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ORIGINAL ARTICLE

New European socio-economic scenarios for climate change research: operationalising concepts to extend the shared socio-economic pathways

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Abstract

Scenarios have been recognised as a useful tool for planning, which have resulted in a strong increase in the number of (multi-scale) scenarios in climate change research. This paper addresses the need for methodological progress and testing of conceptual considerations, by extending the global shared socio-economic pathways (SSPs). We present a set of four European SSPs until 2100 and a novel method to develop qualitative stories for Europe equivalent to the global SSPs starting from an existing set of European scenarios. Similar to the global SSPs, the set includes a sustainable future with global cooperation and less intensive lifestyles (We are the World; Eur-SSP1); a future in which countries struggle to maintain living standards in a high-carbon intensive Europe (Icarus; Eur-SSP3); a world in which power becomes concentrated in a small elite and where Europe becomes an important player (Riders on the Storm; Eur-SSP4); and one where a lack of environmental concern leads to the over-exploitation of fossil fuel resources addressed by technological solutions (Fossil-fuelled Development; Eur-SSP5). We conclude that the global SSPs are a good starting point for developing equivalent continental scale scenarios that, in turn, can serve multiple purposes. There are, however, methodological challenges related to the choice for equivalence and the exact methods by which scenarios are constructed that need to be tested further.

Keywords Shared socio-economic pathways · Socio-economic scenario · Multi-scale · Europe · Narratives

Introduction

Scenarios have been recognised as a useful tool for planning in the face of irreducible complexity and uncertainty. This particularly holds for climate change-related research, where changes in socio-economic behaviour and related greenhouse gas emissions are highly uncertain and take decades to manifest themselves as temperature and precipitation change (O'Neill et al. 2013; Moss et al. 2010; Vermeulen et al. 2013). As a result, the number of scenarios in climate change research and beyond has increased strongly (see Hunt et al. 2012), together with new concepts, tools, and methods to

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develop them. For socio-economic scenario development, however, the first seeds for today's concepts and methods were provided more than a decade ago (Kok et al. 2007; Biggs et al. 2007; Alcamo 2001). Relative to the exploding number of socio-economic scenarios, methodological progress has been lagging behind, with similar issues being put forward repeatedly: top-down or bottom-up process design in multi-scale scenario development (Kok et al. 2007; Kok et al. 2016); development of qualitative, stakeholder-determined scenarios (Oteros-Rozas et al. 2015) and/or quantitative expert-determined models and their integration (Harrison et al. 2013); and the use of participatory methods and degree of stakeholder involvement (Patel et al. 2007). Despite increasing hands-on experience with developing scenarios, structural or theoretical progress has been slow, with some promising recent exceptions (Schweizer and Kurniawan 2016; Absar and Preston 2015). Overseeing the breadth of the environmental scenario development community, a number of observations stand out relevant to this paper:

Firstly, recent scenario reviews have illustrated just how many sets of scenarios have been developed, globally, nationally, and locally (Priess and Hauck 2014; Amer et al. 2013; Rounsevell and Metzger 2010; Rothman 2008). Although they differ in theme, focus, and content, there are similarities. Rather than developing scenarios from scratch, this (growing) body of evidence on plausible future outlooks should be used. Ample experience has been acquired with downscaling of (global) scenarios particularly related to the Millennium Ecosystem Assessment (MA 2005; Lebel et al. 2006) and the IPCC SRES scenarios (IPCC 2000). Yet, to date efforts remain largely uncoordinated and methods that build on existing scenarios remain ad hoc. Secondly, there is a lack of experiments, i.e. endeavours that go beyond a case study-specific implementation aimed at high-quality outputs, towards structurally testing conceptual recommendations on complex systems, scale, and scenarios. Although existing conceptual papers (e.g. Zurek and Henrichs 2007; Cash et al. 2006; Kok and Veldkamp 2011) are often quoted, recommendations are rarely adopted. Landmark papers on multi-scale scenario development methods (e.g. Kok et al. 2007; Scholes et al. 2013) date back to, again, the Millennium Ecosystem Assessment. As also argued by Schweizer and Kurniawan (2016), there is a need to revisit the concepts and attempt to link these with practical scenario development exercises. This paper will address the need to expand methods to include the use of existing scenarios, whilst operationalising concepts of multi-scale scenario development.

The considerations above are particularly valid since the completion of a new set of global climate scenarios, the representative concentration pathways (RCPs; Van Vuuren et al. 2011) and the shared socio-economic pathways (SSPs; O'Neill et al. 2013). The SSPs have been put forward as a set of scenarios that would be a useful starting point for scenarios development at others scales and for other sectors. Contrary to earlier global scenario sets, the SSPs are partly designed to be useful beyond their original purpose of being part of the new global climate scenarios. The SSPs were constructed along two axes; challenges to adaptation and challenges to mitigation (see Electronic Supplementary Material 1, ESM 1). A close link exists between socio-economic challenges to mitigation and adaptation and the wider dimensions of sustainability. The SSPs, thus, cover a large range of development and sustainability outcomes. O'Neill et al. (2017) openly invite other research groups to use, explore, and extend the SSPs to other sectors and geographic scales. Indeed, since their release, the SSPs have been used in multiple studies, globally (Riahi et al. 2016) and sub-globally (Absar and Preston 2015) with many more on the way. Most of those studies apply the SSPs by using quantitative numbers for variables such as population and GDP provided by the SSP database at a country level (https://tntcat.iiasa.ac.at/SspDb). Although a perfectly valid method, this does not address the conceptual issue of downscaling, nor the sub-regional variability. At the same time, a small but growing number of research groups also uses the narratives and extend the SSPs employing novel tools and methods, based on multi-scale scenario concepts (e.g. Schweizer and Kurniawan 2016; Nilsson et al. 2017; Palazzo et al. 2017). This paper builds on and contributes towards that second body of literature, with a specific focus on operationalising a conceptual approach.

Introducing the concepts

Zurek and Henrichs (2007) propose a conceptual approach to link scenarios across geographical scales with two elements: (i) the level of interconnectedness across scale or the similarity of the content of scenarios at different scales, and (ii) the type of scenario development process that is followed. Five levels of interconnectedness are listed (a) equivalent scenarios, where outcomes are directly transferred between scales; (b) consistent scenarios, where higher scale scenarios provide strict boundary conditions and main scenario assumptions and drivers are set to be similar; (c) coherent scenarios that follow the same paradigm and can be seen as a different representation of the same scenario archetype (see also Section 'Challenges and risks when developing equivalent scenarios'); (d) comparable scenarios, covering potentially very different aspects and connected mainly by shared concepts or general issues that are addressed; and (e) complementary scenarios, when developed independently with differences in the logics and assumptions across scales, but with complementing information. The paper describes five types of processes by which scenarios can be developed and the relationship between process and scenario content (see ESM 2). In the context of this paper, it is important to note that Zurek and Henrichs do not provide an operationalisation of the concepts,

whilst the use of existing scenarios challenges their process-related recommendations.

Objectives

In this paper, the invitation to use the global SSPs is taken as the challenge of downscaling the qualitative narratives. The main research questions were: how to operationalise this 'extension' of the SSPs, and how to conceptualise extension beyond the use of one particular set of scenarios? The overall objective of the paper is to provide details on a novel method for the development of a set of scenarios equivalent to a higher level set, whilst consistent and where possible coherent with another set of existing scenarios. A second objective is to present the resulting European SSPs (Eur-SSPs) such that these, in turn, can be used as an existing set of scenarios for more local studies. We operationalise the concept of multi-scale connectedness as proposed by Zurek and Henrichs (2007) and evaluate its usefulness within the framework of a large EU-funded project.

Methods

Broader research context

Within the European research community, there is an important role for (large) international, multi-partner, EU-funded projects. The research in this paper uses existing European scenarios as developed within a project called CLIMSAVE (www.climsave.eu) and describes work undertaken as part of the IMPRESSIONS project (see Harrison et al. 2018; www.impressions-project.eu). CLIMSAVE focused on climate change impacts and adaptation; IMPRESSIONS on adaptation and mitigation. Within IMPRESSIONS, multi-scale, integrated climate and socio-economic scenarios, including high-end climate scenarios and more extreme SSPs, were developed. The integrated scenarios serve two distinct purposes, namely as an input for a range of climate change impact models for which quantification of the SSPs is needed, and as a context for the development of adaptation and mitigation pathways. Sets of downscaled SSPs were developed during professionally facilitated scenario workshops (see Gramberger et al. 2015) for five case studies—continental (Europe); multi-national (Central Asia); national (Scotland); transboundary river basins (Iberia); and municipal (Hungary). Each case has a different degree of similarity to the global SSPs, based on similar but slightly different processes (ESM 1 and ESM 4). Here, we focus on the development process for the Eur-SSPs. Kok et al. (2015); Kok and Pedde (2016); and Pedde et al. (in review) provide more detail on the existing scenarios, the scenario development process, and resulting multi-scale scenarios in IMPRESSIONS.

The starting point: existing socio-economic scenarios

Global socio-economic scenarios—the shared socio-economic pathways

The global SSPs are a set of five scenarios that describe plausible future outlooks of a range of demographic, economic, technological, social, and environmental factors (O'Neill et al. 2013, 2017). The scenarios are relevant for both the analysis of emissions drivers and mitigation measures, and the analysis of societal vulnerability to climate change impacts and adaptation measures. The narratives are basic stories that can be the starting point for more detailed scenario studies. The SSPs are purposefully short and simple, but contain sufficient detail to guide development of alternative scenarios related to the basic SSPs. For many applications, 'extended SSPs' are likely to be required, which would contain additional, more detailed information for particular regions, sectors, or variables. For more information on process and content, we refer to O'Neill et al. (2017) and ESM 3.

Within this study, it was decided to use an even number of scenarios, to minimise the risk that stakeholders or other users would select one as the best estimate (Moss et al. 2010). Additionally, SSP2 (Middle of the Road) lacks its own 'identity' as almost all elements change moderately, which could hamper the process of developing new SSP2-based stories. Consequently, SSP2 was excluded and is not described in subsequent sections.

European socio-economic scenarios—the CLIMSAVE scenarios

Within CLIMSAVE, a set of four socio-economic scenarios were developed for Europe (see Gramberger et al. 2012; Kok et al. 2013; ESM 5). The scenarios include a utopian future where effective governments change the focus from GDP to welfare, which leads to a redistribution of wealth, and thus to less inequality and more (global) cooperation (We are the World); a dystopian outlook where short-term policy planning and a stagnating economy lead to the disintegration of social fabric and the shortage of goods and services (Icarus); a future in which strong economic recessions hit hard, but are successfully countered with renewables and green technologies (Riders on the Storm); and a second dystopian future with an increased gap between rich and poor, political instability and conflicts, and people living in an insecure and unstable world (Should I Stay or Should I Go).

Rationale for equivalent scenarios

The Eur-SSPs were the starting point for most of the other case studies, and it was decided to make those as similar as possible to the global SSPs and aim for two sets of equivalent

scenarios, i.e. their outcomes can be directly transferred between scales. This had a number of consequences. First and foremost, we refrained from including a large number and a broad range of stakeholders during scenario development. The stakeholder-driven process undertaken in the other case studies cannot guarantee to result in SSPs equivalent to the global versions. Thus to ensure equivalence, we organised a meeting, using the same methods as in the participatory workshops, but involving exclusively scientific experts on scenarios as participants (see Section 'Developing European-shared socio-economic pathways'). Secondly, the global scenarios needed to take precedence over the existing European scenarios in case of inconsistencies between the two sets. As a result, some important assumptions and details of the European scenarios were changed. Finally, to maximise similarity the Eur-SSPs were constructed to be rather general, following the content of the global SSPs.

Mapping the shared socio-economic pathways onto the CLIMSAVE scenarios

The first step in the process of developing new scenarios for Europe was to map the global SSPs onto the CLIMSAVE scenarios, in order to maintain as much as possible the European and stakeholder-determined flavour. Recently, novel methods have been proposed to systematically link qualitative elements of scenarios, also across scale, particularly cross-impact balances (Schweizer and Kurniawan 2016) and the factor-actor-sector approach (Absar and Preston 2015). Although both could have been suitable, we preferred a more informal discussion format. Formalising a post hoc comparison, e.g. by structuring drivers and their possible states, would limit discussions on comparability of underlying worldviews and perspectives, which were considered crucial. The mapping exercise was executed by a small team of researchers prior to the broader expert workshop. There are many similarities (see ESM 6): both have been developed as part of a set of more integrated climate change scenarios; both served as an input to integrated assessment models; and both were relatively long term. Yet, there are also crucial differences: The CLIMSAVE scenarios have a time horizon of the 2050s whilst the global SSPs have an outlook until 2100. More importantly, the CLIMSAVE scenarios used different main uncertainties for the basic foundation of the scenarios, which hampers a direct comparison. Overall, however, we concluded that there were sufficiently strong overall similarities in the main economic, environmental, and social aspects to perform a preliminary matching exercise (Table 1). An analysis of this information and the storylines of both scenario sets revealed that:

- Three out of four SSPs match one of the CLIMSAVE scenarios to a greater or lesser degree.
- The strongest match is with the utopian SSP1/We are the World and the dystopian SSP3/Icarus. A fair match is found between SSP4 and Riders on the Storm, mostly in relation to low social cohesion and other social indicators, coupled with a medium and instable economic growth, which leads to social stratification. Environmental interest, however, is maintained and (local) policies are in place. The match between SSP5 and Should I Stay or Should I Go is poor, mostly because of the fundamental assumption of a strong fossil fuel-dominated energy consumption, in combination with a lack of interest in natural capital. This is not assumed in the Should I Stay or Should I Go scenario.
- Overall, the SSPs assume a higher economic growth than the European scenarios. This is particularly evident from the quantitative projections from the SSP database and the scenario quantification embedded in the CLIMSAVE Integrated Assessment Platform (Harrison et al. 2013). Social sustainability is likewise lower in some of the European scenarios.

In conclusion, the SSPs and the European scenarios match to a degree sufficient to assume that they could be linked and synchronised further. This is particularly the case for SSP1 and SSP3, and to some extent for SSP4. However, it was clear that linking SSP5 to the CLIMSAVE scenarios was not possible.

The second step was a more detailed comparison between the global SSPs and the European CLIMSAVE scenarios. For this, we used a list of so-called main uncertainties that was part of the CLIMSAVE scenarios and matched those with 'key assumptions' as listed in O'Neill et al. (2017). It is beyond the scope of this paper to provide an in-depth overview of all matches and how they were interpreted (see ESM 8). Table 2 gives an overview of the CLIMSAVE uncertainties and comparable global SSP main elements that were used to match the scenarios. Some entries are identical (international cooperation, globalisation), whilst most others are similar (attitude towards human health and health investments).

Developing European-shared socio-economic pathways

The final step was the actual development of the new European scenarios during an expert workshop. We organised a two-day meeting with 22 participants from the IMPRESSIONS project in January 2015. Criteria to participate included geographical diversity (case-study representatives), sectoral and methodological expertise (WorkPackage leaders), age, gender, and knowledge of CLIMSAVE scenarios. Although only project partners were involved, the CLIMSAVE scenarios were developed using participatory

Table 1 Comparison of CLIMSAVE and global-shared socio-economic pathway (SSP) scenarios with a focus on Europe with illustrative examples of economic, environmental, and social content

Socio-economic scenario	Economic growth	Environmental policies	Social cohesion	Match
We are the World	Gradual increase	Effective sustainable solutions	High	Very similar
SSP1	Medium in high-income countries	Towards sustainable development	High	
Icarus	Gradual decline	No priority and ineffective	Decline, then picking up	Very similar
SSP3	Slow	Low priority	Low	
Riders on the Storm	Up and down, declining	Effective solutions	Low	Similar in many aspects, but different for some, including income growth
SSP4	Medium in high-income countries	Focus on local issues	Low and stratified	
Should I Stay or Should I go?	Up and down	Ineffective solutions, no priority	Low, but growing	Strong differences in economic and social factors
SSP5	High	Priority when related to well-being	High	

methods, which ensured stakeholder views to be part of the final product. During the meeting, the following aspects were discussed and confirmed or agreed upon: First, the initial mapping of the global SSPs onto the CLIMSAVE scenarios using the degree of compatibility between the CLIMSAVE and global SSP uncertainties (Table 2). Subsequently, an outline of new stories for three time slices (2010–2040, 2040–2070, 2070–2100) based on the list of uncertainties, CLIMSAVE stories, and global SSPs, thus extending the CLIMSAVE scenarios from the 2050s to 2100. Finally, trends and quantification of key model parameters were estimated for the new Eur-SSPs to match the global equivalent (see ESM 10). The output of the workshop was a first draft of the storylines for the three Eur-SSPs which closely match the CLIMSAVE scenarios, and the development of an outline for a European version of SSP5. There was also consensus on the process by which the stories should be further fleshed out.

After the workshop, for every time slice and for every scenario, stories of about one page in length were constructed that are equivalent to the global SSPs, and as similar as possible to the CLIMSAVE scenarios. In this process, we first examined the CLIMSAVE scenario text. If this was sufficiently similar, we used or adapted it. As part of the process, we examined the need to modify the ending of the CLIMSAVE scenarios around the 2050s to ensure that they could be extended to 2100. Where it was not, we used and extended the global SSP text. Figure 1 summarises the logic that was followed; Table ESM 4 provides the details for all Eur-SSPs and time slices. To illustrate the practicalities of the process, the process for Eur-SSP1 is elaborated in ESM 9.

Table 2 CLIMSAVE uncertainties and comparable global-shared socio-economic pathway (SSP) main elements used to match the scenario sets

CLIMSAVE uncertainty	Global SSP main element
Decision making level (local/international)	Globalisation
Geopolitical stability (low/high)	Political orientation
International cooperation (weak/strong)	International cooperation
Social and environmental respect of non-state actors (low/high)	Social cohesion
Population/migration (within regions/between regions)	Migration
Economic development (gradual/rollercoaster)	Economic growth and inequality
Globalisation (constrained/unconstrained)	Globalisation
Choice (restricted/free)	Societal participation
Attitude towards human and natural health (influential/respectful)	Health investments and environmental policy
Social cohesion (low/high)	Social cohesion
Solutions by innovation to depletion of natural resources (non-effective/effective)	Institutions and technology development
Social belief systems (plural/dominant)	Societal participation
Health investments (low/high)	Health investments
Education (low/high)	Education

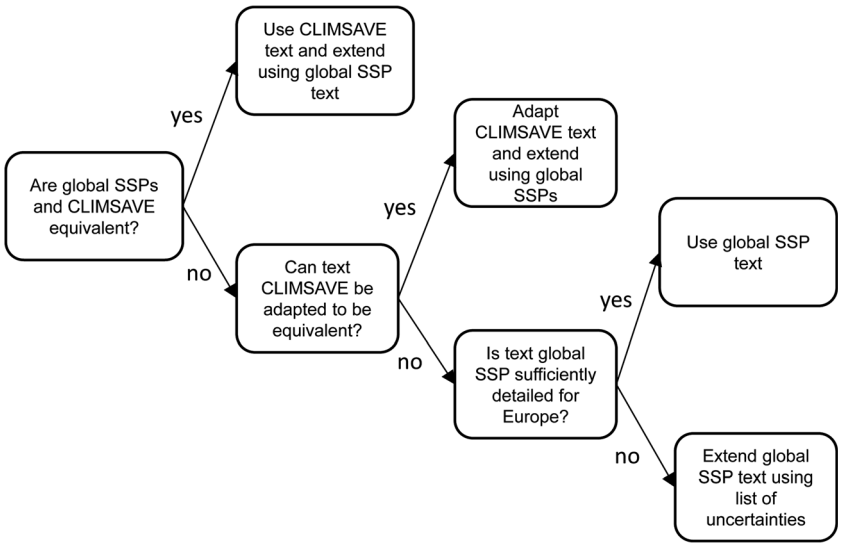

Fig. 1 Schematic representation of decision tree followed to develop the European Shared Socio-economic Pathways

Results

Similar to the global SSPs, the Eur-SSPs consist of various products. Here, we limit ourselves to a presentation of a summary of the stories with accompanying trends for key elements (Section 'The basic European-shared socio-economic pathways—stories and trends') and an analysis thereof. A second main output of the workshop, (quantified) trends in key model parameters, are provided in ESM 10 (see also Pedde et al. 2018).

The basic European-shared socio-economic pathways—stories and trends

A summary of the four Eur-SSPs is provided; the full stories can be found in ESM 7. The first sentence of each SSP story describes the general developments and is largely taken from the text of the global SSPs (O'Neill et al. 2017). Table 3 summarises some of the key elements across all four Eur-SSPs; Fig. 2 positions the scenarios along two axes.

European-shared socio-economic pathway 1 (Eur-SSP1)—We are the World

There is a high commitment to achieve sustainable development goals through effective governments and global cooperation, ultimately resulting in less inequality and less resource-intensive lifestyles.

The interplay of financial, environmental, and economic crises fuel the feeling that behaviour has to change away from an unregulated market-driven economy to a sustainable development path. This puts governments under pressure to take ambitious measures, including stimulating an energy transition towards renewables and facilitating innovative research, accompanied by investments in health, education, and social support. A decrease in conflicts in Europe's southern and eastern border regions leads to higher political stability and moderate but steady economic growth in an increasingly equitable Europe. The European Union expands further and participates in new global governance initiatives. Advances in green technologies are further stimulated by international competition leading to a CO_2 neutral society by 2050. By 2100, Europe is characterised by a high level of sustainability-oriented political and societal awareness, focusing on renewable energy and low-material growth in a strongly regulated but effective multi-level governance structure.

European-shared socio-economic pathway 3 (Eur-SSP3)—Icarus

Sparked by economic woes in major economies and regional conflict, antagonism between and within regional blocs increases, resulting in the disintegration of social fabric and many countries struggling to maintain living standards.

With the economy gradually picking up, the demand for resources increases, which turns out to be a tipping point for the state of the environment with severe ecosystem failures. The persistence of conflicts and decline in trade also substantially increases energy and food prices, whilst initiating a massive build-up of the military industry, which is resource hungry but not resource efficient. Long-term policy planning becomes rare with hardly any money for education, research or innovation. Eventually, the EU breaks down, with new regional blocs forming in the north and in the south of Europe, whilst new alliances with other countries are forged to ensure sufficient energy supply. Social countermovements temporarily appear but do not take root in a fragmented and divided Europe with strong regional rivalry and conflict. Ultimately, a high-carbon intensive Europe emerges that is not worse off than the rest of the world, but struggles not to become the

Table 3 Key elements of the four European-shared socio-economic pathways (Eur-SSPs), representing the situation towards 2100

Key elements	Eur-SSP1 We are the World	Eur-SSP3 Icarus	Eur-SSP4 Riders on the Storm	Eur-SSP5 Fossil-fuelled Development
Decision-making level	International/EU leader	National/local widespread fragmentation	International / Europe leader on the global scale	International/EU not a leader on the global scale
International cooperation	Strong, EU important player	Weak	Strong, EU important player	Strong (trade)
Migration	Low immigration	Outmigration	Selected immigration	High to cities and from poorer countries
Economic development	Gradual (with hiccups at the beginning)	Low	High	High
Mobility	No barriers, but movements are limited	Low	High	High
Social cohesion	High	Low EU/higher within countries	Low	High
Technology development	High, but not pervasive	Low	High in some areas; low in labour intensive areas	Strong and crucial
Quality of Governance	High—focus on sustainability	Low and ineffective	High and effective	High with focus on businesses
Human health investments	High	Low	High for elites, medium for lower class	High
Education investments	High	Low	High for elites, medium for lower class	High
Environmental respect	High	Low	High in pockets	Low, with high 'not in my backyard'

world's backwater with high inequalities predominantly between, but also within, countries.

European-shared socio-economic pathway 4 (Eur-SSP4) —Riders on the Storm

Globally, power becomes more concentrated in a relatively small political and business elite, accompanied by increasing disparities in economic opportunity, leading to substantial proportions of populations having a low level of development, although Europe becomes an important player in a world full of tensions.

Sparked by economic crisis and extreme weather events, the EU increases commitment to find innovative solutions to the depletion of natural resources and climate change. In combination with current relatively high levels of social cohesion,

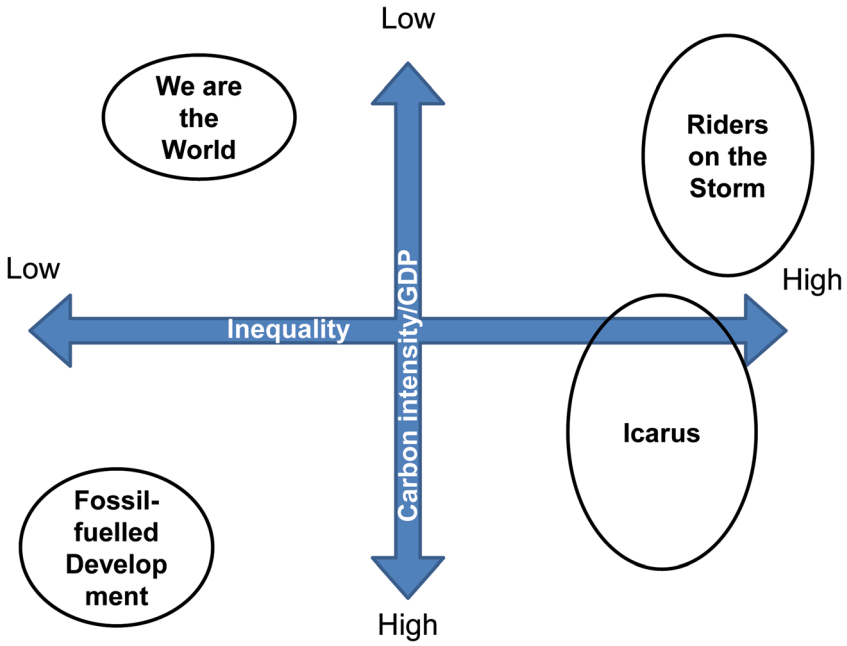

Fig. 2 Four European Shared Socio-economic Pathways representing different combinations of degree of inequality and carbon intensity per unit of Gross Domestic Product

energy efficiency, and environmental policy making this initiates a shift towards a high-tech green Europe. This transformation is strongly supported by large businesses that successfully seek collaboration with the increasingly powerful European government. At the same time, however, inequalities are rising because of a number of simultaneously acting factors, including highly unequal investments in education. This leads to a large and widening gap between an internationally connected society and a more fragmented collection of lower income societies that work in a labour intensive, low-tech economy. Technological development has not resulted in reduced energy prices, but has instead established an oligarchy of green business developers that control energy supply. By 2100, Europe is relatively strong, but with growing inequalities across and within European countries.

European-shared socio-economic pathway 5 (Eur-SSP5) —Fossil-fuelled Development

People place increasing faith in competitive markets, innovation, and participatory societies to produce rapid technological progress and development of human capital as the path to sustainable development. A lack of environmental concern leads to the exploitation of abundant fossil fuel resources.

Global markets are increasingly integrated, with interventions focused on removing institutional barriers. There are also strong investments in health, education, and institutions to enhance human and social capital. The push for economic and social development is coupled with the exploitation of abundant fossil fuel resources, including large-scale extraction of shale gas. This further stimulates economic wealth, part of which is used to stimulate the development of (green) technologies. Europe regains its leading position in the global economy. Faith is strong in the ability to effectively manage social and ecological systems, including by geo-engineering. Population across all societal classes adopts a very energy-intensive lifestyle. The environment degrades, but the majority of the population is unaware because of successful technological innovation. Towards 2100, the environment is locally seriously degraded as non-renewables are further exploited, which eventually results in a slow re-emergence of investments in renewables.

Analysis across the European-shared socio-economic pathways

The Eur-SSPs were constructed to be equivalent to the global SSPs and, therefore, likewise to cover a broad range of challenges to mitigation and adaptation, which makes them relevant for the climate change community in Europe. Additionally, like the global SSPs, the Eur-SSPs cover a wide range of the dimensions of sustainability and development, by including highly unequal (SSP3 and SSP4) and equal (SSP1 and SSP5) societies, but also very resource intensive (SSP5 and SSP3) and lower consumption worlds (SSP1 and SSP4). Within the set of SSPs, Eur-SSP4 arguably stands out as both the most 'difficult' story to tell and the most interesting addition, because of a high inequality within countries in combination with a strong and connected elite that nonetheless persists in a society with low human and social capital, yet with, e.g. strong technological development and high financial capital. SSP3 and SSP4 are rather similar, regarding a large share of the key elements and parts of the narrative. There are differentiating assumptions (inequality, technological development), but their main difference is in the associated potential GHG-emissions, which are rather low for SSP4 and high for SSP3. The same holds for SSP1 and SSP5, with potentially low emissions for SSP1 and very high emissions for SSP5. This reflects a main motive from the global climate change community to explore future outlooks that decouple challenges to mitigation and adaption, under relatively similar socio-economic circumstances.

Discussion

From concepts to practise—methods to develop equivalent scenarios

One of the main challenges described in this paper is the development of a set of Eur-SSPs equivalent to a higher level set, whilst consistent and where possible coherent with another set of existing scenarios. The resulting set of Eur-SSPs can be considered equivalent with the higher-level global SSPs, whilst three out of four were consistent with the CLIMSAVE scenarios that were used as a second starting point. The development of the Eur-SSPs using two sets of existing scenarios at different (temporal and spatial) scales thus proved to be successful.

Yet, there are important methodological aspects that deserve more attention. Firstly, the mapping exercise was rather subjective. There are no pre-existing guidelines to decide whether similarities are sufficient to pair two scenarios. In case of a good match, the exercise might seem more straightforward, but the devil is in the details. For example, Eur-SSP1, that needed to be constructed from a global SSP1 that assumed relatively high economic growth and We are the World that assumes a dematerialising Europe. In case of a partial but sufficient match, criteria are lacking, and 'partial' comes in many shapes: Part of the geographical area, part of the temporal extent, part of the sectors, etc. In the case of Eur-SSP4, the experts during the workshop felt that the global SSP4 could be combined with Riders on the Storm. The lack of European-specific information in the global SSP4 and the shorter time horizon on Riders on the Storm made it difficult to substantiate the claim that the resulting Eur-SSP4 is

equivalent with its global counterpart. In case of an insufficient match, objective criteria are likewise missing. In the case of SSP5 and Should I Stay or Should I Go, we based our conclusion on important aspects such as globalisation, social cohesion, and economic growth, in a workshop setting with a large number of experts, both on the CLIMSAVE scenarios and the global SSPs. This decision is justifiable as the two worlds are fundamentally different, but rather subjective.

Secondly, comparing uncertainties and their polarities (CLIMSAVE scenarios) and key assumptions (global SSPs) is partly comparing apples and oranges. Geopolitical stability is not the same as international cooperation, even if they are not unrelated. The same holds, for example, for social participation and social cohesion. This is directly related to the fact that the processes by which the scenarios were developed were completely independent. This will be an issue for any combination of existing scenarios.

Thirdly, the scenario development exercise was likewise rather subjective. Crucial choices were made for every time slice on what scenario to use (see Fig. 1), without clear criteria for when detail for Europe was sufficient to use the text, or whether two sets of stories were equivalent or equivalence is needed to be created. Note that 'equivalence' is defined in terms of 'outcomes', thus including more than the stories. In IMPRESSIONS, we used some of the quantifications for Europe as given by the SSP database—notably population and GDP, based on the global SSPs. Thus, by definition, the outcomes were equivalent.

In short, it is fairly straightforward to show how a set of scenarios can be developed that is (very) similar to two existing sets of scenarios. Yet, the methods to create equivalence with one set and consistency with another set are in their infancy.

We hope that the method employed here can be further fine-tuned in other similar exercises, as it will be tested in other case studies of IMPRESSIONS. Particularly promising advances could include:

- More work on scenario archetypes (see Section 'Challenges and risks when developing equivalent scenarios').
- Protocols to standardise what qualitative socio-economic scenarios should contain. The Eur-SSPs have the same elements as the global SSPs (stories, tables with trends, and quantification of key parameters), yet they are not easily or fully comparable. The use of structured methods such as cross-impact balances (Schweizer and Kurniawan 2016) or the factor-actor-sector approach (Absar and Preston 2015) could facilitate a full comparison up front.
- Develop equivalent scenarios during a stakeholder workshop. It is worthwhile to attempt equivalent scenario development during a workshop with (a broader range of) stakeholders, to increase usefulness, relevance, and/or legitimacy of the new set of scenarios. This could lead to tensions with the goal of equivalence, which is worth experimenting with.
- Link with suggestions from recent multi-scale scenario literature. Although not focusing on equivalence, structuring tools such as cross-impact balances (Schweizer and Kurniawan 2016); explicit a priori choices of granularity, resolution, and scale (Scholes et al. 2013), or an external consistency analysis (cf. Brand et al. 2013) are promising avenues to pursue.

Characteristics of equivalent scenarios

The Eur-SSPs are equivalent to the global SSPs. This has a number of consequences. An important advantage is that the two sets of scenarios can be combined. Climate change (impacts), for example, can directly be taken from the global models. Additionally, assumptions on global trade, international policies, etc. can directly be linked to the European scenarios. Vice versa, global scenario users could include details from the Eur-SSPs in their global model runs. The tight coupling between exploratory scenarios facilitates a tight coupling between the subsequent uses of multi-scale scenarios. Another advantage relates to the visibility and credibility of the lower level scenarios, when equivalent to well-known global scenarios. Many sets of European scenarios exist, but those most known are often those that were linked to global scenarios, notably the IPCC SRES (Rounsevell et al. 2005; Verburg et al. 2008). The same will, hopefully, hold for the Eur-SSPs. Finally, within IMPRESSIONS, equivalent scenarios allow for a true cross-scale scenario development design (see Gramberger et al. 2015). Using consistent or coherent Eur-SSPs would inhibit the execution of developing local extensions of the global SSPs.

Challenges and risks when developing equivalent scenarios

Developing and using equivalent scenarios bring about several important risks and challenges. Firstly, O'Neill et al. (2017) introduce the global SSPs as 'pathways', which also means that narratives are short and simple. Equivalence of a lower-scale set of scenarios results in likewise simple and short narratives. As a result, the Eur-SSPs are less detailed than the European CLIMSAVE scenarios, as we omitted material of the existing scenarios to increase equivalence. This might have also reduced relevant regional context material. Secondly, by definition, the Eur-SSPs cover the same uncertainty space as the global SSPs. Although not an unreasonable starting point, Europe-specific uncertainties might have been ignored. Because the CLIMSAVE scenarios consist of stakeholder-determined stories and expert-based quantitative models that were developed iteratively (Harrison et al. 2013;

Gramberger et al. 2015; Kok et al. 2015), the risk of missing key uncertainties was small. Thirdly, any shortcoming in the global SSPs might be propagated, particularly related to the newly added SSP4 and SSP5. Finally, this paper relates to two-scenario sets for climate research. When using the SSPs and existing scenarios that have been developed for a different purpose other challenges surface: (a) Mismatches between the drivers, factors, sectors, actors, and hence content will hamper comparison and creating equivalent scenarios. As SSPs will be sectorally extended, this challenge will reduce over time; (b) existing scenarios might have been constructed using fundamentally different uncertainties, which might hinder matching the SSPs. Particularly, when methods such as Morphological Analysis or CIB have been employed, existing scenarios might be difficult to relate. As these methods will be more common, this challenge might increase.

In short, the resulting Eur-SSPs are an excellent product to be further used, very much like the global SSPs. Yet, also analogous with their global equivalent, they might be in need of further 'extension'. Moreover, creating an equivalent set of European SSPs carries over any issue with the global SSPs.

Scenario archetypes as overarching constructs

A number of authors have proposed the classification of scenarios into a limited number of scenario archetypes or scenario families (Hunt et al. 2012; Van Vuuren et al. 2012; Rothman 2008). Although the exact number and content of these archetypes—particularly in the context of the global SSPs—is under discussion, there are strong indications that existing scenarios can be clustered into a small number of more general, archetypical descriptions. All efforts seem to agree that the archetypes include a utopian future (cf. Eur-SSP1), a dystopian future (cf. Eur-SSP3), and a future closer to business-as-usual (cf. Eur-SSP5 and global SSP2). There is less agreement on the plausibility and therefore desirability to include SSP4 as a scenario archetype. A future outlook with a powerful, green, elite is regarded plausible in many countries across Latin America and Africa, whilst in Europe plausibility, credibility, and therefore usability of such a scenario has been questioned. Yet, the resemblance with the CLIMSAVE scenario Riders on the Storm suggests that it is an emerging type of future outlook, also in the eyes of the broader stakeholder community. Work on scenario archetypes needs to be prioritised and extended, because it has the potential to aid in the comparison and categorisation of existing scenarios, and therefore also in developing criteria to decide on the degree of matching between scenarios.

Revisiting the concepts

The conceptual degrees of connectedness, as proposed by Zurek and Henrichs (2007), have proven to be useful, whilst the need for further conceptualisation has become apparent. Selecting a type of connection before embarking upon the scenario development process is an essential first step. The choice for equivalent scenarios has led to important modifications in process and content of the scenarios, with a workshop with experts rather than a broader selection of stakeholders and with resulting scenarios that were simpler than the original European scenarios. Opting for consistent or coherent scenarios would have led to different choices and a different product. As argued in the Introduction, the scenario community has more than sufficient hands-on experience, but lacks conceptual foundations. This paper has helped show where those might be found and how they can be operationalised.

The approaches that are listed by Zurek and Henrichs were intended for developing new scenario sets rather than existing ones and are, therefore, in need of revision given the increasing importance of existing scenarios. Zurek and Henrichs present a concluding table, where for example five processes of scenario development are related to the level of connectedness. They conclude that it is (very) unlikely that independent processes can lead to more than comparable scenario sets. Based on this paper, this table should be reassessed when starting from existing scenarios. We hypothesise a marked shift from joint processes to rather independent processes, with a need to adapt existing, independently developed material, rather than jointly constructing new material, but continuing to aim for equivalent consistent or coherent scenarios across scale.

Conclusions

We conclude that the global SSPs are an excellent starting point to develop lower scale scenarios. The resulting Eur-SSPs, in turn, can serve the same multiple purposes as its equivalent set of global scenarios. The combination of global SSPs with a set of existing lower-scale scenarios proved possible without jeopardising the European identity of the original set for most of the scenarios. We hope that the set of Eur-SSPs will be further extended across spatial, temporal, and thematic scales. Whilst we advertise the use of the resulting Eur-SSPs, however, there are methodological challenges related to the choice for equivalence and the exact methods by which scenarios are constructed. Particularly, when existing scenarios are not related to climate research, or when scenarios cannot easily be related to the SSPs, seeking equivalence rather than consistency or coherency might not be the best choice. Methods employed need to be tested further, with a specific role for scenario archetypes and recently proposed more structured approaches to compare scenarios.

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