



Developing narratives for policy-relevant water-energy-food-ecosystem nexus pathways: How global and European Union drivers interact

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ABSTRACT

The shared socioeconomic pathways (SSPs) and representative concentration pathways (RCPs) were created for socioeconomic and climate change assessments and are widely used in global environmental assessments. However, mapping SSP-RCP pathways and policies for water, energy, food and ecosystems (WEFE) remains elusive. There is uncertainty on how to integrate current European Union (EU) policies with climate and socioeconomic pathways. To address that uncertainty, we developed narratives describing possible policy-relevant WEFE nexus pathways until 2050 by collaborating with a broad range of stakeholders and experts. By mapping several SSP-RCP pathways with EU-WEFE policies, three primary policy-relevant WEFE pathways, namely “Sustainable Development,” “Weak Cooperation,” and “Global Fragmentation”, and two extreme pathways, “Emissions Neutrality” and “Global Risk,” were identified. For each of these pathways, a narrative was developed explaining how global and EU drivers interact. These narratives integrate climate, socioeconomic and governance drivers. Findings show that the Emissions Neutrality pathway would require a high level of coordination between global and EU commitments. At the other end, Global Fragmentation represents a challenging future for the EU, showing that the global trends will condition the achievement of EU-WEFE objectives and highlighting the need for global coordination. Beyond the results, these narratives contribute to a better understanding of WEFE nexus. Furthermore, they can serve as a basis to explore potential future developments and assess WEFE nexus solutions.

1. Introduction

Changes in climate, environment, and society put pressure on natural resources and generate negative consequences, such as migration pressure, food price shocks, water scarcity, and imbalances in energy markets. These changes have been identified as some of the major challenges facing the EU and threaten water, energy, and food security, as well as ecosystems conservation. Future developments of climate, socioeconomic and policy drivers are highly uncertain (EEA, 2019; Matti et al., 2023). Moreover, significant uncertainty still surrounds the contribution of EU policies to the security of the water-energy-food-ecosystems (WEFE) nexus.

Hence, understanding the interlinkages between climate,

socioeconomic, and WEFE developments is essential for foresight analysis and policy impact assessment, and can contribute to formulating more coherent policies and solutions for the WEFE sectors.

In this study, we define a future scenario as a plausible and internally consistent description of how the future might unfold under a set of assumptions about the evolution of key driving forces and uncertainties. Future scenarios are typically broad, encompassing a wide range of possible developments and can be used to understand the implications of different decisions and to support policymakers in designing coherent policies aligned with the desired goals (Mitter et al., 2020). The scenario-building process begins by developing alternative plausible pathways (Van Vuuren et al., 2017) and is followed by the narratives that describe those pathways and facilitate the definition of quantitative

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scenarios (Alcamo and Henrichs, 2008).

In this context, a pathway refers to a sequence or series of events and actions that lead from the present to a specific future outcome or state, contributing to the realization of a particular scenario. Pathways provide insights into the dynamics and factors that drive the transition from the current state to the envisioned future, helping to identify critical junctures and tipping points.

A narrative is a qualitative description of the relationships and dynamics of a pathway, focusing on the characteristics, general logic, and developments underlying a particular future scenario. They may include drivers of change, storylines, and detailed descriptions that make the pathway more understandable. In addition, narratives can consider social and cultural perceptions and the views of stakeholders. By highlighting synergies and trade-offs, they also help to form our understanding of the world, the potential future scenarios, and the actions required to achieve those futures under conditions of uncertainty (Raven and Elahi, 2015).

The development of narratives describing alternative plausible policy-relevant WEFEE nexus pathways requires considerations of multiple values, views, voices, and tensions between them. Contrasting perspectives on desirable sustainability pathways may be held by actors from different WEFEE sectors (Aguiar et al., 2020). Improved comprehension of the effects of global change across scales and disciplines, as well as enhanced ability of stakeholders to handle uncertainty and complexity, are among the numerous advantages of qualitative narrative development (Tompkins et al., 2008; Oteros-Rozas et al., 2015; Strasser et al., 2019). Effective stakeholder engagement in the scenario-building process can help increase the acceptability and credibility of the final scenarios (Alcamo, 2001; Cabello et al., 2021). When actors interact face-to-face, they utilise narratives as a means of communication to establish expectations and share knowledge and points of view (Koch et al., 2023).

Narrative development for alternative plausible pathways has gained importance over the last decade because of its wide applicability in research and practice. In environmental research, narratives have been used to explore the evolution of environmental assessment (Gazzola and Onyango, 2024; Morrison-Saunders et al., 2024). In and the area of governance, narratives are essential, especially when tackling complex challenges, such as climate change. For instance, narratives are used to expand our understanding of the WEFEE nexus complexities and challenges at various levels (global, continental, and national) (Paschen and Ison, 2014; Aguiar et al., 2020). Also, narratives can help to investigate how different uncertainties may impact future pathways (Matti et al., 2023).

To assess the impacts of climate change, the shared socioeconomic pathways (SSPs) and the representative concentration pathways (RCPs) are widely used in global environmental research. A set of narratives describing the SSPs has been developed on a global scale (O'Neill et al., 2017). These narratives have been developed to highlight key scenario features and causal connections between climate and socioeconomic driving forces, helping to interpret potential trajectories (IPCC, 2022a). Due to their global coverage, those narratives do not consider policy drivers or national or subnational sectoral characteristics. The mapping between the SSP-RCP pathways and WEFEE policies at the European level has not been established so far. This information is, however, key to assessing policy impact and investigating the potential future developments of the WEFEE sector and its impacts on the environment at the European level.

Some attempts to combine the RCP-SSP pathways with sectorial developments include global studies analysing green growth trends (Van Vuuren et al., 2017) or crop productivity growth (Wang et al., 2020). At the continental level, narratives have been developed to evaluate the transformation of the food and agricultural systems in Africa (Aguiar et al., 2020). At the local level, narratives have been developed focusing on the interconnections between water and agriculture, but without being aligned with climate and socioeconomic pathways (Cabello et al.,

2021).

Focusing on the European Union (EU), some studies have developed narratives for EU energy and food systems. Pathways have been developed to assess the impact of the EU energy transition on social health and well-being (Dahal et al., 2024). In addition, quantitative storytelling has been applied to assess the connections between energy and water resources (Di Felice et al., 2023). Based on the set of SSPs, storylines have been developed describing alternative plausible future developments for EU agrifood systems until 2050 (Mitter et al., 2020). With an emphasis on consumer trends, narratives have been developed for the food sector in the EU, based on the SSPs and complemented by expert knowledge and data on certain topics, such as nutrition and food safety (Mathijs et al., 2018). SSPs have also been expanded to account for pesticide use in Europe, from farm to continental scale, but excluding policy drivers (Nagesh et al., 2023).

Despite an increasing number of studies adopting narratives describing pathways, most of them remain focused on a subset of WEFEE sectors and do not sufficiently integrate current EU policies and strategies. Existing studies generally fail to take into account the diversity of viewpoints in developing narratives and have, in many cases, been constructed from the top down, adopting the ideas of selected experts in one sector but ignoring other key actors from other sectors (Alcamo and Henrichs, 2008). They either remain at the conceptual level (Mitter et al., 2020), are not consistent with the SSP-RCP framework (Cabello et al., 2021) or do not provide sufficient detail on the climate, socioeconomic, and policy drivers (O'Neill et al., 2017; Van Vuuren et al., 2017; IPCC, 2022b).

In our view, narratives to assess the WEFEE nexus in the EU require a participatory approach, including and connecting all WEFEE nexus components, integrating climate, socioeconomic and policy drivers, and being capable of measuring the degree of compliance of WEFEE policy objectives. However, to the best of our knowledge, no previous study considers all these criteria. Hence, the main objective of this study is to develop policy-relevant WEFEE narratives for the EU that are compliant with the SSP-RCP framework and consider EU policy objectives.

The novelty of this research lies in the mapping of the existing SSP-RCP pathways with the EU policy drivers for the WEFEE sectors. Therefore, the resulting pathways integrate current WEFEE policies at the EU level with global climate and socioeconomic drivers until 2050. For each pathway, a policy-relevant WEFEE narrative was developed using participatory approaches. The policy-relevant WEFEE narratives describe critical drivers of change, trends, and potential future events, highlighting how global and European drivers interact and how climate, socioeconomic, and policy drivers can threaten or strengthen the WEFEE nexus security. Such information is useful for researchers and policy-makers to perform impact assessments of climate, environment, and societal challenges at the EU scale and under different socioeconomic and climate pathways.

The rest of the paper is organized as follows: Section 2 explains the methodological approach and the process to develop policy-relevant WEFEE narratives. Section 3 describes the various inputs obtained from the literature review and stakeholder engagement and presents the five policy-relevant WEFEE narratives developed. Section 4 discusses the narratives developed. Finally, section 5 outlines the relevant points and concluding remarks.

2. Methodological approach

2.1. Process to developing policy-relevant WEFEE narratives

Fig. 1 presents the participatory approach for developing policy-relevant WEFEE narratives. A comprehensive background study and analysis to examine current pathways was conducted. Based on these studies, climate and socioeconomic drivers were selected to serve as the foundation for developing the narratives. Furthermore, a literature review of policy documents was conducted to review the main EU-WEFEE

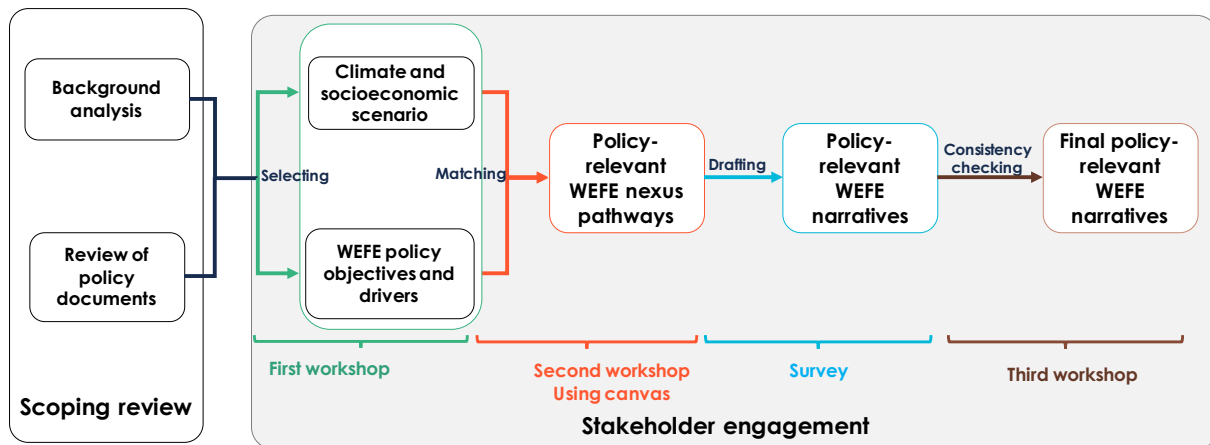


Fig. 1. Methodological approach to develop policy-relevant WEFE narratives. Source: Our own elaboration.

policy objectives and drivers. By mapping the various existing SSP-RCP scenarios with the EU-WEFE policy objectives, policy-relevant WEFE pathways were developed based on stakeholder engagement. For each pathway, a narrative was drafted and discussed with relevant stakeholders.

The development of the pathways narratives was undertaken through a series of structured workshops involving a diverse group of stakeholders and experts, including national and European organizations and academia.

Hence, the process of developing a set of policy-relevant WEFE narratives for WEFE future quantitative scenarios considers the following steps:

2.2. Scoping review

2.2.1. Climate and socioeconomic scenario selection

The development of the policy-relevant WEFE narratives is guided by selecting the main climate and socioeconomic drivers that influence these interconnected systems. In the existing literature, numerous studies explore potential future scenarios by examining the climate and socioeconomic drivers (IPCC, 2021). Typically, these studies focus their analyses on previous assessments by the IPCC. In our case, we specifically considered the most recent studies, encompassing assessments from the Coupled Model Intercomparison Project Phase 6 (CMIP6), integrating various SSPs and RCPs scenarios. Based on these scenarios, climate and socioeconomic drivers were identified. Our approach incorporates recent advancements, integrating Shared Socioeconomic Pathways (SSPs) and Representative Concentration Pathways (RCPs) to reflect plausible futures. Based on these scenarios, critical drivers were identified and used as foundational elements to shape the policy-relevant WEFE narratives. These drivers provide a structured pathway to address key WEFE policy objectives.

2.2.2. Review of EU-WEFE policy objectives and drivers

Additionally, to investigate whether and how are the relationships between sectoral policies in the EU, a grey literature from pertinent European policies was consulted, encompassing existing policies and strategies such as the EU Green Deal and the anticipated changes in the EU water, energy, food and environmental policies. Overall, 11 policy documents have been examined: four related to the water policy area, three to the energy policy area, three to the food policy area, and one to the ecosystem policy area (see Annex 1). In this step, a panel of 20 experts participated in an online workshop where we presented and discussed the main WEFE policy objectives of the EU (see Table 1). The experts engaged in this first workshop brought together a broad range of perspectives that were key to selecting the main WEFE policy objectives.

Table 1

Summary of the participatory approach (workshops and surveys).

Participatory event	Date and place	Experts' affiliation and role	Objective
First workshop	March 2023, online	20 experts: <ul style="list-style-type: none"> 5 representatives from EU Commission services in the areas of food, climate action, energy, and environment 6 experts from water 4 experts from food 3 experts from energy 2 experts from ecosystem 	Selection of main EU-WEFE policy objectives
Second workshop	May 2023, Como (Italy)	20 WEFE experts: <ul style="list-style-type: none"> 3 experts from energy 3 experts from ecosystems 6 experts from food-water 2 experts from climate 11 experts from water 	Matching climate and socioeconomic scenarios to EU-WEFE policy objectives to identify WEFE pathways
Survey	June 2023, online	10 WEFE experts: <ul style="list-style-type: none"> 3 from food-water 2 from energy 2 from ecosystem 3 from water 	Provide insights into the compliance of specific EU-WEFE policy objectives in each selected WEFE pathway
Third workshop	September 2023, Madrid (Spain)	120 experts (60 in person, 60 online), including: <ul style="list-style-type: none"> European policymakers in the fields of food, environment, and climate WEFE experts from non-governmental organizations and the private sector 	Consistency check

Source. Our own elaboration.

2.3. Identification of policy-relevant WEFE pathways

After analysing climate and socioeconomic scenarios and reviewing the main EU-WEFE policy objectives, we explored the evolution of the

drivers of change as well as their related uncertainties. Expanding upon the existing pathways outlined in socioeconomic and climate scenarios, we introduced a policy dimension to develop the policy-relevant WEFÉ pathways, incorporating inputs from stakeholders. During a second workshop held in Italy, we presented the SSP-RCP context as well as the main EU policy objectives to a panel of 25 experts (different from the experts of the first workshop) representing various sectors of the WEFÉ nexus (see Table 1). Using a canvas methodology, this panel of experts was actively engaged in aligning climate and socioeconomic scenarios to future developments of climate, socio-economic, and governance drivers (see Annex 3). The fundamental concept of the canvas approach is to decompose intricate systems into essential components that are showcased on a one-page visual layout (Osterwalder and Pigneur, 2010). This approach facilitates a comprehensive understanding of the system as a whole and eases stakeholder dialogue via a common visual language. Based on expert feedback, the policy-relevant WEFÉ pathways were identified. Furthermore, a survey was developed and sent to 15 WEFÉ experts to gather approximate qualitative information regarding the degree of achievement of WEFÉ policy objectives for each of the WEFÉ pathways. 10 WEFÉ experts answered this survey, which can be considered as a fair response rate for this type of study. According to Powell (2003), the accuracy of a panel depends more on the quality of the participants than on the quantity (see Table 1). In that sense, stakeholder input played a significant role in shaping the content and direction of the policy-relevant WEFÉ narratives.

2.4. Drafting of policy-relevant WEFÉ narratives and consistency check

Policy-relevant WEFÉ narratives were developed based on the mapping of the selected WEFÉ policy objectives and policy drivers to the pathway's elements of the climate and socioeconomic drivers generated from experts' feedback (canvas and survey). These inputs from experts were synthesized into preliminary narratives by the research team. However, an early challenge was ensuring that the language used in the narratives was accessible to all participants, not just WEFÉ experts. For each policy-relevant WEFÉ pathway, a narrative was developed. These policy-relevant WEFÉ narratives incorporate climate, socioeconomic, and policy drivers and consider the degree of achievement of a set of EU-WEFÉ policy objectives, identified through a review of current EU policies and expert knowledge. After drafting policy-relevant WEFÉ narratives, a consistency check was conducted during a third workshop held in Madrid with a panel of stakeholders representing European policy-makers in agriculture, environment, and climate, along with WEFÉ experts from non-governmental organizations and the private sector (see Table 1). The experts provided feedback on the alignment of WEFÉ policy objectives within each narrative and on the uncertainties surrounding the integration of current policies with climate and socioeconomic scenarios within the WEFÉ nexus context.

3. Results

This section illustrates the results obtained following the policy-relevant WEFÉ narrative development process mentioned above.

3.1. Climate and socioeconomic scenarios

Numerous studies address possible future climatic scenarios based on climate and socioeconomic drivers. These studies generally focus their analyses on previous IPCC assessments. In our case, we have considered the SSP-RCP scenario matrix encompassed by the Coupled Model Intercomparison Project Phase 6 (CMIP6) (IPCC, 2022a).

From the combinations between RCPs and SSPs and expert knowledge (feedback provided during the second workshop), four scenarios were selected: SSP1-1.9 and SSP1-2.6 (related to achieving the goal of not surpassing 1.5 and 2 degrees of global warming, as indicated in the Paris Agreement), SSP3-7.0 (upper-middle scenario considering the

continuation of recent trends and the ongoing energy transition) and SSP5-8.5 (worst-case scenario). Table 2 shows the main characteristics of the selected scenarios, where the SSPs encompass a set of drivers (technology development, land-use change, population growth, and international trade).

3.2. Main EU-WEFÉ policy objectives

Critical and main WEFÉ policy objectives were reviewed based on the ongoing EU policies, the EU Green Deal, and envisaged changes in EU water, energy, food and environmental policies. From this review, we selected 42 objectives relevant to the WEFÉ nexus (the full list of WEFÉ policy objectives is presented in annex 2).

This list of WEFÉ policy objectives was presented to a panel of experts during the first workshop on March 2023, in which representatives from EU Commission services in charge of the policies related to agriculture and rural development, climate action, energy, and environment, as well as WEFÉ experts, were invited to provide feedback. During this first workshop, stakeholders were asked to select the objectives they deemed most relevant for developing policy-relevant WEFÉ narratives. From the initial pool of 42 policy objectives, 19 main WEFÉ policy objectives were identified (see Table 3).

3.3. Identification of policy-relevant WEFÉ-nexus pathways

To identify the policy-relevant WEFÉ pathways and their narratives, the existing climate and socioeconomic scenarios should match the main European WEFÉ policy objectives selected during the first workshop. This step was realized mainly based on stakeholder's feedback. During the second workshop, WEFÉ experts already familiar with the SSP-RCP framework first helped to identify the relevant SSP-RCP pathways for this study (see Section 3.1). Next, using the Canvas methodology, these experts provided feedback on how to match current and foreseen EU-WEFÉ policies with the SSP-RCP scenarios until 2050 (see Annex 3). Based on the Canvas results, feedback from experts highlighted the need for additional clarification of certain technical terms and concepts, prompting adjustments in how information is presented in each pathway. Significant divergences and uncertainties emerged among experts regarding the integration of current EU-WEFÉ policies with climate and socioeconomic scenarios. These divergences necessitated further deliberations and processing (ranking) to reconcile varying perspectives. While these methods improved consensus, they also underscored the challenges of fully harmonizing priorities across diverse WEFÉ sectors.

During the workshop, the panel of experts highlighted several pertinent aspects regarding the complexity of mapping the current WEFÉ policies with the selected SSP-RCP pathways. They observed that achieving equitable progress in complying with WEFÉ policy objectives across different dimensions of the WEFÉ nexus is challenging under the various SSP-RCPs. Interactions within the WEFÉ nexus often involve various trade-offs; compliance with objectives in one dimension of the nexus can result in non-compliance with objectives in other nexus dimensions. Additionally, assessing the attainment of WEFÉ policy objectives across different spatial scales generates complex implications.

Experts agreed that, despite the EU's significance in the global context, there is a weak link between the fulfilment of EU-WEFÉ policy objectives and global climate and socioeconomic developments. However, the influence in the opposite direction is strong: global developments can significantly impact the EU's ability to achieve its WEFÉ policy objectives. As a conclusion, a lower or higher EU climate ambition will not be enough to move from one SSP-RCP pathway to another.

By mapping the existing various SSP-RCP pathways with EU-WEFÉ policies, three primary WEFÉ pathways were identified during the second workshop:

Table 2
Main characteristics of climate and socioeconomic scenarios.

Scenarios	Radiative forcing (W/m ²)	Range of global mean temperature increase in 2100 (°C)	Technology development	Land use change regulation	Population growth	International trade
SSP1–1.9	1.9	~1 to ~1.5	Rapid	Strong	Low	Intermediate
SSP1–2.6	2.6	~1.5 to ~2	Rapid	Strong	Low	Intermediate
SSP3–7.0	7.0	~4	Slow	Limited	High	Low
SSP5–8.5	8.5	> 4	Rapid	Incompletely regulated	Low	High

Source. Own elaboration based on IPCC (2022a).

- Sustainable Development: high climate ambition both at global and EU levels, aligned with SSP1–2.6.
- Weak Cooperation: global consensus to mitigate climate change, but weak cooperation and socioeconomic problems hinder the transition to sustainable development, aligned with SSP3–7.0.
- Global Fragmentation: high climate ambition at EU level, in a context of global fossil-fuelled development and increasing geopolitical tensions, aligned with SSP5–8.5.

Two extreme pathways were also discussed:

- Emissions Neutrality: aligned with SSP1–1.9.
- Global Risk: aligned with SSP5–8.5+ (upper extreme of SSP5–8.5).

All pathways assume that the EU will keep the foreseen level of climate ambition until 2050. However, it is important to mention that, while we considered relevant to keep the SSP-RCP framework, our pathways do not exactly match the SSP-RCP narratives, mainly because expert expectations on future global trends have significantly changed in recent years due to health crisis and geopolitical tensions.

In particular, stakeholders agreed that the “Global Fragmentation” and “Global Risk” pathways will represent a challenging future for the EU because, despite its climate mitigation policies, the EU will have to cope with rising climate change. Stakeholders considered that the “Global Fragmentation” and “Global Risk” pathways will lead to SSP5-RCP8.5, reflecting that current geopolitical tensions and a lack of concerted action could jeopardize environmental objectives more than socioeconomic ones.

3.4. Match of WEFE pathways with achievement of EU-WEFE policy objectives

During the second workshop, experts were also asked to identify the main indicators to consider when measuring the degree of compliance of the selected policy objectives. Based on their feedback, five WEFE indicators were selected for this purpose, and different levels of compliance for each indicator were established as thresholds for each narrative (see Table 4). An online survey allowed us to gather approximate semi-quantitative information regarding the degree of achievement of EU-WEFE policy objectives in the three primary WEFE pathways, “Sustainable Development,” “Weak Cooperation,” and “Global Fragmentation”.

The EU aims at achieving a good status for all water bodies by 2050. According to the survey respondents (Fig. 2), in the Sustainable Development pathway, this indicator would reach 70 to 80 % by 2050. In the Weak Cooperation pathway, most experts believe that the proportion of water bodies with good status would be 50 to 60 % by 2050. For Global Fragmentation pathway, according to most experts, the water bodies in good status would reach 50 to 60 %. In conclusion, in all three narratives, the target will not be reached by 2050.

The EU has set a minimum target of 45 % of energy from renewable sources by 2030. In the Sustainable Development pathway, most experts stated that the share of energy from renewable sources would exceed 40 % by 2030. For the Weak Cooperation pathway, most experts stated that the share of renewable energy would reach 25 to 30 %. For Global

Fragmentation pathway, most experts considered that the share of energy from renewable sources would only reach 20 to 25 %, meaning the situation will be far from the target.

According to survey results, final energy consumption would decrease by 4–6 % in 2030 compared to 2020 in the Sustainable Development pathway. In the Weak Cooperation pathway, this indicator would decrease by 2–4 % in 2030. Most experts considered that the final energy consumption would not decrease in Global Fragmentation pathway.

The EU set an objective to reduce GHG emissions from transport by 90 % in 2050. In Sustainable Development pathway, most experts stated that GHG emissions from transport would decrease by 60–80 % by 2050. The Weak Cooperation pathway shows uncertainties regarding this indicator: four experts estimated a decrease by 0–20 %, while another four declared a decrease of 40–60 %. For Global Fragmentation pathway, most experts agreed that GHG emissions from transport would not decrease.

As for the last indicator (share of protected area), the experts considered that the share of protected area would reach more than 28–30 % by 2030 in the Sustainable Development pathway. In the Weak Cooperation pathway, experts predicted that this indicator would reach 26–28 % by 2030. In Global Fragmentation pathway, most experts estimated the share of protected areas would reach 24–26 % by 2030. Fig. 2 provides a general estimate of policy objective compliance for each narrative, based on experts’ feedback.

3.5. Description of policy-relevant WEFE narratives

Building upon the selected WEFE pathways and their match to EU policy objectives, we designed narratives for each policy-relevant nexus WEFE pathway by synthesizing the views of the stakeholders. Those narratives first consider the global context (based on literature and expert feedback) and then focus on the achievement of EU-WEFE policies (based on feedback from stakeholders). Feedback from experts highlighted that some technical terms and concepts required additional clarification, leading to adjustments in how the information was presented. This iterative refinement enhanced the inclusivity and usability of the narratives, particularly for policymakers. Below, we detail the narratives for each of the policy-relevant WEFE pathways shown in Fig. 3.

3.6. Emissions neutrality

The Emissions Neutrality pathway is the most ambitious path to global sustainability goals, aligning with SSP1–1.9. Globally, it envisions a world capable of achieving the most ambitious goals of the Paris Agreement, including reaching net-zero global emissions by 2050 and limiting the increase in global surface temperature to 1.5 °C above pre-industrial levels, followed by a downward trend and stabilisation around 1.4 °C by the end of the century (2100). This pathway assumes significant changes in human behaviour, including a shift toward more sustainable lifestyles and consumption patterns, driven by a focus on equity and general well-being above economic growth. The pathway depicts an environmental awareness in societies around the world, and a move toward less resource-intensive lifestyles. This shift is also driven by a

Table 3
Set of EU-relevant WEF E policy objectives selected.

WEFE dimensions	Objective	Description
Water	Secure supply of drinking water	Guarantee a stable and secure supply of drinking water, by encouraging the incorporation of the risks of climate change in risk analyses. Reduce water use by raising the water-saving requirements for products, encouraging water efficiency and savings, and by promoting the wider use of drought management plans as well as sustainable soil management and land use.
Water	Reduce water use	Ensure the goal by improving the coordination of thematic plans and other mechanisms, such as water resource allocation and water permits.
Water	Ensure climate-resilient and sustainable water use	Achieve good status or potential for all water bodies by 2027. Promote and facilitate water reuse in agricultural irrigation to reduce water abstraction (the Water Reuse Regulation of 2020 sets new rules on minimum water quality requirements for the safe reuse of treated wastewater).
Water Environment	Ensure good status for all water bodies	Increase the overall binding target from the current 32 % to a new level of 42.5 % of renewables' share in the EU final energy consumption mix by 2030 (RED III directive).
Water Food	Encourage water reuse in irrigation	Achieve a reduction of 11.7 % of final energy consumption by 2030 compared to the 2020 EU Reference Scenario.
Energy Climate Environment	Increase renewable energy	Reduce the overall use and risk of chemical pesticides by 50 % and the use of more hazardous pesticides by 50 % by 2030.
Energy	Reduce energy consumption	Reduce overall EU sales of antimicrobials for farmed animals and in aquaculture by 50 % by 2030.
Food Environment	Reduce the risk and use of chemical pesticides	Increase the area of agricultural land under organic farming management and the adoption of agroecological practices in agriculture.
Food Environment	Reduce antimicrobial resistance	Reduce the losses of nutrients from fertilisers by 50 %, reducing the use of fertilisers by at least 20 %.
Food Environment	Foster organic farming	Reduce food waste by 2030, by 10 % in processing and manufacturing, and by 30 % (per capita) at retail and consumption.
Food Environment	Reduce fertilisers use	Achieve 310 MtCO ₂ eq of greenhouse gas (GHG) removals in the Land Use Change and Forestry sector (LULUCF) and increase the quality and quantity of the EU's forests and other natural carbon sinks.
Food	Reduce food waste	Plant at least 3 billion additional trees by 2030, following sustainable re- and afforestation practices while fully respecting ecological principles.
Environment Land	Increase CO ₂ removals	Reduce net greenhouse gas (GHG) emissions by 2030, by at least 55 % compared to 1990 levels.
Environment	Increase forest quantity	Achieve a 90 % reduction in overall transport emissions (compared to 1990 levels) by 2050.
Climate Environment	Reduce net GHG emissions	Legally protect a minimum of 30 % of the EU's land and sea area, with a
Climate	Reduce transport emissions	
Environment Land	Legally protect the land area	

Table 3 (continued)

WEFE dimensions	Objective	Description
Environment Water	Restore free-flowing rivers	third of these strictly protected (undisturbed by human activity). Restore at least 25,000 km of free-flowing rivers.
Environment Biodiversity	Preserve biodiversity	Ensure that Europe's biodiversity will be on the path to recovery by 2030.

Source: Our own elaboration.

Table 4
List of policy objectives, indicators, and targets.

WEFE Dimension	Objective	Indicator	Level (2020)	Target
Water-Environment	Ensure good status for all water bodies	Water bodies in good status (%)	42	100 (2050)
Energy-Climate Environment	Increase renewable energy	Share of energy from renewable sources (%)	22	45 (2030)
Energy	Reduce energy consumption	Final energy consumption (Mtoe)	905	763 (2030)
Climate	Reduce transport emissions	Reduction of GHG emissions from transport (%)	30	90 (2050)
Environment Land	Legally protect the land area	Share of protected areas (%)	26	30 (2030)

Source: Our own elaboration.

high degree of care for social inclusion, cultural heritage, and environment conservation. The improvements in human well-being will lower population growth. Cooperation among different countries will be excellent, with reduced tariffs and subsidies in international trade while strengthening local businesses globally. All of this will achieve sustainable development goals globally.

At the EU level, this pathway assumes rapid and far-reaching transitions in energy, land use, urbanisation, and industrial systems, resulting in very low levels of GHG emissions. Through EU policies such as the Renewable Energy Directive (RED) and Energy Efficiency Directive, it implies significant technological advancements, which will allow for a renewable energy matrix, and will include developing and implementing carbon dioxide removal technologies. The share from renewable energy sources will achieve more than 40 % by 2030. This will reduce GHG emissions from the energy sector by more than 80 % by 2030, paving the way toward a more sustainable future. The final energy consumption will be reduced by approximately 8 % by 2030. The Water Framework Directive (WFD) will lead to lower water demand and improved water efficiency, coupled with mitigated global warming, will enable achieving water security and improve the condition of aquatic and terrestrial ecosystems. The water bodies with good status will reach more than 90 % by 2050.

Through strategies such as farm-to-fork (F2F) and the EU biodiversity strategy, the environmental and climate impact of the food system is reversed, preserving food productivity, and guaranteeing food security in the face of climate change and the global biodiversity loss. With this pathway, the share of protected areas will increase to reach more than 30 % by 2030. These actions will allow us to achieve the targets of the WFD and most of the objectives of the EU Biodiversity Strategy. The resulting climate framework would not significantly differ from the current one, albeit with greater impacts related to the higher magnitude of warming. Despite more frequent extreme weather events, under this pathway, the world can avoid most of the worst impacts of climate change, and this can facilitate the achievement of WEF E policy objectives at the EU level. This pathway will imply significant socioeconomic

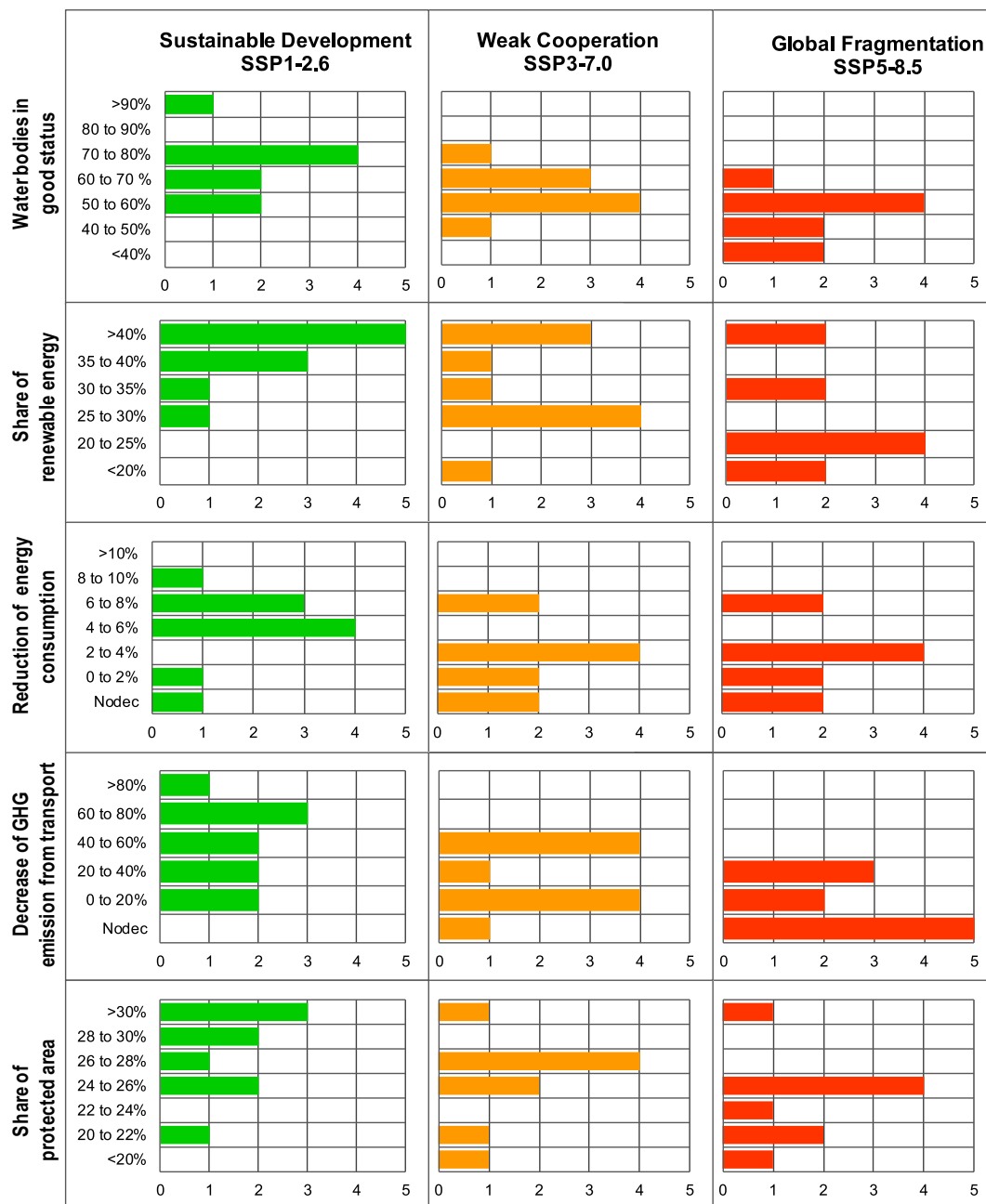


Fig. 2. Policy-relevant WEFE narratives survey results. Source: our own elaboration.

changes and, therefore, it is not the most likely to be achieved.

3.7. Sustainable development

The “Sustainable Development” pathway presents a high-ambition sustainability outlook toward reducing global GHG emissions and achieving net-zero global emissions after 2050. It is aligned with SSP1–2.6. Specifically, it is projected that, by the end of the century, the global surface temperature will rise by approximately 1.8 °C above pre-industrial levels. Globally, sustainable development is strongly emphasised, with a central commitment to achieving sustainable development goals. Within the socioeconomic trend, the world shifts gradually toward a more sustainable path, emphasising inclusive development that respects environmental boundaries. This shift is driven by increasing evidence and accounting for the social, cultural, and economic costs of environmental degradation and inequality.

Inequality is reduced both across and within countries and improvements in human well-being will decrease the population. This narrative predicts global trends toward abolishing current import tariffs and export subsidies, while granting preferences to regionally produced agricultural products.

Through EU policies such as the Renewable Energy Directive (RED) and Energy Efficiency Directive, the development of environmentally friendly technologies will be encouraged, and renewable energy sources such as wind, solar, and hydropower will constitute a substantial proportion of the energy mix. The share from renewable energy sources will achieve more than 40 % by 2030. This will reduce GHG emissions from the energy sector by 60–80 %, paving the way toward a more sustainable future. The final energy consumption will decrease by 4–8 % by 2030. The WFD will enable achieving relatively lower water demand and improved water efficiency. This will achieve water security, and water bodies with good status will reach 70–80 % by 2050. Adopting strategies

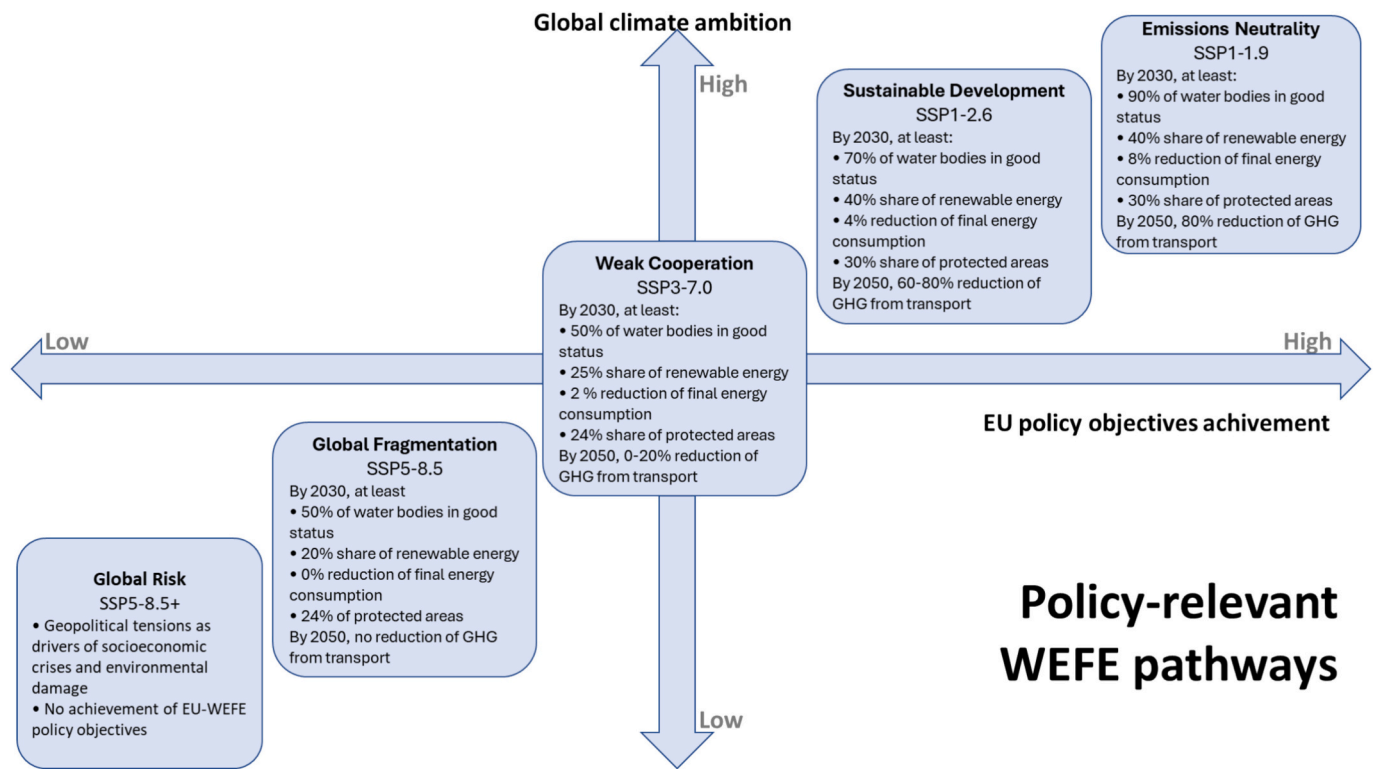


Fig. 3. Policy-relevant WEF E pathways.

such as F2F and promoting organic farming practices will effectively reduce the climate impacts on the food system. With this pathway, the share of protected areas will increase to reach more than 30 % by 2030, making at least a third of terrestrial area unavailable for agricultural expansion. Such practices will help reduce the use of chemical pesticides, soil, water, and air pollution, as well as biodiversity loss. Reduced consumption of animal products is expected to decrease the environmental impact of food consumption. Innovations will improve crop yields and irrigation efficiency while minimizing food waste to increase competitiveness and strengthen links in the food supply chain. These actions will allow us to achieve most of the targets of the WFD and many of the objectives of the EU Biodiversity Strategy. In this pathway, thanks to the harmonization of EU and global efforts, the EU-WEFE policy objectives will be largely achieved by 2050.

3.8. Weak cooperation

The Weak Cooperation pathway represents a medium level of ambition to achieve sustainability goals by mid-century, as countries become increasingly competitive with each other, prioritizing national security rather than cooperating to achieve sustainable development. It is aligned with SSP3–7.0. Globally, GHG emissions and temperatures continue to increase. By the end of the century, the global surface temperature is projected to have risen by 3.6 °C above pre-industrial levels. The world will face an increasingly fragmented future, characterised by economic and geopolitical tensions. Regional rivalries will hinder international cooperation and development, impeding progress in mitigating climate change and achieving sustainable development goals. High population growth in developing countries will lead to income inequalities and pockets of extreme poverty alongside moderate wealth. Consumption will remain material-intensive as investments in green technologies will be low. Inequality will persist and countries will prioritise their energy and food security goals at the expense of broader development.

At the EU level, adopting the WFD will enable achieving good status

for 50 to 60 % of water bodies by 2050. Pressure to achieve food and energy security will lead to growing water-use intensity. This, combined with the significant increase in droughts due to climate change, will aggravate water scarcity. Through EU policies such as the RED and Energy Efficiency Directive, the final energy consumption on this pathway will decrease by 2–4 % by 2030. The low technological development and high material consumption leave economic activity strongly linked to high levels of final energy demand. Due to concerns about energy security, fuel preferences will be based primarily on price, limiting the development of renewable energy sources. The share of renewable energy sources will therefore only reach 25–30 % by 2030. Trade barriers to fossil fuel supplies and the slow development of renewable energy technologies mean that traditional biofuels will be phased out at a slower pace, resulting in a small reduction in GHG emissions from transport (0–20 %).

In terms of agriculture, intensive agriculture will be promoted, and crop yield and irrigation efficiency will rise with GDP. The consumption of animal products and food waste continues to follow the current trend. Through the EU biodiversity strategy, protected areas for land use will reach 24–26 % at the EU level by 2030, and the scarcity of natural reserves and unsustainable agricultural practices will contribute to reduce ecosystem services. As a result, it will be difficult to achieve the WFD targets and the objectives of the EU Biodiversity Strategy. Growing resource intensity, fossil fuel dependency and strong environmental degradation, along with difficulty in achieving international cooperation and slow technological change, imply high challenges to meet the EU-WEFE policy objectives by 2050.

3.9. Global fragmentation

The Global Fragmentation pathway reflects low ambition for sustainability, and it is aligned with SSP5–8.5. In this pathway, the world economy experiences rapid growth, driven by extensive fossil fuel exploitation and highly energy-intensive lifestyles, resulting in a substantial increase in GHG emissions and global temperature. By 2100, the

global surface temperature will have increased by a staggering 4.4 °C above pre-industrial levels. The pathway also assumes limited progress in climate adaptation and a significant increase in the frequency and severity of climate-related disasters, leading to substantial economic and social disruptions. This pathway envisions a future world in which policies are fragmented, and governance is focused on national self-interests. Developing countries experience rapid macro-economic growth, depending on the use of fossil fuels, but developed countries continue to dominate the global economy. The world experiences high levels of population growth, income inequality, and fossil fuel dependency. Adaptation to climate change and mitigation efforts are hindered by low global sustainability ambition, leading to significant challenges.

For the EU, even with energy policies (RED and energy efficiency directive), the energy sector largely relies on fossil fuels, with limited technological advancements in renewable energy sources. The share of energy from renewable resources will only reach 20–25 % by 2030. This will not decrease energy consumption by 2030. Furthermore, the GHG emissions from transport at the EU level will not decrease by 2050.

Water security will be a pressing concern, as demand for water increases rapidly, and water quality declines due to pollution and over-extraction, preventing the achievement of most WFD targets. Through WFD, the water bodies with good status will reach 50–60 % by 2050 in this pathway. All these factors lead to increased resource pressure, including land and water scarcity, and significant environmental degradation.

Agriculture will face significant challenges in food production and security. Strategies such as F2F and EU Biodiversity Strategy will have a very limited effect. Pesticide and chemical use will be prioritised to increase agricultural yields, harming ecosystems. Conservation of ecosystems and biodiversity will be limited due to the prioritisation of economic growth over environmental protection. Land use will be characterised by deforestation and the conversion of natural habitats for agriculture and urbanisation, further contributing to environmental degradation. The share of protected areas will only reach 24–26 % by 2030.

For the EU, this pathway will entail a challenging future because, despite its efforts toward sustainability, the WEFE policy objectives will only be achieved to a very limited extent, highlighting the dependence of the EU on global agreements and cooperation.

3.10. Global risk

The Global Risk is a pathway with intensified geopolitical conflicts and armed wars as the primary drivers of socioeconomic crises, environmental damage, and scarcity of food and natural resources. This pathway represents the upper extreme of SSP5–8.5, projecting a long-term (2081–2100) average temperature increase of a catastrophic 5.7 °C above pre-industrial levels. The global population will decrease, largely due to collateral casualties from armed conflicts. Investment, industry, and technological development will focus on military weaponry rather than renewable energy sources or sustainable development. By 2030, this pathway will demonstrate a slight improvement from the actual situation. Fossil fuels will largely dominate the energy mix and the GHG will not be reduced by 2050. The conflicts will revolve around controlling natural resources, particularly oil and gas, mineral deposits, and even water and arable land. Consequently, widespread famine and migration will ensue, driven by war, climate crises, and hunger.

3.11. Consistency check

After drafting the narratives, a consistency check was performed with a panel of experts in a workshop held in Madrid on September 2023. The stakeholders gave their feedback about compliance of WEFE policy objectives in each narrative and the mapping between these WEFE policy objectives and climate and socioeconomic pathways based

on Fig. 4.

The panel included experts representing European policymakers in the fields of agriculture, environment, and climate, together with WEFE experts from non-governmental organizations and the private sector. During this session, the experts highlighted the high level of uncertainty in future pathways:

- Several uncertainties exist regarding how to achieve future WEFE policy objectives equitably for instance, achieving reduced emissions require an increase in the share of renewable energy. However, compliance with this objective may lead to non-compliance with certain other objectives outlined in the WFD and those related to food.
- There are uncertainties regarding the pace of technological change and how new technologies will affect the trade-offs between different WEFE policy objectives in the future.
- Additionally, uncertainties exist about the evolution of the drivers of change and trends, and exploring their implications is crucial for developing policy-relevant WEFE narratives.

4. Discussion

The primary contribution of this study is to develop policy-relevant WEFE narratives that describe alternative plausible pathways for the WEFE nexus in the EU until 2050. The policy-relevant WEFE pathways were developed by mapping the EU-WEFE related policies to a selection of global SSP-RCP pathways, while accounting for the current global context. The policy-relevant WEFE pathways play crucial roles in defining future quantitative-policy WEFE scenarios for policy impact assessment, contributing to the broader scenario-building process. Narratives developed for policy-relevant WEFE pathways help in exploring and understanding how various uncertainties may impact the security of the WEFE nexus at the EU level.

This study makes several novel contributions to the design and application of policy-relevant WEFE narratives.

First, a distinguishing feature of this study is its comprehensive coverage of all four WEFE sectors throughout the narrative development process. While many previous efforts have focused on only one or two dimensions of the nexus, this approach addresses interlinkages across all sectors. Such holistic integration enhances the coherence, policy relevance, and practical applicability of the resulting narratives.

Second, the participatory nature of the methodology represents a major strength. The development process involved a diverse and balanced group of experts and stakeholders from across the WEFE sectors, selected to reflect a wide range of institutional backgrounds, disciplines, and perspectives. Conducted through a series of structured workshops, this inclusive process fostered knowledge co-production, grounded the narratives in real-world insights, and strengthened their legitimacy and usability in policy contexts.

Third, the research advances existing climate and socioeconomic scenarios by explicitly embedding the EU policy dimension and accounting for the changing geopolitical context. As a result, the proposed WEFE pathways provide relevant insights for policymaking processes.

Fourth, although the primary focus of the narratives is at the EU level, their development explicitly incorporates global drivers and interdependencies. This dual-scale perspective increases the relevance of the narratives in a globally interconnected context and enhances their potential to inform both EU and international strategies.

Fifth, the final set of policy-relevant WEFE narratives defines a set of representative futures that capture a wide range of uncertainties. These narratives are particularly well-suited for scenario-based policy evaluation, providing a structured approach to test the robustness of policy options and assess progress toward integrated WEFE objectives. To the best of our knowledge, no other study has integrated the European WEFE policies with the existing climate and socioeconomic pathways based on participatory approaches. Despite an increasing number of

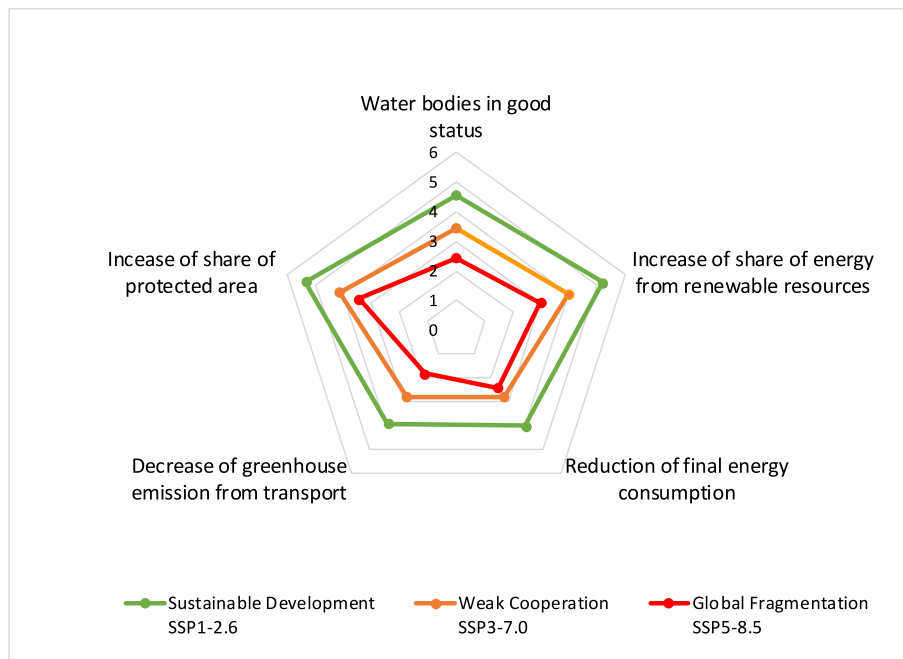


Fig. 4. EU-WEFE objectives compliance in each policy-relevant WEFE pathways. Source: our own elaboration.

studies adopting narratives describing pathways, most of them remain focused on a subset of WEFE sectors and do not sufficiently integrate current EU policies and strategies. Existing studies generally fail to take into account the diversity of viewpoints in developing narratives and have, in many cases, been constructed from the top down, adopting the ideas of selected experts in one sector but ignoring other key actors from other sectors (Alcamo, 2008). They either remain at the conceptual level (O'Neill et al., 2014; Mitter et al., 2020), are not consistent with the SSP-RCP framework (Cabello et al., 2021) or do not provide sufficient detail on the climate, socioeconomic, and policy drivers (O'Neill et al., 2017; Van Vuuren et al., 2017; IPCC, 2022b). Unlike the IPCC report (IPCC, 2022a), which developed narratives aligned with only climate and socioeconomic drivers, this study includes policy drivers in its qualitative narratives, thereby complementing the scenario-building process. This approach enables us to map potential future paths and provide deeper insights into the complex causal dynamics underpinning conflicts between WEFE sectors.

Furthermore, the integration of Shared Policy Assumptions (SPAs) into the SSP-RCP pathways, creating the SSP-RCP-SPA structure, is an emerging trend in climate modelling. This approach aims to establish more nuanced connections between global climate scenarios and specific regional or sectoral policy objectives (Arnell et al., 2011; Riahi et al., 2017; Kebede et al., 2018; IPCC, 2022a). By integrating EU-WEFE policy objectives into global SSP-RCP pathways, our study addresses a critical gap for impact assessment studies, which has also been identified by other authors (Aguar et al., 2020). The primary limitations in the development of policy-relevant WEFE narratives are linked to the challenge of achieving equitable progress in compliance with WEFE policy objectives across different dimensions of the WEFE nexus. Interactions within the WEFE nexus frequently involve various trade-offs, in which achieving compliance with objectives in one dimension may result in non-compliance with objectives in other dimensions of the nexus. Inferring the achievement of WEFE policy objectives while considering different spatial levels also introduces complex implications. According to expert declarations, there is uncertainty and complexity regarding the mapping of the WEFE policies on the EU level with the existing SSP-RCP pathways on the global level.

Another key challenge was ensuring that the narratives effectively captured the complexity of the WEFE nexus while remaining accessible

to a wider audience, including non-specialists. Feedback from experts highlighted the need for clarification of some technical terms and concepts, which led to adjustments in how information was presented. This iterative refinement enhanced the inclusivity and usability of the narratives, particularly for policymakers. A significant divergence arose among experts regarding the integration of current EU-WEFE policies with climate and socioeconomic scenarios. This divergence necessitated additional deliberations and the adoption of a structured methodology (e.g., ranking) to reconcile varying perspectives. While these methods improved consensus, they also underscored the challenges of fully harmonizing priorities across diverse WEFE sectors. The participatory approach of different groups of experts, which involved workshops, surveys, and the Canvas methodology, generated a rich dataset but also presented logistical challenges in synthesizing the diverse inputs into cohesive narratives.

Another key challenge that emerged from the expert workshops conducted over the past three years to identify policy-relevant WEFE-nexus pathways is that, although we considered it relevant to retain the SSP-RCP framework, our pathways do not fully align with the existing SSP-RCP narratives. In particular, the experts identified the Global Fragmentation pathway as one of the most relevant scenarios. Under this scenario, rising geopolitical tensions and a lack of concerted efforts to achieve sustainability targets will result in higher GHG emissions by mid-century. By prioritizing environmental drivers over socioeconomic ones, the experts considered the Global Fragmentation trajectory to be aligned with SSP5-8.5, which could be questionable because this represents a departure from the original framing of SSP5, published in 2017 (O'Neill et al., 2017). Nevertheless, it is important to note that narratives are not static, and our research shows the relevance of frequently updating the socioeconomic drivers.

In a next step, the narratives derived from our study will be quantified using models. It is imperative to engage with models that go beyond mere inferences, employing a process similar to that used to quantify SSPs and RCPs (O'Neill et al., 2014; Riahi et al., 2017). This will allow for a more rigorous and quantitative exploration of the policy-relevant WEFE narratives, facilitating a deeper understanding of the potential impacts and trade-offs within the WEFE nexus across different dimensions and spatial levels (González-Rosell et al., 2023).

5. Concluding remarks

In this study, we have developed five policy-relevant WEFE pathways until 2050. For each pathway, a narrative elucidates how climate, socioeconomic, and policy drivers influence the sustainable transition of the WEFE sectors in the EU, while taking into account the global context. These narratives serve as descriptive frameworks, offering a foundation for defining future quantitative-policy WEFE scenarios for foresight studies and policy impact assessments. These policy-relevant WEFE narratives complement the quantitative scenarios in the scenario-building process and serve as instruments to enhance our understanding of the driving forces and impacts of WEFE-sustainability challenges at various levels.

By encompassing all components of the WEFE nexus and determining how to integrate EU policies into climate and socioeconomic pathways, the policy-relevant WEFE pathways present a consistent and integrated approach to understanding tendencies in critical WEFE resources, while highlighting the synergies and trade-offs involved. Each narrative describes WEFE trends and approximates the achievement of specific EU-WEFE policy objectives aligned with climate and socioeconomic driving forces.

Understanding the connections between WEFE sectors based on EU-WEFE policy objectives and mapping them with global SSP-RCP pathways, these WEFE pathways contribute to addressing uncertainty about the future WEFE sustainable state of the EU and the changes necessary to achieve it. The policy-relevant WEFE narratives were established at the EU level, incorporating stakeholder concerns and viewpoints through EU nexus dialogues and workshops. The engagement of stakeholders in this process brings several benefits, including an increased capacity for stakeholders to address uncertainties and complexities and acquire an improved understanding of the impacts of global changes across the WEFE nexus.

Findings show that the Emissions Neutrality pathway would require a high level of coordination between global and EU commitments, which makes this scenario difficult to be achieved. At the other end, Global Fragmentation represents a challenging future for the EU because it shows that EU-WEFE objectives will not be reached in a high-emission scenario, showcasing the need for global coordination to achieve WEFE sustainability.

Furthermore, these narratives for policy-relevant WEFE pathways were created to facilitate policy impact assessments and foresight studies to define scenarios and design coherent and efficient solutions to mitigate climate threats to the WEFE nexus.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Supplementary Material has been added

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.eiar.2025.108122>.

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