors would like to thank all SPES partners for their input provided in several SPES meetings and communications.

Cite as:

Zens, G., Hoffman, R., Alain, M., Belmin, C. (2024). *Sustainable Energy Futures: Transition Scenarios and Instruments in Selected Case Study Regions.* SPES Working paper no. 10.1, SPES project – Sustainability Performances, Evidence and Scenarios. Florence: University of Florence.
Available at: https://www.sustainabilityperformances.eu/publications-deliverables/

Disclaimer

This Working Paper 10.1 for the project SPES has been prepared by the International Institute for Applied Systems Analysis (IIASA) with the support of Partnership for Economic Policy (PEP) and University of Florence, as part of Task 10.1 "Literature review of transition pathways and scenarios to sustainable societies" / Work Package 10. This task was conducted for the selected case study countries with a focus on identifying enabling factors for a transition.

This deliverable contains original unpublished work except where clearly indicated otherwise. Acknowledgement of previously published material and of the work of others has been made through appropriate citation, quotation or both.
The information and views set out in this report are those of the authors and do not necessarily reflect the official opinion of the Commission. Neither the Commission nor any person acting on the Commission's behalf may be held responsible for the use which may be made of the information contained therein.
The project SPES is funded by European Union's Horizon Europe Programme under Grant Agreement No. 101094551.

Table of contents

1. Introduction

It is widely recognized that urgent action is needed to combat climate change and to transition to a more sustainable societal and economic path. A key focus is the energy transition, which refers to the shift from fossil fuel-based energy systems to renewable and sustainable energy sources, with the aim of reducing carbon emissions and mitigating climate change. Various models and analytical tools have been developed to describe and explore different scenario pathways for this transition (Weyant et al., 1995; Weyant, 2017; Hare et al., 2018). These scenario pathways are structured, model-based narratives that describe possible futures based on a set of defined assumptions. They provide plausible projections based on models that aim to replicate the complex and nonlinear dynamics of energy, economic, and climate systems. These scenarios are not intended to be used as predictive tools, but rather as constructs to help conceptualize potential outcomes. In the context of strategic planning, they provide decision-makers with a clearer understanding of different pathways to a sustainable future, considering factors such as technological advances, policy changes, and societal responses (Wiek et al., 2006; Alcamo, 2008). Considering a range of scenarios can provide a better understanding of their attributes and consequences, which in turn can inform strategy formulation. Scenario analysis is therefore a relevant tool for policy makers dealing with climate change and transition management (Wiek et al., 2006).

A wide range of scenario narratives, and thus many specific scenario pathways, are available for the analysis of energy transitions. Prominent scenario pathways have been developed, synthesized, re-analyzed and published, for example, by the Intergovernmental Panel on Climate Change (IPCC, 2023), the International Energy Agency (Bouckaert et al., 2021), the World Energy Council (Kober et al., 2020), the Deep Decarbonization Pathways Project (Bataille et al, 2016), as well as by (supra-)national entities such as the European Union and its institutions (Capros et al., 2016; Tsiropoulos et al., 2020), and academic and semi-academic consortia such as the Network for Greening the Financial System (Bertram et al., 2020; Richters et al., 2022). All these scenarios have specific themes, assumptions, and narratives behind them, and have been developed with a specific goal in mind. With thousands of scenarios available, summarizing each one is a daunting, if not impractical, task for policy makers.

This report aims to present the key components of transition scenarios from prominent scenario formulations. The goal is to highlight critical transition drivers, key energy transition concepts, and potential heterogeneity across selected case study regions around the globe. The report provides high-level insights and guidance on the evolution of energy systems for policy makers, businesses and other stakeholders. Within the EU-funded Sustainability Performances Evidence & Scenarios (SPES) project, this report serves as an input for discussions and workshops with policy makers and stakeholders.

In **Section 2**, we summarize broad overarching themes from flagship scenario reports, providing a "global" perspective and highlighting key components that are likely to be relevant in any current sustainability transition context. **Section 3** focuses on regional dynamics, providing more detailed insights through illustrative scenario pathways. The section also discusses key transition risks under different scenario narratives. **Section 4** complements the regional scenario pathways with a country-specific review of the academic literature on sustainability transitions. **Section 5** provides concluding remarks, identifies future research avenues, and discusses limitations of the scenario literature reviewed.

2. Global Insights: Summarizing a Sample of Flagship Scenario Reports

This section provides a summary of key messages drawn from several prominent scenario reports. These insights are likely to be relevant to many current transition contexts, regardless of regional focus. For this exercise, we collect broad, overarching themes that are consistent across multiple reports and scenarios analyzed. These broad conceptual ideas are illustrated with specific scenarios later in Section 3 and complemented with country-specific insights in Section 4.

In terms of reports, we focus in this section on the following ten publications (listed in no particular order):

- ’10 New Insights in Climate Science’ of the WRCP (Future Earth, The Earth League, WRCP, 2023)
- ‘NGFS Climate Scenarios’ (Bertram et al., 2020; see **Section 3** for details)
- ‘Carbon-Free Europe Annual Decarbonization Perspective 2023’ produced by ‘Evolved Energy Research’ for the organization ‘Carbon-Free Europe’
- ‘Industrial Innovation: Pathways to deep decarbonisation of Industry’ produced by ICF Consulting Services Limited and Fraunhofer Institute for Systems and Innovation Research (ISI) for the European Commission Directorate-General for Climate Action
- IPCC AR6 report’s ‘Summary for Policy Makers’, Section B (IPCC, 2023)
- ‘Towards a Fair And Sustainable Europe 2050: Social and Economic Choices in Sustainability Transitions’ by the European Policy Lab (Matti et al., 2023)
- ‘Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach (2023 Update)’ by the IEA
- ‘Towards net-zero emissions in the EU energy system by 2050’ by the JRC (Tsiropoulos et al., 2020)
- ‘World Energy Outlook 2023’ of the IEA
- ‘World Energy Scenarios: Composing energy futures to 2050’ of the WEC (Frei et al., 2013).

This set of publications covers a wide range of topics, regions, organizational backgrounds, and policy positions. It includes both technical and policy-oriented analyses. Therefore, the ten selected reports are expected to reflect a large portion of the literature on energy transition scenarios. However, a limitation of this set of reports is that they are produced exclusively by Western institutions and researchers. As a result, these scenarios not only reflect a specific perspective on energy transitions, but may also lead to a reinforcement of existing energy inequalities between the Global South and the Global North (Hickel and Slameršak, 2022; Distefano et al., 2024). For each report, we extracted the section of the report that contained the key messages, such as executive summaries or lists of key takeaways. We then summarized these findings into two broad thematic areas, as follows.

Impacts of Climate Change

Reports focusing on climate trends, such as the IPCC AR, imply that overshooting global climate targets is now almost inevitable. Global surface temperature will continue to rise until at least mid-century, and global warming of 1.5°C and 2°C will occur during the 21st century unless CO2 and other greenhouse gas emissions are drastically reduced in the coming decades. Many effects of such a temperature increase, resulting from past and future greenhouse gas emissions, are irreversible for centuries to millennia. Examples include changes in the oceans, ice sheets, and global sea level. If global warming overshoots 1.5°C, physical risks (described in detail in Section 3) become more severe with each incremental temperature increase. In addition, climate change may accelerate the loss of biodiversity. The impacts on humans and ecosystems worsen with the magnitude and duration of the overshoot (i.e., how much and for how long temperatures exceed 1.5°C). To mitigate these impacts, it is important to minimize the intensity and duration of any overshoot period. Central to this effort is limiting the amount of greenhouse gases emitted and reducing the time they remain in the atmosphere.

Economic and social restructuring

The reports agree that achieving this goal through a sustainable transition will require a restructuring of both the energy sector and the functioning of society and the economy. The design and implementation of sound policies is a key step in initiating and sustaining such a restructuring process. Transitioning the energy sector requires an orderly phase-out of fossil fuels and a reduction in emissions, typically based on three broad developments. First, electrification of transport, industry and buildings is essential to reduce demand for fossil fuels. Second, a significant expansion of renewable energy sources such as solar, wind, and hydro energy is needed to meet energy demand during a fossil phase out. Third, increasing energy efficiency is seen as a key factor in reducing energy demand and relieving pressure on the renewable energy system as fossil fuels are phased out. These three points focus mainly on reducing the level of new greenhouse gas emissions. In addition, there is an overarching focus on reducing the amount of greenhouse gases already in the atmosphere through carbon dioxide removal (CDR). This term includes reversing climate-changing land use practices such as deforestation and developing novel carbon capture and storage (CCS) technologies. However, despite the potential benefits of CCS technology, over-reliance on CCS is often viewed as a risky and uncertain strategy, which can potentially discourage full commitment to necessary policy changes that penalize future emissions (Lenzi et al., 2018).

In terms of social and economic reforms, structural behavioral changes are needed on both the supply (production) and demand (consumption) sides. A fundamental question is how to design an economic and social system that delivers sustainable products, sustainable technologies and sustainable consumer behavior. An important focus is the food system, which has a significant impact on emissions. Restructuring the food system requires changes in both the way food is consumed (demand side) and the way it is produced (supply side). More generally, a redefinition of the concept of well-being from material well-being to broader notions of quality of life is seen as an important aspect of sustainability transitions.

While these overarching goals are clearly defined, particularly with respect to changes in the energy sector, it is much less clear what specific policies should be implemented to achieve these goals. Many different policies could potentially achieve similar goals, and the specific focus and implementation will vary, for example, depending on the regional context. In addition, how and when policies are implemented can also affect outcomes. In terms of transition risks, orderly and rapid transitions are preferable to disorderly, late and potentially more disruptive changes in the energy, economic and social sectors.

3. Regional Level: NGFS Regional Scenario Pathways & Sustainability Transitions

To illustrate the broader insights provided in Section 2 and complement them with a more regional perspective, we use selected future transition pathways in case study regions based on eight selected SPES case study countries: Italy, France, Hungary, Pakistan, Nigeria, Kenya, Colombia and India. The scenario narratives explored in this report were developed by the Network for Greening the Financial System (NGFS), an international alliance of central banks and supervisory authorities. The NGFS scenarios provide a strategic framework for analyzing potential energy transition pathways to achieve net-zero CO2 emissions by 2050. The academic consortium involved in the development of the NGFS scenarios includes the Potsdam Institute for Climate Impact Research (PIK), the International Institute for Applied Systems Analysis (IIASA), the University of Maryland (UMD), Climate Analytics (CA), the Eidgenössische Technische Hochschule Zürich (ETH) and the National Institute of Economic and Social Research (NIESR). The narratives underlying the scenarios are based on an expert panel of climate scientists and economists.

The decision to use the NGFS scenarios, a subset of the scenarios summarized in Section 2, is due to the fact that these scenarios are based on recent data and evidence, ensuring that the strategic analysis is relevant to contemporary policy making. In addition, the NGFS scenarios have been specifically designed for policy makers, making them particularly suitable for this audience (Bertram et al., 2020). The NGFS scenarios are the result of collaboration between the financial sector, climate science and policy experts, providing an interdisciplinary perspective and understanding. While it is important to note that the NGFS pathways used in this report are a set of illustrative examples among many existing scenarios, their key findings are broadly consistent with other scenario reports and databases.

The computations underlying the NGFS scenario pathways are based on *integrated assessment models* (IAMs), which combine theoretical modeling with empirical data (Parson & Fisher-Vanden, 1997). IAMs are based on a set of assumptions about future global changes, such as policy objectives and transition pathways of socio-economic variables. They also consider the cost implications of different energy sources and carbon sequestration technologies. With respect to socio-economic factors, the NGFS scenarios considered here are based on the Shared Socioeconomic Pathway 2 (SSP2) narratives, which depict a "middle-of-the-road" future in which societal development largely reflects a continuation of past trends (Riahi et al., 2017).

The NGFS scenarios we consider are based on the Global Change Assessment Model (GCAM), a dynamic recursive market equilibrium model that captures the interactions between the energy system, water, agriculture and land use, the economy, and climate change. The GCAM, which has been continuously developed and refined over the past decades to incorporate updated data and assumptions (Calvin et al., 2019), is one of the most widely used IAMs. It provides a relatively high level of regional granularity, consistent with the objectives of this report. The technical documentation for the GCAM[1] and NGFS scenarios provides more detailed information on the modeling framework and underlying assumptions. While this report primarily analyzes the NGFS scenarios generated using GCAM, it recognizes the need for further research and quantitative analysis to explore a wider range of scenarios and to incorporate additional uncertainties, such as comparing scenario pathways generated using different IAMs and alternative approaches, such as agent based models (Berger & Troost, 2014).

Regarding limitations, it is important to reiterate that the NGFS scenarios, like any scenario pathway, are not meant to be predictions or forecasts, but rather plausible narratives that illustrate how the energy transition might unfold. They provide strategic views rather than technical feasibility assessments.

3.1 Risks associated with Sustainability Transitions

In the NGFS scenario pathways, the challenges posed by both climate change and sustainability transitions are conceptualized as 'transition risks' and 'physical risks'. In brief, transition risks refer to the social, financial and market disruptions caused by the transition to a low-carbon economy, while physical risks refer to the impacts of climate change itself, such as extreme weather events.

Transitional and physical risks are intertwined, as the transition to a net zero carbon economy can help mitigate physical risks by reducing greenhouse gas emissions and promoting resilience. However, both types of risk pose uncertainties and challenges. Transition risks affect the economy through energy use, policy changes and investment uncertainty, while physical risks manifest themselves in the damage and disruption caused by climate change. It is important to recognize that the impact of physical risks on the economy is subject to considerable uncertainty and that the estimated damages in the scenarios do not cover all sources of risk. This underscores the need for comprehensive assessments and policies that address both transition and physical risks to achieve sustainable and resilient outcomes.

Physical Risks

The term *physical risks* is used to refer to direct consequences of climate change phenomena. They are broadly divided into acute and chronic risks. Acute risks arise from extreme weather events such as hurricanes, floods, and wildfires, which can cause immediate and severe damage to infrastructure, disrupt supply chains, and lead to loss of life and property (Kunkel et al., 1999). Chronic risks develop over a longer period of time and may result from sustained higher temperatures, sea level rise, or long-term shifts in precipitation patterns. These long-term changes can lead to reduced agricultural yields, changes in water availability, and sustained damage to infrastructure due to phenomena such as coastal erosion or recurrent heat waves. As these physical risks materialize, there are further potential implications for reduced economic productivity, increased insurance claims, and challenges to the viability and insurability of certain regions or properties (Charpentier, 2008; Kjellstrom et al., 2009).

[1] https://jgcri.github.io/gcam-doc/toc.html.

Transition Risks

As the global community transitions to a low-carbon economy, *transition risks* are gaining increasing attention. These risks arise from a myriad of factors, including changes in climate policies and regulations, shifts in market preferences toward greener products, technological breakthroughs that may render existing products or services obsolete, and reputational risks for companies that fail to adapt or are seen as lagging in their sustainability efforts (Shin & Ki, 2019). Financial markets may reassess the valuation of large carbon-intensive assets, which could lead to stranded assets, particularly in the fossil fuel sector (Ansari & Holz, 2020). There is also potential for abrupt market adjustments due to rapid policy changes or technological advances, leading to uncertainty and financial instability (Diluiso et al., 2021). Labor markets in carbon-intensive sectors may face disruptions, and there may be a need for significant upskilling or retraining to adapt to new green technologies or industries (Sokołowski et al., 2022).

Accounting for Political and Cultural Risks and a Just Transition

While much of the existing literature highlights the importance of social, cultural, and political developments in sustainability transitions (see, for example, Chapter 5 of the WG3 contribution to the IPCC AR6 report; Creutzig et al., 2022) and emphasizes the need for a just transition for all (Zimm et al., 2024), such considerations are typically not explicitly included in classical energy transition scenarios. The NGFS scenarios are no exception. Relevant risk factors that have received attention in the literature include the exacerbation of inequalities affecting marginalized populations and the potential resistance to radical changes in traditional behaviors or practices (Sovacool, 2021). In addition, disruptive changes, particularly those forced by policy, may undermine public trust in institutions, which is linked to the dynamics of transition (Smith & Mayer, 2018; Cologna & Sigrist, 2020). There are also intergenerational considerations, where prioritizing immediate gains may burden future generations with compounded environmental, social, and economic challenges (Page, 2008). The complex dynamics of climate-induced migration (Piguet et al., 2011; Hoffmann et al., 2021), climate-related poverty (Heger et al., 2020), the role that energy poverty reduction plays in reducing population growth (Belmin et al., 2022), the tension between local autonomy and global coordination, and the varying acceptance of lifestyle changes across cultures add to the complexity. Finally, the mental health implications of climate change-induced stress have received attention (Cianconi et al., 2020). In general, a richer scientific exploration of the socio-cultural aspects and costs of mitigation and transition, and the incorporation of these results into scenario analyses, is likely to be fruitful for future scenario assessments and policy design.

3.2 Two Contrasting Pathways and a ‘Delayed Transition’ Scenario

In this report, we focus on three NGFS scenarios. First, two contrasting NGFS scenarios (the "Current Policies" scenario and the "Net Zero 2050" scenario) are selected. Although not fully comparable, similar scenario pathways include the IPCC's representative concentration pathways 1.9 (limiting global warming to 1.5°C) and 8.5 (representing a continuation of current trends pathway) and the stated policies scenario (STEPS) versus the International Energy Agency's Net Zero Energy by 2050 (NZE2050) scenario. The third scenario we included is the NGFS *Delayed Transition* scenario, which represents a "middle path. The narratives behind the three sample scenarios, adapted from their respective descriptions in the NGFS documentation materials, are summarized below

'Net Zero 2050' Scenario

The *Net Zero 2050* scenario represents a pathway that limits global warming to 1.5°C through strong and ambitious climate policies and technological innovation. In this scenario, net zero CO2 emissions are achieved globally by 2050. This requires a holistic transition across all economic sectors. The scenario emphasizes the importance of decarbonizing the power sector, improving energy efficiency, increasing renewable energy, and using innovative new technologies to address hard-to-reduce emissions. Transition risks to the economy arise from higher emissions costs and shifts in business and consumer preferences. The *Net Zero 2050* scenario is characterized by relatively low physical risks associated with climate change impacts. It illustrates a "best case" path to a sustainable future with reduced global warming and minimal irreversible physical damage.

'Current Policies' Scenario

This “business-as-usual” scenario assumes that current climate policies remain unchanged, with no future increase in policy ambition. In other words, this scenario reflects a continuation of existing efforts and policies. Under this assumption, the scenario is characterized by high physical risks from a combination of large global temperature increases and insufficient mitigation efforts. Emissions continue to rise until 2080, culminating in global warming of around 3°C. This scenario underscores the urgent need for additional action and increased ambition to avoid significant and irreversible impacts, such as increased sea level rise, disruptions to ecosystems, health, infrastructure and supply chains. The business-as-usual policy assumption can be seen as a lower bound for actual policy implementation in the coming decades, making the *Current Policies* scenario a "worst-case" pathway among the NGFS scenarios.

‘Delayed Transition Scenario’

The *Delayed Transition* scenario reflects a narrative in which global annual emissions do not begin to decline until 2030, requiring aggressive policies to keep warming below 2°C, with limited deployment of negative emission technologies. It assumes a delay in the introduction of new climate policies until 2030, with policies varying widely across countries, potentially leading to prolonged reliance on fossil fuels. The scenario assumes limited availability of CCS technologies. As a result, emissions show steeper declines after 2030 in order to stay below 2°C of global warming. This scenario is characterized by higher transition and physical risks compared to *the Net Zero 2050* scenario, with a policy ambition of 1.6°C, a delayed policy response, uncertain technological change, and low to medium use of CDR amidst high regional policy variation.

Comparison of Transition Risks and Physical Risks in the NGFS scenarios

Table 1 summarizes the assumptions and narratives relevant to the *Current Policies*, *Delayed Transition*, and *Net Zero 2050* scenarios, with a particular focus on physical and transition risks. With respect to physical risk, the scenarios are evaluated based on their policy ambition and policy response. The *Net Zero 2050* scenario targets a 1.5°C limit and involves immediate and smooth policy responses to climate change, complemented by rapid technological development and medium-term implementation of carbon removal strategies. Conversely, the *Current Policies* scenario, associated with a target of more than 3°C, lacks any specific policy ambition or response and shows a slow evolution in responding to climate challenges, together with minimal deployment of carbon removal technologies. The *Delayed Transition* scenario falls in between, with a policy ambition of 1.6°C global warming, low to medium use of CCS technology and wide regional policy variation.

	Physical Risk	Transition Risk			
Scenario	Policy Ambition	Policy Reaction	Technological Change	Carbon Dioxide Removal	Regional Policy Variation
Net Zero 2050	1.4°C	Immediate and Smooth	Fast Change	Medium Use	Medium Variation
Current Policies	3°C +	None	Slow Change	Low Use	Low Variation
Delayed Transition	1.6°C	Delayed	First Slow, then Fast	Low-Medium Use	High Variation

Table 1: Summary of the various assumptions and narratives included in the selected NGFS scenario paths.

Transition risks are significant in the *Net Zero 2050* scenario, which requires immediate and robust policy action to mitigate the impacts of climate change. As a result of these mitigation actions, physical risks are not as pronounced in this scenario. Conversely, the transition risk in *the Current Policies* scenario is relatively low due to the implementation of fewer high-impact transformation processes. In comparison, the physical risks are pronounced in this scenario, as temperatures are assumed to rise significantly under *Current Policies*. Similar notions of low transition (high physical risks) in “business-as-usual” scenarios and high transition (low physical risks) in strong mitigation scenarios are common in scenario databases outside the NGFS. The *Delayed Transition* shows a medium long-term physical risk, as mitigation is still successful, and the temperature increase is limited to +1.6°C. However, this scenario is characterized by a high transition risk due to the late policy and technology transition, which requires a rapid and disruptive change in economic, social and political pathways.

3.3 Selected Case Study Regions

The selection of NGFS scenarios calculated with GCAM allows for a regional focus in the analysis of scenario pathways. This report focuses on seven selected case study regions that represent a significant proportion of the global population. These regions were chosen to cover a wide range of geographical locations, developmental and sustainability transition challenges, and to facilitate stakeholder interaction for partner organizations within the SPES project. The selection of these case study regions provides a diverse representation of different global regions, reflecting different stages of development, geographical characteristics and sustainability transition challenges.

- EU-15: The EU-15 region represents some of the most economically developed countries in the world, including countries such as France, Italy and Denmark.[2] Regional challenges include the complexities of phasing out older, established energy infrastructure in favor of innovative, sustainable solutions. The EU-15 illustrate the dual objective of enhancing overall well-being and quality of life while also meeting stringent environmental targets and fostering sustainable development.
- EU-12: The EU-12 region includes Eastern European countries such as Hungary and Romania. The energy transition in this region poses the challenge of further improving the standard of living while at the same time transitioning, in part, from former socialist systems to market-driven economies under contemporary sustainability imperatives, such as the ambitious sustainability goals of the EU.
- India: India's energy transition is central to global efforts to achieve sustainability. Its challenges stem from the energy needs of its large population, an existing coal-heavy energy infrastructure, and the need to provide access to energy for all while balancing economic growth, well-being, sustainable practices, and transition management in a highly heterogeneous and large country.
- Pakistan: With a growing population and economy, Pakistan faces challenges in securing a stable energy supply and transitioning away from fossil fuels. Political dynamics further complicate the energy transition.
- Colombia: Colombia has vast natural resources and is facing the dual challenge of harnessing its resources for economic growth and improving well-being while maintaining environmental and sustainability standards. Colombia provides insights into the interplay between economic aspirations and conservation imperatives in a resource-rich country affected by long-run conflict activity.
- Western Africa: West Africa, which includes countries such as Nigeria, Ghana, and Burkina Faso, is characterized by a diverse landscape of energy needs and resources. The region faces the challenge of expanding energy access, addressing infrastructure challenges, and using resources sustainably.
- Eastern Africa: East Africa, including countries such as Kenya, Tanzania and Uganda offers insights into a contrast of urban and rural energy dynamics and faces the challenge of improving energy access while integrating renewable energy sources. The region exemplifies

[2] For a comprehensive mapping of the selected case study regions and their respective scenarios, readers are referred to the GCAM modeling framework technical documentation (https://jgcri.github.io/gcam-doc/toc.html).

the complexities of transitioning to sustainable energy in a rapidly developing context, including issues of energy infrastructure, rural electrification and renewable energy integration at a regional scale.

While the NGFS scenarios used in this report provides several regional perspectives, it is important to acknowledge that these may lack granularity due to the significant differences between countries within each region. The regional focus is consistent with current practice in the IAM literature. While there are obvious issues of complexity associated with the production of country-specific scenarios, they would be valuable to policy makers who often operate predominantly at the national level. In this sense, the lack of comparable country-specific scenarios can be seen as a shortcoming of the current literature. We expect that as downscaling algorithms become more widely used and available, more granular pathways will be developed, allowing for a more detailed assessment of specific countries within each region. To provide insights beyond the regional level, Section 4 aims to complement the regional results with country-specific literature on sustainability transitions, while also highlighting the limitations of such an exercise.

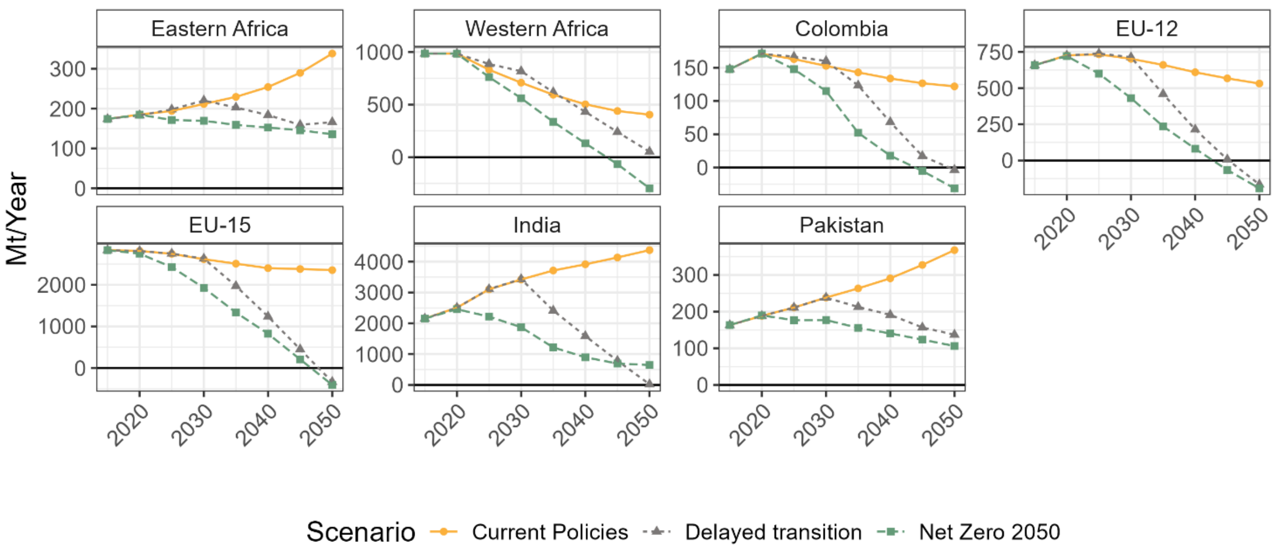

Figure 1: Scenario pathways for CO2 emissions in the selected case study regions, measured in megatons per year for the selected scenarios. Note that the y-axis uses different scales per panel for visualization purposes

3.4 Policy, Technology and Structural Change in the Energy Sector

Achieving significant reductions in greenhouse gas emissions is, by definition, an essential component of the transition to a net zero carbon economy. Figure 1 visualizes scenario pathways for CO2 emissions in the seven selected case study regions. In all regions, large absolute emission reductions are required to achieve net zero emissions. For India, Pakistan and East Africa, the business-as-usual emissions trajectories point steeply upward. Meanwhile, regions such as West Africa, Colombia and the EU could experience slightly negative emissions growth rates even under current policies. The *Delayed Transition* scenario illustrates the fact that if emissions reductions do not start until 2030, a steeper emissions gradient is needed to reach net-zero by 2050. The substantial reductions in CO2 emissions in the *Net Zero 2050* and *Delayed Transition* scenarios require the implementation of targeted mitigation strategies based on robust policy instruments, as well as technological change, as illustrated in the remainder of this section.

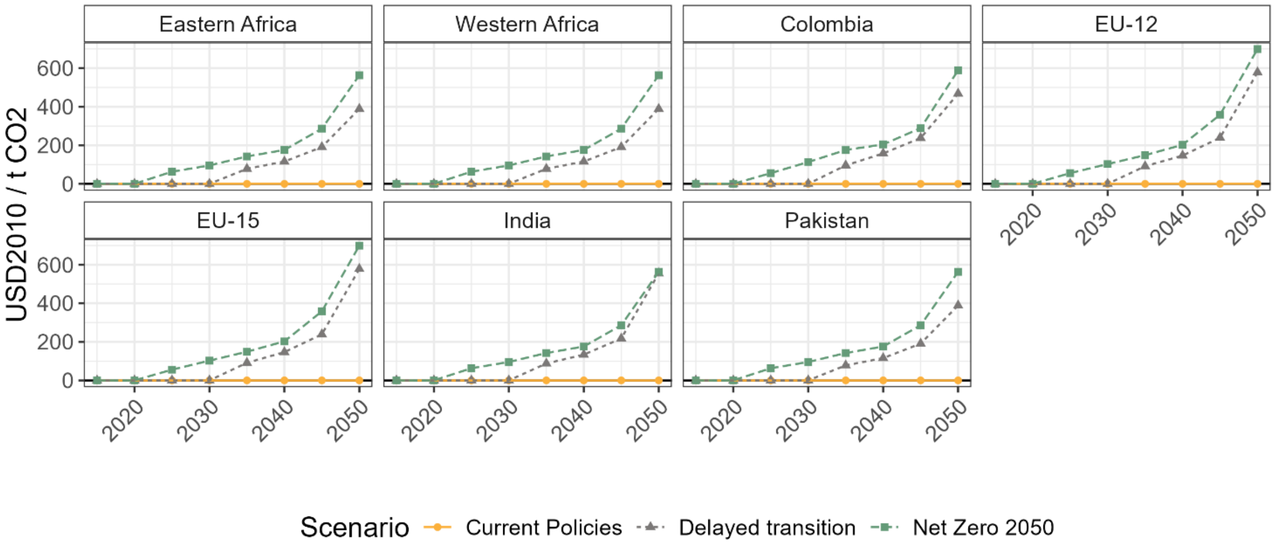

Figure 2: Shadow carbon price scenario paths in the selected case study regions, measured in 2010 USD per ton CO2 for selected scenarios.

Direct and Indirect Carbon Pricing

In terms of policy, the NGFS scenarios summarize the main policy instruments that can drive the required emissions reductions in a single policy variable of interest: the cost of producing carbon emissions. Direct and indirect carbon pricing are seen as primary policy instruments for reducing emissions because they provide financial incentives to reduce emissions and potentially steer investment toward low-carbon technologies. Governments are assumed to use a variety of fiscal and regulatory policies that directly and indirectly affect the cost of emissions. In the NGFS scenarios, the carbon price therefore represents a so-called *shadow emissions price* that reflects not only an actual price or tax on carbon emissions, but a combination of policies.[3] In the NGFS scenarios, a higher shadow price of emissions implies a generally stricter policy approach.

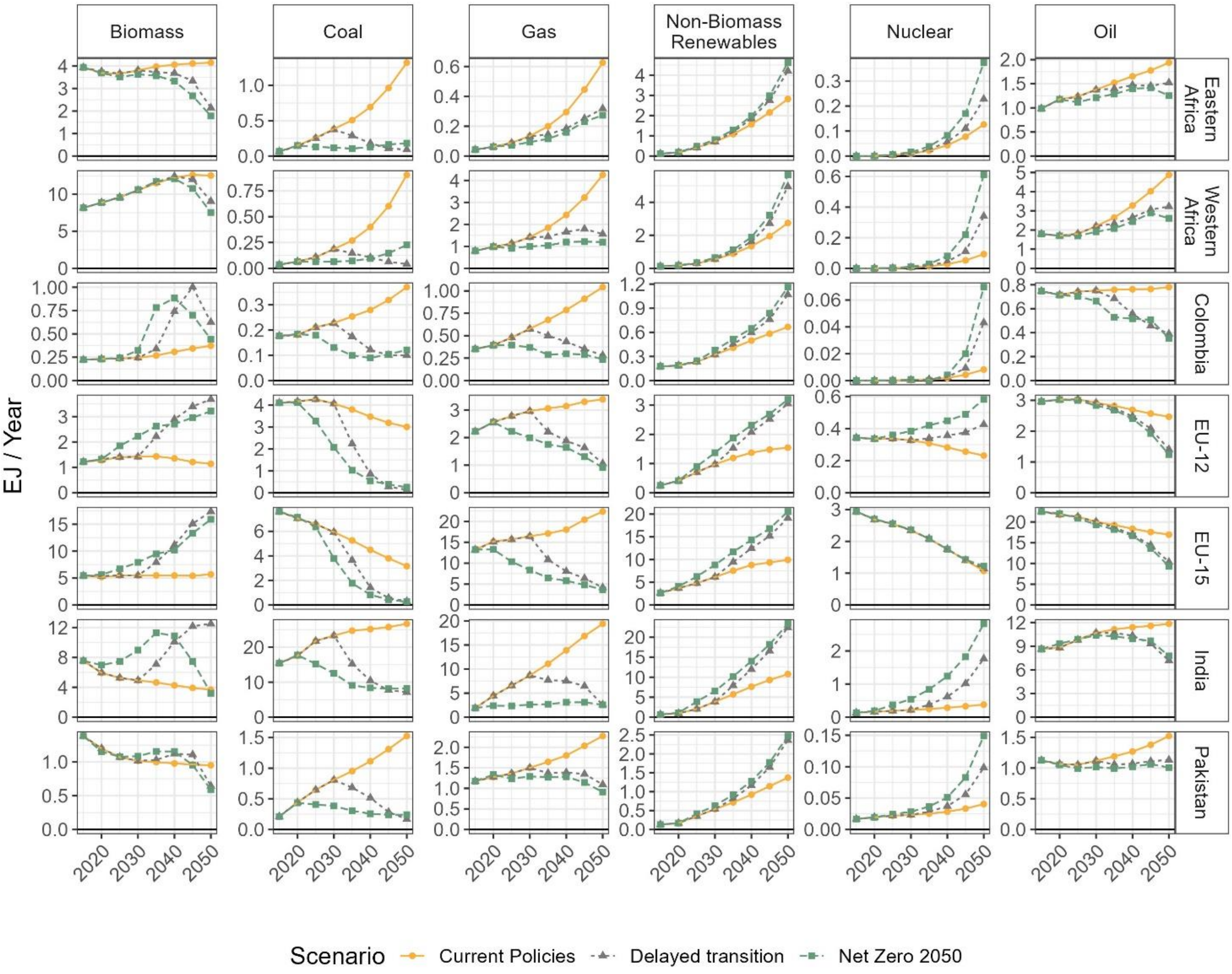

Figure 3: Primary energy consumption scenario paths by energy type in the selected case study regions, measured in exajoules per year for the selected scenarios. Note that the y-axis uses different scales per panel for visualization purposes.

[3] Carbon pricing mechanisms can be divided into direct and indirect approaches, depending on how they affect greenhouse gas emissions. A *shadow* carbon price reflects the implicit monetary cost of emitting a ton of CO2 caused by a given mix of these direct and indirect policy measures. Direct carbon pricing mechanisms include emissions trading systems (ETSs), in which emitters can trade a limited number of emission allowances, effectively capping total emissions; carbon taxes, which set a fixed price for each ton of CO2 emitted; carbon credits, which allow emitters to compensate for their emissions by investing in projects that reduce, avoid or remove emissions elsewhere; and results-based financing, in which payments are made only after emission reduction targets are met and verified. Conversely, indirect carbon pricing mechanisms include fuel taxes, which are designed to reduce the use of fossil fuels and encourage the transition to renewable energy; renewable portfolio standards, which require that a certain percentage of an energy provider's supply come from renewable sources; and feed-in tariffs, which incentivize the development of renewable energy by guaranteeing producers above-market prices for their output.

Figure 2 illustrates the path of the shadow carbon price for the selected scenarios. Under current policies, this shadow price is close to zero, and a significant increase is required for a sustainable emissions path in the *Net Zero 2050* scenario. In the *Delayed Transition* scenario, this price increase and disincentive must be implemented much more quickly, potentially leading to greater social and economic disruption.

Renewable Primary Energy Mix

Figure 3 provides a more detailed analysis of primary energy consumption scenarios by type of energy source. A sustainable energy sector by mid-century requires a rapid and significant reduction in the use of emission-intensive fossil fuels such as gas, coal and oil. In the medium term, a significant increase in the use of renewable energy sources such as solar, wind and hydro is essential. During the transition period, biomass can act as a "buffer energy source" in some regions, easing the transition to renewable alternatives.

Electrification and Carbon-Neutral Fuels

The transition from carbon-intensive fuels such as coal, oil and gas to carbon-neutral electricity, combined with the electrification of many sectors, including buildings, industry and transport, is key to reducing greenhouse gas emissions (Schiermeier et al., 2008; Sacchi et al., 2022). Figure 4 provides a detailed view of the electricity shares in final energy for the three illustrative scenarios, broken down into the "industry", "buildings" and "transport" sectors. The scenario paths imply strong increases in the share of electricity in final energy consumption in all sectors, but with particular emphasis on the buildings and transport sectors. The transition to carbon-neutral fuels, such as green hydrogen, biofuels and synthetic fuels, can provide viable alternatives where electrification is not feasible. Additional investment and policy incentives are needed to scale up these carbon-neutral fuel options and ensure that their production is carbon-neutral.

Increasing Energy Efficiency

The phase-out of fossil fuels leads to a reduction in energy supply. If renewables cannot provide enough energy during the transition period, this can put upward pressure on energy prices. An important mechanism for reducing the burden on the renewable sector is increased energy efficiency, which reduces overall energy demand and allows a given building, transport or industrial unit to operate with less energy. Figure 5 shows the scenario paths for total primary energy consumption in exajoules per year. The net-zero and delayed transition paths indirectly reflect significant investments in energy efficiency compared to the business-as-usual scenario, where total energy demand grows more rapidly.[4]

[4] Examples of actions that can lead to increased energy efficiency include investing in R&D for energy-efficient technologies, conducting energy audits, or setting industry performance standards.

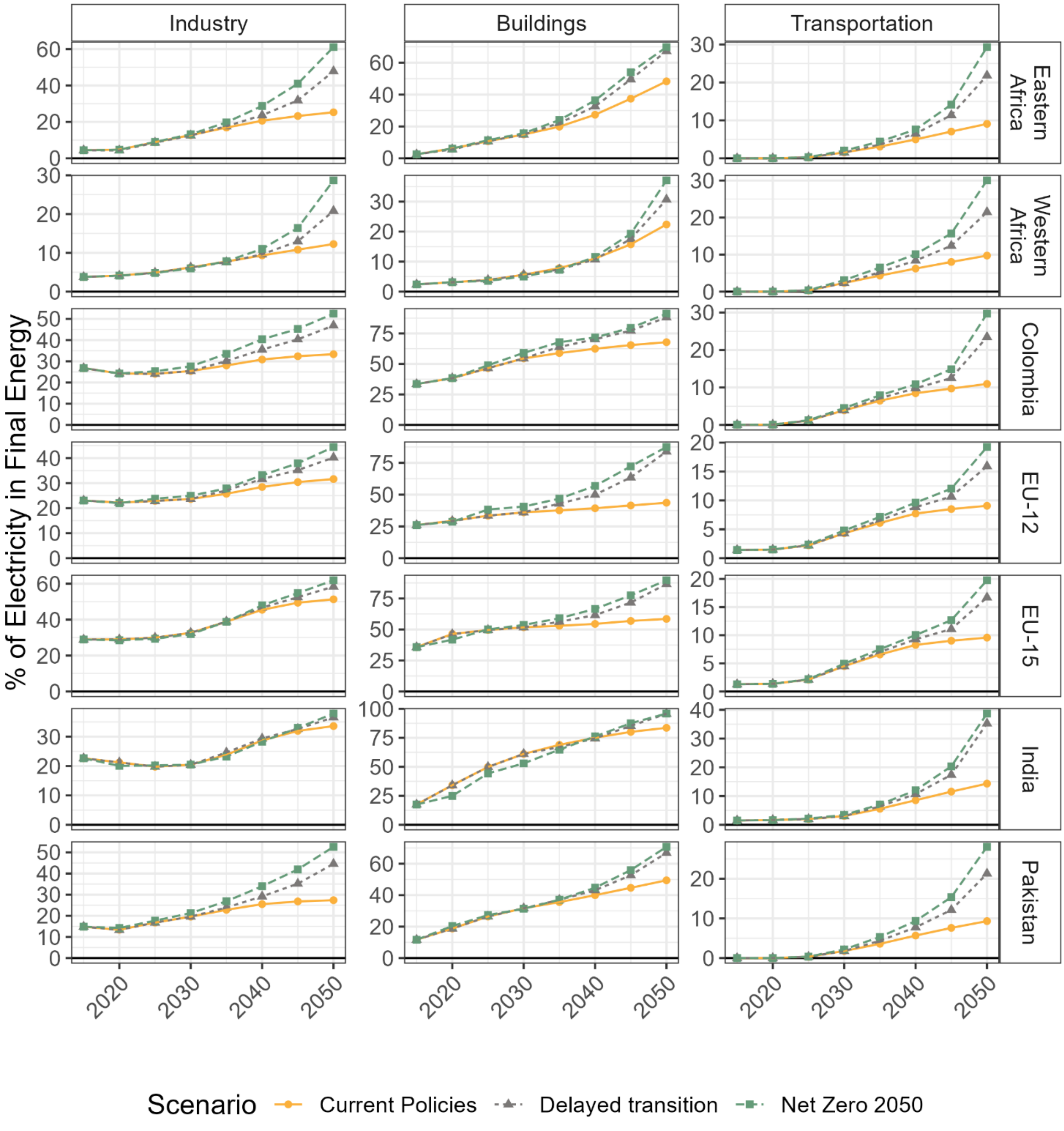

Figure 4: Share of electricity in the final energy scenario paths in the selected case study regions, measured in exajoules per year for the selected scenarios. Note that the y-axis uses different scales per panel for visualization purposes.

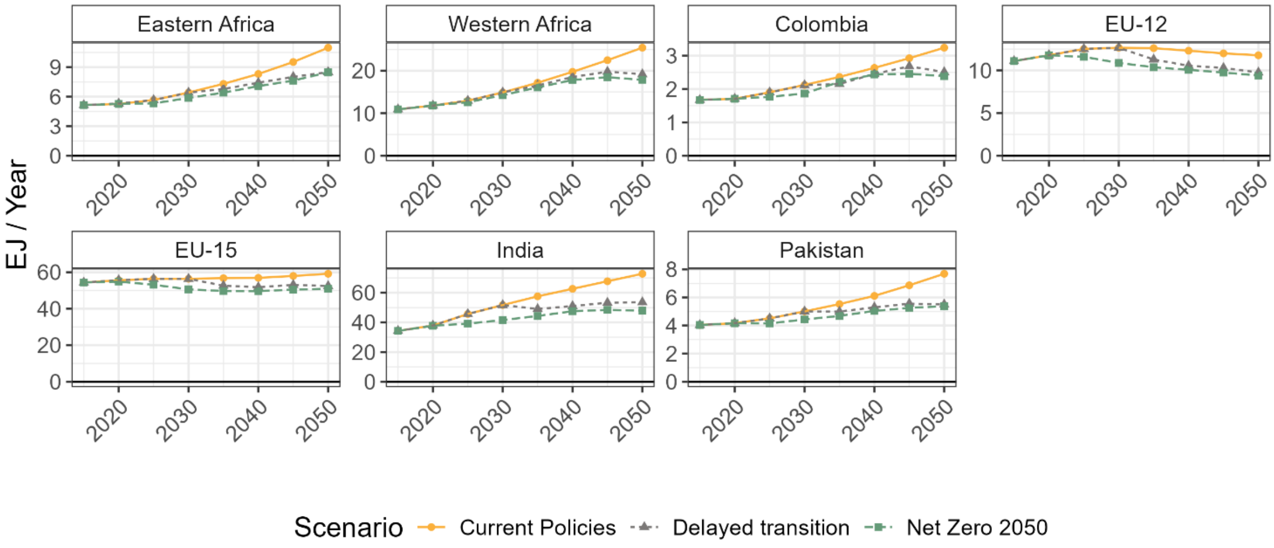

Figure 5: Total primary energy consumption scenario paths in the selected case study regions, measured in exajoules per year for the selected scenarios. Note that the y-axis uses different scales per panel for visualization purposes.

Decarbonizing Agriculture, Forestry, and Other Land Use

Agriculture, forestry, and other land use (AFOLU) accounts for a significant proportion of greenhouse gas emissions, largely due to deforestation and land clearing (Houghton et al., 2012). Achieving net zero targets will require addressing deforestation and promoting sustainable agricultural practices. Examples include reducing emissions from nitrogen-based fertilizers, phasing out intensive farming, adopting more environmentally friendly land management strategies, and possibly introducing dietary changes such as reducing meat consumption. In addition, AFOLU-oriented policies have the potential to reduce existing atmospheric greenhouse gases, for example through reforestation efforts.[5]

[5] In addition to afforestation and reforestation programs and forest protection regulations, reducing emissions in the AFOLU sector depends on land-use planning combined with financial incentives to support sustainable land use, such as maintaining permanent grasslands. Other measures include tax incentives and subsidies for sustainable agriculture, R&D investments in climate-resilient and low-emission crops, and innovative farming techniques, incentives for changes in food production, particularly in livestock farming, and changes in consumption patterns, such as reducing meat consumption.

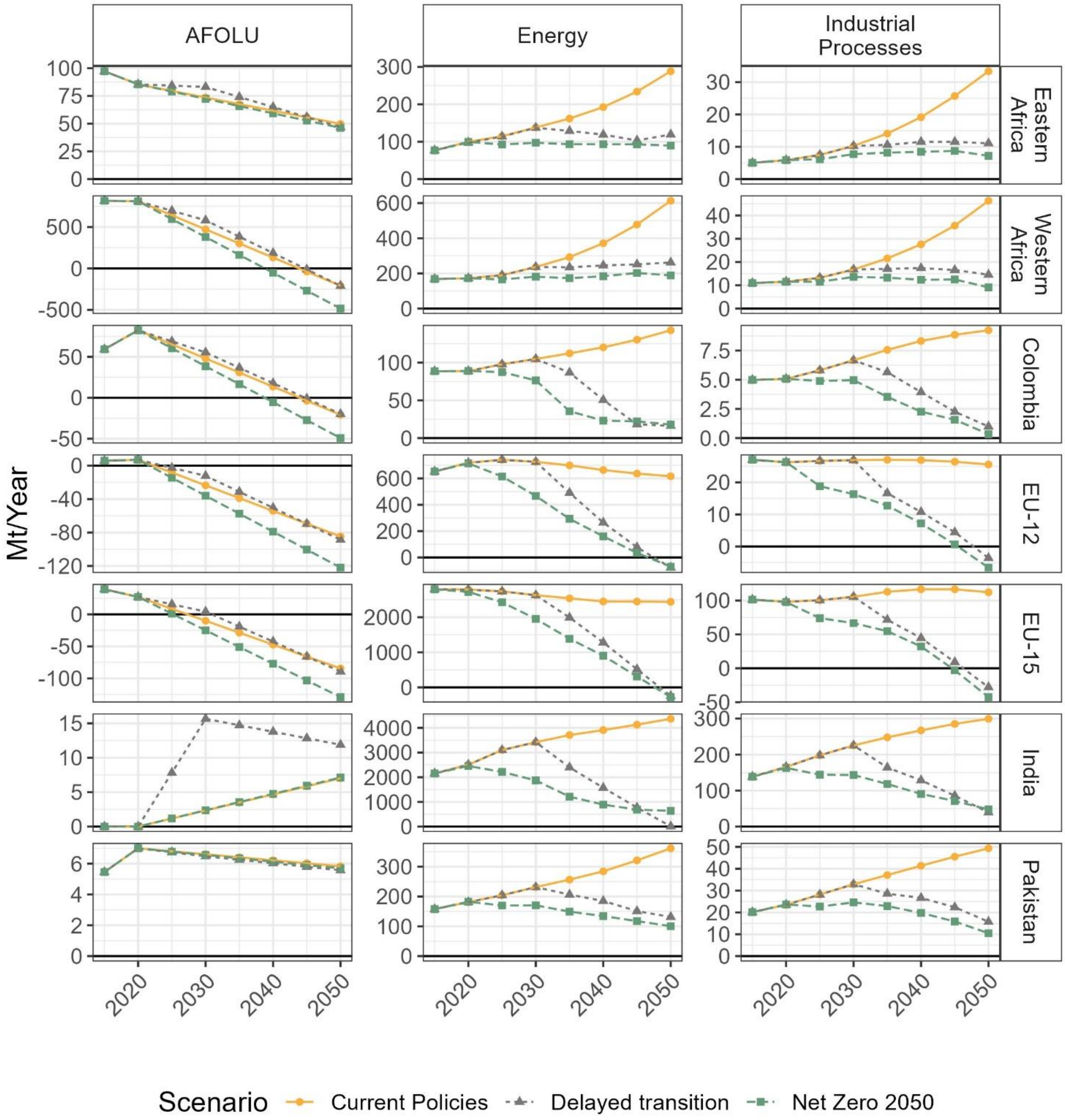

Figure 6: Sectoral scenario pathways for CO2 emissions in megatons per year for the selected scenarios in the selected case study regions. AFOLU stands for Agriculture, Forestry and Other Land Use. Note that the y-axis uses different scales per panel for visualization purposes.

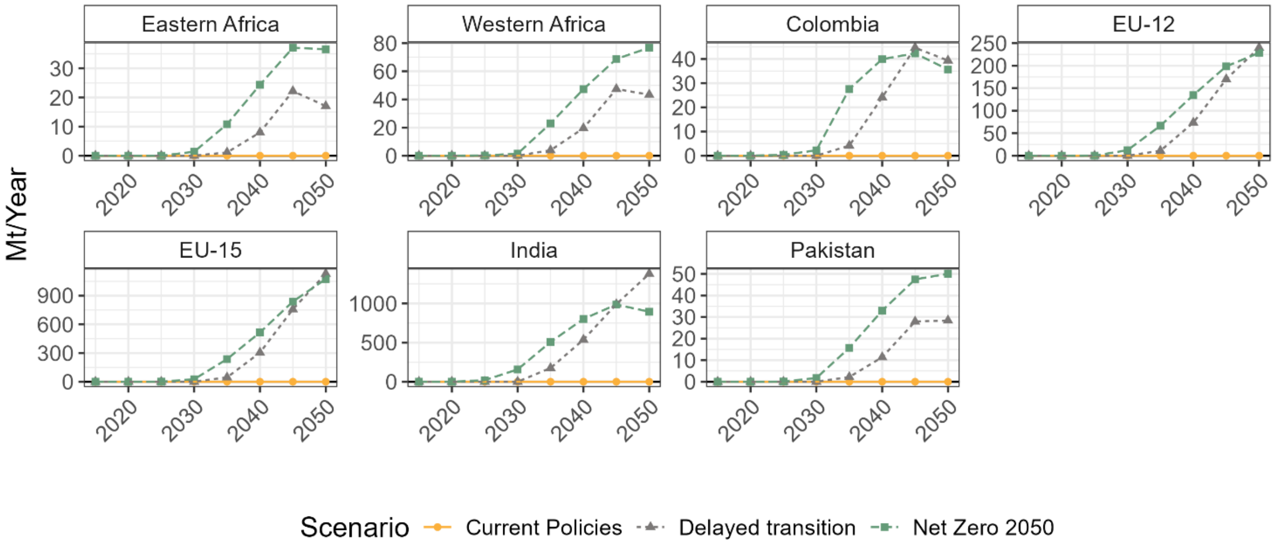

Figure 7: Carbon sequestration in megatons of CO2 per year for the selected scenarios in the selected case study regions. Note that the y-axis uses different scales per panel for visualization purposes.

Figure 6 breaks down the scenario pathways for CO2 reductions into three sectors: AFOLU, the energy sector, and industrial processes. The latter category includes processes other than fuel combustion, such as cement production. In all regions studied, the energy sector plays a key role in the sustainability transition. According to the NGFS scenarios, the AFOLU sector warrants particular attention in Colombia, East Africa and West Africa, where its emissions are similar in magnitude to those of the energy sector. While it appears feasible to reduce emissions from the AFOLU sector under currently enforced policies, more rigorous efforts and a further reduction in emissions characterizes the Net Zero 2050 scenario.

Carbon Capture and Storage (CCS) Technologies

Despite the fact that progress on CCS technologies remains uncertain and focusing on CCS can be viewed as controversial (Lenzi et al., 2018), they play a critical role in reducing atmospheric greenhouse gas emissions in current IAM based scenario analysis. **Figure 7** shows the scenario pathways for carbon sequestration in megatons per year for the selected case study regions. Beginning in 2030, some carbon sequestration is assumed in all regions to achieve net zero by mid-century. The *Net Zero 2050* scenario assumes a moderate level of availability of these technologies. The *Delayed Transition* scenario assumes a relatively late deployment of CCS technologies, and CCS is often deployed at lower levels. In general, this reflects the importance of the R&D sector and technological progress over the course of the energy transition.

4. Country Level: Complementing Regional Insights with Country-Specific Literature

One of the shortcomings and limitations of current scenario assessments is that most scenario literature focuses at most on regional narratives. While such analyses are likely to have some relevance for countries within these regions, they are likely to be too coarse to capture idiosyncratic country-specific factors relevant to sustainability transitions. Therefore, we aim to complement the "global" insights from major scenario reports and the "regional" insights from the NGFS scenarios with country-specific literature collected on various topics related to energy transitions and sustainability pathways, covering a variety of sustainability dimensions.

4. Methodology

Specifically, we conducted an AI-assisted literature review based on a search of the Semantic Scholar database, which contains more than 200 million academic articles from all academic disciplines.[6] After aligning the broader literature on scenario analysis, and the SPES sustainability framework (Biggeri et al., 2023), we focused the review on twelve prompts for each country, resulting in a total of 88 prompts. For each prompt, the AI tool retrieved the top eight most relevant papers from the Semantic Scholar database. The prompts focus on different dimensions of sustainability and are as below:

1. What are key sustainability challenges and opportunities identified in scenario analyses of sustainability transitions in [COUNTRY]?
2. What policy frameworks and strategies have been proposed or implemented for sustainability transitions in [COUNTRY]?
3. How do scenario analyses address technological innovations and their role in sustainability transitions in [COUNTRY]?
4. What economic impacts are associated with sustainability transitions in [COUNTRY] according to scenario analyses?
5. How do societal attitudes and behaviors influence sustainability transitions in [COUNTRY], as depicted in scenario analyses?
6. What environmental outcomes are projected or aimed for in sustainability transition scenarios in [COUNTRY]?
7. How do scenario analyses address the role of international cooperation and global frameworks in [COUNTRY]'s sustainability transitions?
8. What are the identified barriers and enablers for achieving sustainability transitions in [COUNTRY] according to scenario analyses?
9. How do scenario analyses incorporate considerations of equity and justice in sustainability transitions in [COUNTRY]?

---

[6] The review was conducted using the proprietary software tool 'Elicit'.

10. What future research directions are suggested by scenario analyses for understanding and facilitating sustainability transitions in [COUNTRY]?
11. What are the key sectors to focus on for a sustainability transition in [COUNTRY], according to scenario analyses?
12. How do scenario analyses address the impacts of carbon emissions markets and border adjustments, specifically focusing on the EU ETS2 and the Carbon Border Adjustment Mechanism (CBAM), on sustainability transitions in [COUNTRY]?

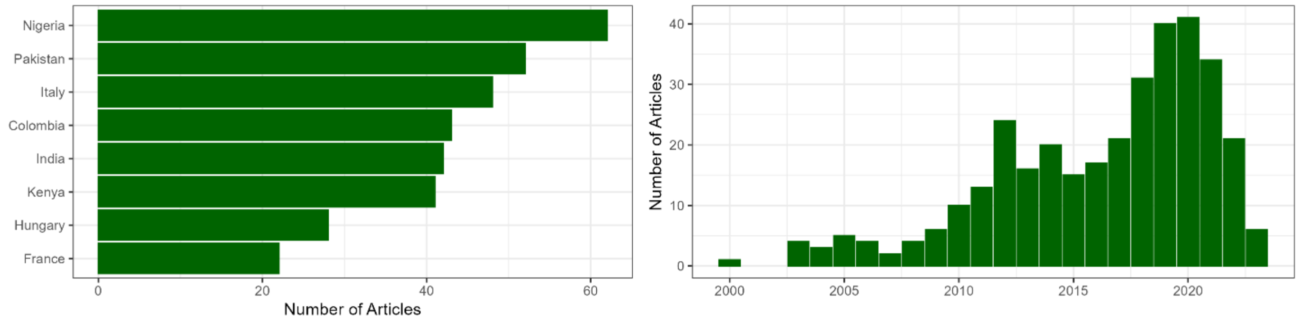

Figure 8: Distribution of 338 retrieved articles in country-specific literature by focus country and year of publication.

This set of prompts has been selected to provide a detailed assessment of the literature related to sustainability transitions in the selected case study countries. The prompts cover key aspects such as sustainability challenges and opportunities, policy frameworks, technological impacts, economic impacts, societal attitudes, environmental goals, international cooperation, barriers and enablers, equity and justice, and others. Each question is designed to explore a specific area of interest, to ensure a comprehensive understanding, and to actively seek some overlap in the results the AI provides after searching the Semantic Scholar database to make the set of results more robust.

All queries were performed for each case study country, collecting information on the titles, authors, years of publication, citation counts, and AI-based summaries of the abstracts and content of each article. The resulting set of 768 academic articles was then manually pre-screened for duplicates, articles that did not specifically refer to one of the case study countries in the title, abstract, or summary, and articles that were otherwise considered irrelevant or off-topic. In addition, to focus on recent evidence, we restricted the set of articles to those written after 1999. This pre-screening resulted in a total of 338 articles.

4.2 Results

Figure 8 shows the distribution of these articles by country and year. Depending on the country, we collected between 22 (France) and 62 (Nigeria) articles for further analysis. Most of the articles we retrieved were written in recent years. To isolate key policy areas and summarize the content of the articles for quick communication, we manually reviewed

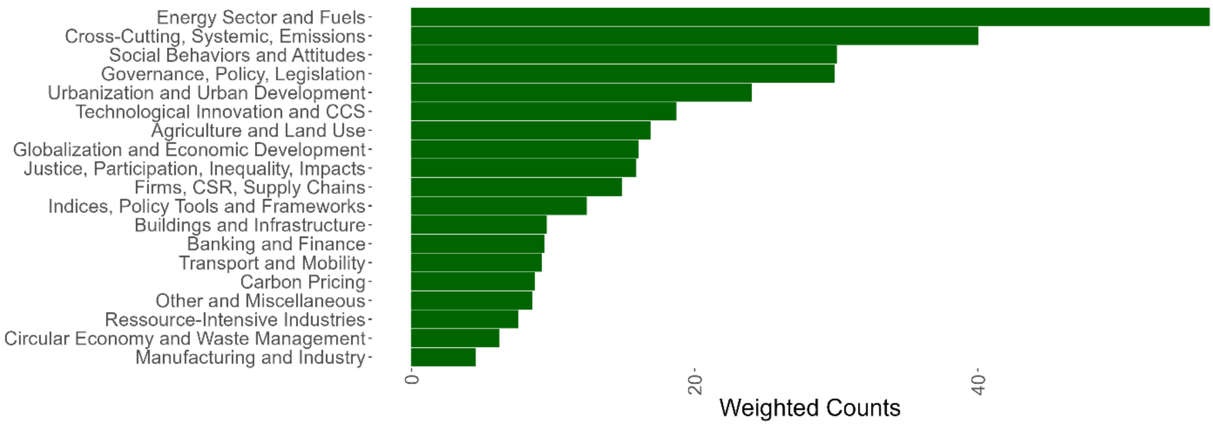

Figure 9: Weighted scores by policy area from country-specific literature review. Refer to the text for details.

the summarized content of each of the 338 articles. Based on these summaries, we assigned codes to describe the overall topic or policy area of the article. Between one and three codes were used for each article. Based on the thematic similarity of these codes, we further summarized them into 19 topic clusters, which are detailed and illustrated in Appendix A.

For each article, we calculate a score that relates the article to the categories. If an article is coded in only one category, the score is 1; if the article is coded in two categories, we use 1/2 as the weight for both categories; and if an article is coded in three categories, the weights are 1/3 for each category. Figure 9 shows the distribution of the scores of the 338 articles analyzed across these broad categories. Unsurprisingly, the majority of articles deal with issues related to the energy sector, suggesting the importance of restructuring this sector, regardless of the country. In addition, systemic and cross-cutting issues receive a great deal of scholarly attention, underscoring the systemic nature of sustainability transitions. It should be noted that the articles analyzed not only span the scenario-based literature, but also go beyond it, complementing the scenario literature outlined earlier in this report.

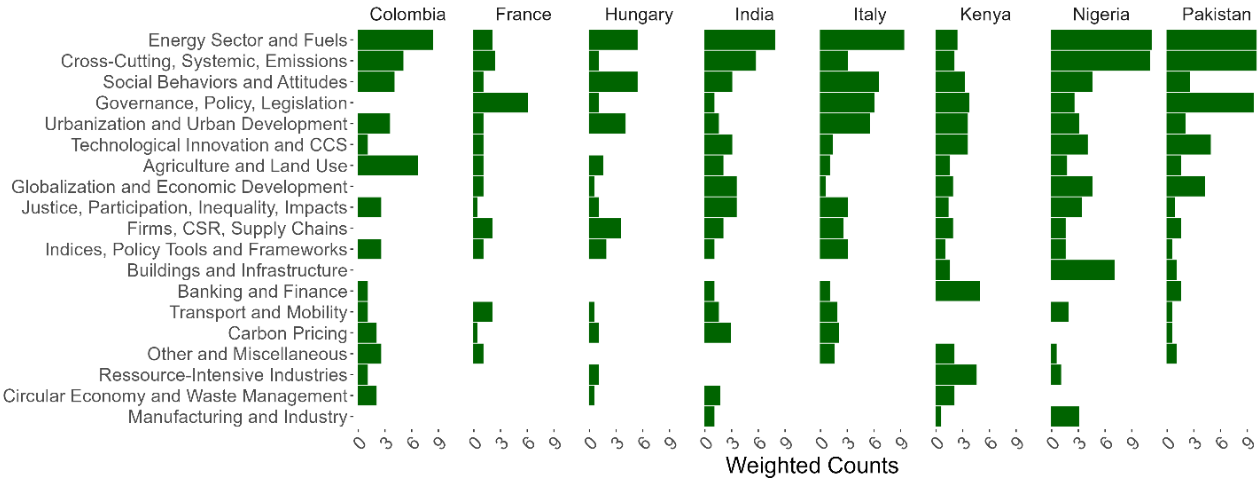

Figure 10: Weighted scores by policy area and country from country-specific literature reviews. Refer to the text for details.

Figure 10 shows the distribution of weighted policy scores by country. On the one hand, this figure again underlines the importance of the energy and fuel sector in this literature. On the other hand, this figure reveals some focal points of academic research that go beyond aggregate and regional findings and point to the existence of sustainability issues that are specific to each country. The results suggest that the literature in Colombia focuses comparatively often on issues related to agriculture and land use. Beyond the categorization of policy codes, it is worth to note that managing sustainability transitions in the context of conflict was a distinct theme that emerged in selected articles related to Colombia. For France, there is a strong emphasis on the category of governance, policy and legislation. In addition, nuclear energy was a rather unique theme that emerged in the review of the papers. For Italy and Hungary, there was a strong emphasis on social behavior and attitudes, while for Italy, urban development was another key issue. For India, there was a strong emphasis on international cooperation and globalization, but also on the role of emissions in the context of economic development. In Kenya, we found that resource-intensive industries (charcoal sector) and finance were key issues discussed in the literature, with a focus on comparisons with countries in the Global North. In Nigeria, there is a strong focus on the building and construction sector. The particular focus of Pakistan that we identify relates to issues of governance, policy uncertainty and political stability, which have been identified as major obstacles to sustainability transitions in the country.

4.3 Limitations

While this country-specific summary of key policy areas is potentially insightful and adds to the global and regional evidence discussed so far, there are a number of limitations to the analysis presented. First and foremost, the policy areas most frequently discussed in the academic literature do not automatically correspond to the most important issues on which policy should focus, but rather reflect what is discussed in the academic literature. However, we expect a significant overlap between the most pressing issues in a country and the issues being researched by academics focusing on that country.

In addition, the Semantic Scholar database likely misses non-academic policy reports on topics of interest. Collecting and reviewing policy reports for each case study country is a promising avenue for future research on sustainability transitions but was not feasible in the course of preparing this report. This task requires in-depth knowledge of local policy landscapes, including monitoring local conferences and presentations, simply to collect the relevant literature - prior to any efforts at interpretation, comparison, or contextualization within local policy frameworks. To strike a balance between comprehensiveness and comparability, we opted for a traditional literature review.

In addition, a likely limitation for the EU countries analyzed in this report is that many important issues and academic discourses take place at the level of the European Union rather than at the country level. However, these issues are usually addressed in the broader regional and global scenario papers discussed earlier in this report, and the regional findings are likely to be more directly applicable to EU countries.

Finally, while the manual coding scheme provides a degree of consistency, it is only one of many possible coding schemes. A further challenge in assigning appropriate codes is that many of the issues and policy areas are closely interrelated and often difficult to separate. We have attempted to account for this by coding papers that cover many issues simultaneously as 'systemic' or 'general' to distinguish them from more focused 'single issue' papers. Further research could look at topic modeling to categorize papers (see also Biggeri et al., 2023).

5. Conclusion and Discussion

This report summarizes several key insights drawn from the overarching and overlapping elements of different scenario reports and pathways. To provide a more nuanced perspective at the regional level, these top-level insights are combined with illustrative scenario pathways that are used to highlight key policy tools and insights on sustainability transitions for a set of case study regions. Finally, to further complement the regional insights, a country-specific literature review is conducted to identify key focal areas of policy interest for each case study country.

The collective assessment and presentation of the selected scenarios and reports underscores the urgent need for significant emissions reductions and a transition to a low-carbon economy. Electrification, increased energy efficiency and the expansion of renewable energy are highlighted as key steps in the energy sector to further reduce emissions, with CDR seen as a core area to reduce accumulated past emissions. The assessment reaffirms the importance of robust climate policies, innovation and coordinated action across sectors and regions to address climate change challenges and meet global climate goals.

While many facets of mitigation and transition are consistent across the regions studied, the GCAM NGFS scenarios highlight some distinct regional differences. For example, while phasing out coal is a universal goal, it is particularly relevant as a central issue in the EU-12, India and Pakistan. Despite this heterogeneity, the overarching qualitative goals remain broadly consistent across regions. The country-specific literature reviews reveal additional country-specific key policy areas, such as policy uncertainty and governance in Pakistan, natural resource-intensive industries in Kenya, or agriculture and land use and conflict in Colombia. Future research could focus on developing country-specific databases that compile comparable information from national policy reports and reports from intergovernmental organizations with a local policy focus. This approach would allow for more tailored policy proposals and tools for each country, a task beyond the scope of this report.

Finally, it is important to acknowledge that while scenario analysis is a valuable tool for strategic planning and for fostering dialogue among scientists, policy makers and stakeholders, scenario building has certain limitations. These limitations include strict assumptions on market and human behavior as well as a tendency to neglect the social costs associated with transitions. The NGFS scenarios offer scenario pathways for selected macroeconomic indicators that could serve as a useful starting point for similar future studies. In general, there is a need to expand currently available modeling tools to include broader concepts of sustainability. In addition, the influence of global uncertainties, such as pandemics and conflicts, on transition requirements and outcomes further complicates reliance on long-term scenarios. At the same time, these uncertainties highlight the need for robust policy development. To address these uncertainties and complexities associated with climate change mitigation and sustainability transitions, more in-depth research and analysis is needed. Two key areas are the development of country-specific scenario pathways of direct relevance to national policy makers, and further and more detailed assessments of socio-economic, political and cultural transition risks.

References

Alcamo, J. (Ed.). (2008). Environmental futures: the practice of environmental scenario analysis. Elsevier.

Ansari, D., & Holz, F. (2020). Between stranded assets and green transformation: Fossil-fuel-producing developing countries towards 2055. World Development, 130, 104947.

Bataille, C., Waisman, H., Colombier, M., Segafredo, L., & Williams, J. (2016). The deep decarbonization pathways project (DDPP): insights and emerging issues. Climate Policy, 16(sup1), S1-S6.

Belmin, C., Hoffmann, R., Pichler, P. P., & Weisz, H. (2022). Fertility transition powered by women's access to electricity and modern cooking fuels. *Nature Sustainability*, *5*(3), 245-253.

Berger, T., & Troost, C. (2014). Agent-based modelling of climate adaptation and mitigation options in agriculture. *Journal of Agricultural Economics*, *65*(2), 323-348.

Bertram, C., Hilaire, J., Kriegler, E., Beck, T., Bresch, D. N., Clarke, L., ... & Yu, S. (2020). NGFS Climate Scenarios Database: Technical Documentation.

Bianchi, S., & Richiedei, A. (2023). Territorial Governance for Sustainable Development: A multi-level governance analysis in the Italian context. Sustainability, 15(3), 2526.

Biggeri, M., Ferrannini, A., Lodi, L., Cammeo, J., & Francescutto, A. (2023). The "winds of change": The SPES framework on sustainable human development. SPES Working paper no. 2.1. University of Florence.
https://www.sustainabilityperformances.eu/wp-content/uploads/2023/10/SPES-Working-paper-2.1_29th-September-2023_FINAL.pdf

Bouckaert, S., Pales, A. F., McGlade, C., Remme, U., Wanner, B., Varro, L., ... & Spencer, T. (2021). Net zero by 2050: A roadmap for the global energy sector.

Bouvart, F., Coussy, P., Heng, J., Michel, P., & Ménard, Y. (2011). Environmental assessment of carbon capture and storage deployment scenarios in France. Energy Procedia, 4, 2518-2525.

Byers, E., Krey, V., Kriegler, E., Riahi, K., Schaeffer, R., Kikstra, J., ... & Al Khourdajie, A. (2022). AR6 scenarios database hosted by IIASA. doi: 10.5281/zenodo.5886911 | url: data.ece.iiasa.ac.at/ar6/

Calvin, K., Patel, P., Clarke, L., Asrar, G., Bond-Lamberty, B., Cui, R. Y., ... & Wise, M. (2019). GCAM v5. 1: representing the linkages between energy, water, land, climate, and economic systems. *Geoscientific Model Development*, *12*(2), 677-698.

Capros, P., De Vita, A., Tasios, N., Siskos, P., Kannavou, M., Petropoulos, A., ... & Kesting, M. (2016). EU Reference Scenario 2016-Energy, transport and GHG emissions Trends to 2050.

Charpentier, A. (2008). Insurability of climate risks. The Geneva Papers on Risk and Insurance-Issues and Practice, 33, 91-109.

Cianconi, P., Betrò, S., & Janiri, L. (2020). The impact of climate change on mental health: a systematic descriptive review. Frontiers in psychiatry, 11, 74.

Creutzig, F., Roy, J., Devine-Wright, P., Díaz-José, J., Geels, F., Grubler, A., ... & Weber, E. (2022). *Demand, services and social aspects of mitigation* (pp. 752-943). Cambridge University

Press.Cologna, V., & Siegrist, M. (2020). The role of trust for climate change mitigation and adaptation behaviour: A meta-analysis. Journal of Environmental Psychology, 69, 101428.

Diluiso, F., Annicchiarico, B., Kalkuhl, M., & Minx, J. C. (2021). Climate actions and macro-financial stability: The role of central banks. Journal of Environmental Economics and Management, 110, 102548.

Distefano, T., Lodi, L., & Biggeri, M. (2024). Material footprint and import dependency in EU27: Past trends and future challenges. *Journal of Cleaner Production*, *472*, 143384.

Edomah, N. (2019). Governing sustainable industrial energy use: Energy transitions in Nigeria's manufacturing sector. Journal of Cleaner Production, 210, 620-629.

Fermani, A., Crespi, I., & Stara, F. (2016). Sustainable hospitality and tourism at different ages: Women's and men's attitudes in Italy. Research in Hospitality Management, 6(1), 83-92.

Frei, C., Whitney, R., Schiffer, H. W., Rose, K., Rieser, D. A., Al-Qahtani, A., ... & Volkart, K. (2013). World energy scenarios: Composing energy futures to 2050 (No. INIS-FR--14-0059). Conseil Francais de l'energie.

Future Earth, The Earth League, WCRP (2023). 10 New Insights in Climate Science 2023/2024. Stockholm

Gómez-Navarro, T., & Ribó-Pérez, D. (2018). Assessing the obstacles to the participation of renewable energy sources in the electricity market of Colombia. Renewable and Sustainable Energy Reviews, 90, 131-141.

Gomez-Valencia, M., Vargas, C., & Gonzalez-Perez, M. A. (2022). Regenerative and Sustainable Futures for Colombia. Regenerative and Sustainable Futures for Latin America and the Caribbean, 161-185.

Hare, B., Brecha, R., & Schaeffer, M. (2018). Integrated assessment models: What are they and how do they arrive at their conclusions. *Climate Analytics*, *8*(4).

Heger MP, Zens G, Bangalore M. Land and poverty: the role of soil fertility and vegetation quality in poverty reduction. *Environment and Development Economics*. 2020;25(4):315-333. doi:10.1017/S1355770X20000066

Hickel, J., & Slamersak, A. (2022). Existing climate mitigation scenarios perpetuate colonial inequalities. *The Lancet Planetary Health*, *6*(7), e628-e631.

Hoffmann, R., Šedová, B., & Vinke, K. (2021). Improving the evidence base: A methodological review of the quantitative climate migration literature. *Global Environmental Change*, *71*, 102367.

Houghton, R. A., House, J. I., Pongratz, J., Van Der Werf, G. R., Defries, R. S., Hansen, M. C., ... & Ramankutty, N. (2012). Carbon emissions from land use and land-cover change. Biogeosciences, 9(12), 5125-5142.

IPCC (2023). Climate Change 2023: Synthesis Report. A Report of the Intergovernmental Panel on Climate Change. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the

Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland.

Johnson, O., Wanjiru, H., Taylor, R., & Johnson, F. X. (2018). Overcoming barriers to sustainable charcoal in Kenya.

Kjellstrom, T., Kovats, R. S., Lloyd, S. J., Holt, T., & Tol, R. S. (2009). The direct impact of climate change on regional labor productivity. Archives of environmental & occupational health, 64(4), 217-227.

Kober, T., Schiffer, H. W., Densing, M., & Panos, E. (2020). Global energy perspectives to 2060–WEC's World Energy Scenarios 2019. Energy Strategy Reviews, 31, 100523.

Kunkel, K. E., Pielke, R. A., & Changnon, S. A. (1999). Temporal fluctuations in weather and climate extremes that cause economic and human health impacts: A review. Bulletin of the American Meteorological Society, 80(6), 1077-1098.

Lazaric, N., Le Guel, F., Belin, J., Oltra, V., Lavaud, S., & Douai, A. (2020). Determinants of sustainable consumption in France: the importance of social influence and environmental values. Journal of Evolutionary Economics, 30, 1337-1366.

Lenzi, D., Lamb, W. F., Hilaire, J., Kowarsch, M., & Minx, J. C. (2018). Don't deploy negative emissions technologies without ethical analysis.

Lopez-Ruiz, H. G., & Crozet, Y. (2010). Sustainable transport in France: is a 75% reduction in carbon dioxide emissions attainable?. Transportation research record, 2163(1), 124-132.

Martini, C. (2009). The distributive effects of carbon taxation in Italy. Department of Economics-University Roma Tre. Working Papers of Economics, 103.

Matti, C., Jensen, K., Bontoux, L., Goran, P., Pistocchi, A., & Salvi, M. (2023). Towards a fair and sustainable Europe 2050: social and economic choices in sustainability transitions.

Mumtaz, M. Z., & Smith, Z. A. (2019). Green finance for sustainable development in Pakistan. IPRI Journal, 19(2), 1-34.

Ngayu, M. N. (2011). Sustainable urban communities: Challenges and opportunities in Kenya's urban sector.

Oyake-Ombis, L., van Vliet, B. J., & Mol, A. P. (2015). Managing plastic waste in East Africa: Niche innovations in plastic production and solid waste. Habitat International, 48, 188-197.

Page, E. A. (2008). Distributing the burdens of climate change. Environmental Politics, 17(4), 556-575.

Parson, E. A., & Fisher-Vanden, A. K. (1997). Integrated assessment models of global climate change. Annual Review of Energy and the Environment, 22(1), 589-628.

Piguet, E., Pécoud, A., & De Guchteneire, P. (2011). Migration and climate change: An overview. Refugee Survey Quarterly, 30(3), 1-23.

Richters, O., Bertram, C., Kriegler, E., Al Khourdajie, A., Cui, R., Edmonds, J., ... & Zwerling, M. (2022). NGFS Climate Scenarios Data Set (3.4) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.7198430

Riahi, K., Van Vuuren, D. P., Kriegler, E., Edmonds, J., O'neill, B. C., Fujimori, S., ... & Tavoni, M. (2017). The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. *Global environmental change*, *42*, 153-168.

Sacchi, R., Bauer, C., Cox, B., & Mutel, C. (2022). When, where and how can the electrification of passenger cars reduce greenhouse gas emissions?. Renewable and Sustainable Energy Reviews, 162, 112475.

Sachin, N., & Rajesh, R. (2022). An empirical study of supply chain sustainability with financial performances of Indian firms. Environment, Development and Sustainability, 24(5), 6577-6601.

Schiermeier, Q., Tollefson, J., Scully, T., Witze, A., & Morton, O. (2008). Electricity without carbon. Nature, 454(7206), 816-824.

Senent-De Frutos, J. A., & Herrera Arango, J. (2022). Contributions of Intercultural Socioenvironmental Justice to the 2030 Agenda in the Colombian Caribbean. Land, 11(6), 835.

Sethi, P., Chakrabarti, D., & Bhattacharjee, S. (2020). Globalization, financial development and economic growth: Perils on the environmental sustainability of an emerging economy. Journal of Policy Modeling, 42(3), 520-535.

Shin, S., & Ki, E. J. (2019). The effects of congruency of environmental issue and product category and green reputation on consumer responses toward green advertising. Management Decision, 57(3), 606-620.

Sierra, C. A., Mahecha, M., Poveda, G., Álvarez-Dávila, E., Gutierrez-Velez, V. H., Reu, B., ... & Skowronek, S. (2017). Monitoring ecological change during rapid socio-economic and political transitions: Colombian ecosystems in the post-conflict era. Environmental Science & Policy, 76, 40-49.

Smith, P. (2004). Carbon sequestration in croplands: the potential in Europe and the global context. European journal of agronomy, 20(3), 229-236.

Smith, E. K., & Mayer, A. (2018). A social trap for the climate? Collective action, trust and climate change risk perception in 35 countries. Global Environmental Change, 49, 140-153.

Sovacool, B. K. (2021). Who are the victims of low-carbon transitions? Towards a political ecology of climate change mitigation. Energy Research & Social Science, 73, 101916.

Sokołowski, J., Frankowski, J., Mazurkiewicz, J., & Lewandowski, P. (2022). Hard coal phase-out and the labour market transition pathways: The case of Poland. Environmental Innovation and Societal Transitions, 43, 80-98.

Szűcs, C., Vanó, G., & Korsós-Schlesser, F. (2017). Agricultural and Food Production in Hungary: On the Road to Sustainability. Visegrad Journal on Bioeconomy and Sustainable Development, 6(2), 59-63.

Toriola-Coker, L. O., Alaka, H., Bello, W. A., Ajayi, S., Adeniyi, A., & Olopade, S. O. (2021). Sustainability barriers in Nigeria construction practice. In IOP Conference Series: Materials Science and Engineering (Vol. 1036, No. 1, p. 012023). IOP Publishing.

Tsiropoulos, I., Nijs, W., Tarvydas, D., & Ruiz, P. (2020). Towards net-zero emissions in the EU energy system by 2050.

Weyant, J. (2017). Some Contributions of Integrated Assessment Models of Global Climate Change. *Review of Environmental Economics and Policy*, *11*(1), 115-137.

Weyant, J., Davidson, O., Dowlatabadi, H., Edmonds, J., Grubb, M., Parson, E. A., ... & Fankhauser, S. (1995). Integrated assessment of climate change: an overview and comparison of approaches and results. *Climate change*, *3*.

Wiek, A., Binder, C., & Scholz, R. W. (2006). Functions of scenarios in transition processes. Futures, 38(7), 740-766.

Zimm, C., Mintz-Woo, K., Brutschin, E., Hanger-Kopp, S., Hoffmann, R., Kikstra, J. S., ... & Schinko, T. (2024). Justice considerations in climate research. Nature Climate Change, 1-9.

Appendix A: Codes and Example References for Country-Specific Literature Review

1. **Agriculture and Land Use** (containing codes related to agriculture, water, land use, deforestation, food security, etc.)
2. Example: '*Agricultural and Food Production in Hungary: On the Road to Sustainability' (Szűcs et al., 2017)*
3. **Banking and Finance** (related to banking, private and public finance, etc.)
4. Example: *'Green Finance for Sustainable Development in Pakistan'* (Mumtaz & Smith, 2019)
5. **Carbon Pricing** (related to carbon pricing, carbon taxes, carbon trading, etc.)
6. Example: *'The distributive effects of carbon taxation in Italy'* (Martini, 2009)
7. **Technological Innovation** (covering innovation, research, educational initiatives and CCS technology)
8. Example: *'Environmental assessment of carbon capture and storage deployment scenarios in France'* (Bouvart et al., 2011)
9. **Circular Economy and Waste Management** (related to the waste sector, recycling, etc.)
10. Example: *'Managing plastic waste in East Africa: Niche innovations in plastic production and solid waste'* (Oyake-Ombis et al., 2015)
11. **Buildings and Infrastructure** (covering articles related to construction, infrastructure, buildings sectors)
12. Example: *'Sustainability Barriers in Nigeria Construction Practice'* (Toriola-Coker et al., 2021)
13. **Firms, CSR, Supply Chains** (covering codes related to firm behavior and supply chains)
14. Example: *'An empirical study of supply chain sustainability with financial performances of Indian firms'* (Sahin & Rajesh, 2021)
15. **Energy Sector and Fuels** (related to renewable energy, electrification, fossil phase-out, etc.)
16. Example: *'Assessing the obstacles to the participation of renewable energy sources in the electricity market of Colombia'* (Gómez-Navarro & Ribó-Pérez, 2018)
17. **Globalization and Economic Development** (covering topics of international cooperation, globalization, financialization and the effects on economic development)
18. Example: *'Globalization, financial development and economic growth: Perils on the environmental sustainability of an emerging economy'* (Sethi et al., 2020)
19. **Cross-Cutting, Systemic, Emissions** (covering articles on a large number of sustainability dimensions, focusing on emissions in generals or systemic sustainability assessment)
20. Example: *'Regenerative and Sustainable Futures for Colombia'* (Gomez-Valencia et al., 2022)
21. **Governance, Policy, Legislation** (related to articles on governance, implementation of policies, policy uncertainty and instability, legislation and institutional barriers)
22. Example: *'Territorial Governance for Sustainable Development: A Multi-Level Governance Analysis in the Italian Context'* (Bianchi & Richiedei, 2023)
23. **Manufacturing and Industry** (covering topics related to the industry and manufacturing sectors)
24. Example: *'Governing sustainable industrial energy use: Energy transitions in Nigeria's manufacturing sector'* (Edomah, 2019)

25. **Indices, Policy Tools and Frameworks** (covering work on specific tools for policy makers to track or assess sustainability transitions)
26. Example: *'Monitoring ecological change during rapid socio-economic and political transitions: Colombian ecosystems in the post-conflict era'* (Sierra et al., 2017)
27. **Justice, Participation, Inequality, Impacts** (covering topics related to justice, equity, participation, social inequality, poverty, energy poverty, social costs and labor market impacts)
28. Example: *'Contributions of Intercultural Socioenvironmental Justice to the 2030 Agenda in the Colombian Caribbean'* (Senent-De Frutos & Herrera Arango, 2022)
29. **Social Behaviors and Attitudes** (related to consumer behavior, social behaviors related to sustainability, attitudes and perceptions of sustainability)
30. Example: *'Determinants of sustainable consumption in France: the importance of social influence and environmental values'* (Lazaric et al., 2020)
31. **Ressource-Intensive Industries** (covering the mining, oil, charcoal and cement sector)
32. Example: *'Overcoming barriers to sustainable charcoal in Kenya'* (Johnson et al., 2018)
33. **Urbanization and Urban Development** (related to questions on rural-urban differentials, urban planning and urban development)
34. Example: *'Sustainable urban communities: challenges and opportunities in Kenya's urban sector'* (Ngayu, 2011)
35. **Transport and Mobility** (covering articles related to transport and mobility) Example: *'Sustainable Transport in France: is a 75% reduction in carbon dioxide emissions attainable?'* (Lopez-Ruiz & Crozet, 2010)
36. **Other and Miscellaneous** (covering articles that do not belong in any other category, for example on sustainability and the space sector, COVID-19 or tourism) Example: *'Sustainable hospitality and tourism at different ages: Women's and men's attitudes in Italy'* (Fermani et al., 2016)

SPES

Sustainability
performances,
evidence & scenarios

www.sustainabilityperformances.eu