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Assessing future cross-border climate impacts using shared socioeconomic pathways

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ABSTRACT

Significant effort has gone into identifying and assessing climate change impacts, often within tightly defined sectoral contexts or within specific administrative boundaries, for example in national adaptation plans. Interest is now growing among policy makers and researchers to better understand the transmission of climate impacts from one location to another. While impacts, adaptation and vulnerability research traditionally failed to take such climate impacts into account, a number of recent national-level scoping studies have recognized the potential significance of cross-border climate impacts. However, these studies have lacked an explicit futures perspective, and implicitly assumed static conditions under which cross-border climate impact is assessed.

This paper addresses this research gap by developing a scenario-based framework for the study of future cross-border climate impacts using the global Shared Socioeconomic Pathways (SSPs). We apply this framework to assess future cross-border climate impacts in Kenya. We develop 'extended SSPs' in a combined top-down and bottom-up approach implemented through a co-production process together with local stakeholders. The bottom-up element of our approach consists of local drivers for understanding Kenya's vulnerability to future cross-border climate impacts, and the top-down element consists of the global SSPs as common boundary conditions. Finally, the extended SSPs combined with identified future cross-border climate impacts are used to stimulate a participatory co-production process to explore and evaluate different sets of adaptation options and activities. These future-oriented adaptation actions have the potential to improve Kenyan adaptation planning to mitigate and adapt to future climate impacts generated from global flows.

1. Introduction

Traditionally, researchers, practitioners and policy makers have treated climate impacts, adaptation and vulnerability (IAV) as strictly regional and/or local issues which need to be planned for and adapted to within the borders of, for example, a certain country

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(Burton, 2011). However, in an increasingly globalized and interconnected world, no country is fully insulated from the impacts of climate change outside its borders. Likewise, adaptation actions in one country might have unintended spill-over effects in another country. Studies on climate change impact and vulnerability have increasingly recognized that climate impacts in different spatial scales and places are linked and interconnected through globally interconnected flows of commodities, people, and resources (Adger et al., 2009).

The relevance of interconnections, globalisation and cross-spatial aspects of climate impacts (Challinor et al., 2017; Gotangco et al., 2017; Moser & Hart, 2015) have been studied through a different set of terminologies, e.g., spill-over effects, indirect climate impacts, traded impact, international effects, systemic impacts, etc. It is especially important to make a clear distinction between impacts transmitted across spatial scales and impacts stemming from adaptation actions (for a review see (Benzie et al., 2017)). Here we adopt the term 'cross-border impacts of climate change' to emphasise risks that are related to physical impacts of climate change and that cross some sort of border, for example, between two national jurisdictions or between the EU and a non-EU member state. We define cross-border impacts of climate change as 'consequences of climate change that occur remotely from the location of their initial impact, where both impacts, and potentially also responses to those impacts such as adaptation, are transmitted across one or more borders.' (Carter et al., in review).

Hitherto, there have been relatively few attempts to conceptualise cross-border impacts of climate change. Some frameworks use 'risk pathways' along which climate related risks are transmitted from one region to another region. The transnational climate impacts framework, for example, recognizes four risk pathways: 1) the biophysical pathway, which encompasses transboundary ecosystems, such as river basins, 2) the finance pathway, which represents capital flows and climate impacts on assets held overseas, 3) the people pathway, which involves the movement of people between countries, like migration and tourism, and 4) the trade pathway, which transmits climate risks across international supply chains (Hedlund et al., 2018). This risk pathway framework was used as the basis for quantifying countries' relative level of exposure to climate impacts that were transboundary (e.g., between neighbouring countries) and teleconnected (i.e., more remote connections). While territorial climate impacts finds countries in sub-Saharan Africa, small island developing states and other least developed countries most exposed, cross-border impacts of climate change shows a more diverse picture: although many sub-Saharan African states are highly exposed, the top 20-list also includes four European states and several countries in the Middle East (Hedlund et al., 2018). More detailed national level studies have been conducted in Finland (Kankaanpää & Carter, 2007), the Netherlands (Vonk et al., 2015), and the United Kingdom (Sentance & Betts, 2012)) and more recently at regional levels (e.g., Europe (Benzie et al., 2019; Lung et al., 2017)).

In 2015, the Paris agreement recognized adaptation as a 'global challenge' and called on the world to commit to a global goal on adaptation seeking to reduce vulnerability and increase resilience (UN 2015, Art 7.1). Since then, as cross-border climate impacts have become more widely recognised and adaptation has risen on global agendas, more recent studies have viewed adaptation as a global challenge and called for not only national responses but also coordinated regional, international, and transboundary adaptation governance (Dzebo & Stripple, 2015; Persson, 2019; Persson & Dzebo, 2019).

However, despite increasing interest in cross-border climate impacts, there is a gap in knowledge in the literature about how these impacts might manifest in future socioeconomic contexts. In other words, most studies do not adopt an explicit future-oriented perspective, implicitly assuming static conditions under which cross-border climate impacts are assessed.

Socioeconomic drivers and conditions are fundamental in determining the level of vulnerability to future climate impacts and for developing adaptation responses (van Ruijven et al., 2014; Carter, 2007). The same climate signal (or the same magnitude of climate change) might have different impacts on different societies with different socioeconomic contexts and pose different risks and even opportunities (Carlsen et al., 2013). Therefore, IAV studies need to analyse and assess how socioeconomic developments determine future climate impacts and associate risks (Wilbanks & Ebi, 2014). In the present context, socioeconomic scenarios are plausible descriptions of how the future may develop using consistent combinations of key driving forces and relationships, and consist of only qualitative data or a combination of qualitative and quantitative data (Elsawah et al., 2020; Moss et al., 2010; van Vuuren et al., 2012).

Traditionally, scenarios have been developed and used to explore future changes at single spatial scales, i.e., global, regional, national, and sub-national. However, more recent scenario studies, especially among the climate change research community, have developed processes and examples of building and using cross-scale scenarios, consisting of a set of linked scenarios constructed at two or more spatial scales (Brand et al., 2013; Kok et al., 2007; Mason-D'Croz et al., 2016; Zurek & Henrichs, 2007). Top-down approaches are most often applied to developing cross-scale scenarios where larger scale (global) scenario information is used as a starting point and downscaled to create regionalized versions relevant at smaller (sub-global) scales. These approaches are often accompanied by quantitative information of key drivers. Bottom up approaches are usually used to develop single-scale scenarios where explorative, qualitative, and participatory scenario techniques are used to generate qualitative storylines for a given geographical context (Absar & Preston, 2015).

Several arguments have been made as motivations for linking scenarios across scales, including better understanding of driving forces, changes, and perspectives at multiple scales (Lebel et al., 2005), maintaining better relevance across multiple decision-making scales (Biggs et al., 2007), and enhancing stakeholder engagement (Wollenberg et al., 2000). The topic of cross-border climate impacts adds yet another argument for linking scenarios across scale. As mentioned before, climate impacts are highly dependent on the socioeconomic context. Hence, impacts that are transmitted across spatial scales are inevitably dependent on socioeconomic contexts of where they originate and where they are transmitted to. In other words, when studying future risks associated with cross-border climate impacts for a given country, it is necessary to understand socioeconomic developments within the borders of that country, but also in other countries and geographical contexts to which that country has interconnections. Given the growing globalization and increasing interconnections between spatial scales and places, we argue that local and regional socioeconomic scenarios for a given country need to be linked to global scenarios in order to provide a consistent baseline for analysing climate impacts originated from global flows.

In this paper, we develop and apply a stakeholder-driven scenario framework to the study of cross-border climate impacts. The framework comprises a set of stakeholder-generated regional scenarios linked to a global scenario set, the Shared Socioeconomic Pathways (SSPs; O'Neill et al., 2017; van Vuuren et al., 2014) developed by the climate change research community. The framework is purposely designed as an awareness-raising tool that aims to engage and inform broader sets of stakeholders on emerging cross-border climate risks (focusing on impacts in our case), and consequently induce more proactive adaptation planning. As a design criterion we opted for a qualitative framing of the adaptation challenge, with quantitative data and analysis playing a secondary illustrative role to enrich the qualitative scenarios. In most cases, more detailed quantitative analysis will be necessary for a comprehensive assessment of specific cross-border climate impacts. Our framework could be used for identifying which cross-border climate impacts should be in focus in further quantitative analyses. This paper, for the first time, combines the emerging literature on cross-border impacts of climate change and the qualitative elements of the global SSP.

We applied this framework to a case study focusing on Kenya. In doing so, we developed a set of stakeholder-generated socio-economic scenarios for Kenya linked to the SSPs and used those scenarios as an analytical tool for exploring future cross-border climate impacts and adaptation options. The empirical question we explore in the case study is: What future cross-border climate impacts may affect Kenya within the 2040–2060 time horizon and how can the national adaptation planning mitigate those impacts? Based on this empirical material, the overarching question for this paper is: How can cross-scale scenarios be utilised in the development of an analysis framework for exploring future cross-border climate impacts?

Following the introduction, we describe our methods and materials, including the participatory co-production process for scenario development, the quantitative modelling process, and finally, the application of scenario analysis framework for exploring future cross-border climate impacts and adaptation options. Next, we present the resulting regional scenarios: the socioeconomic storylines complemented by results of quantitative projections on food security. We then provide illustrative results on future cross-border climate impacts and adaptation options identified for each of the scenarios. Finally, we discuss the benefits and shortcomings of our approach to studying future cross-border impacts through linking local and regional scenarios with global scenarios.

2. Methods and materials

This section describes the main methodological building blocks of our approach, including participatory qualitative scenario building, modelling-based quantitative enhancement, scenario-based impacts analysis as well as response identification (Fig. 1).

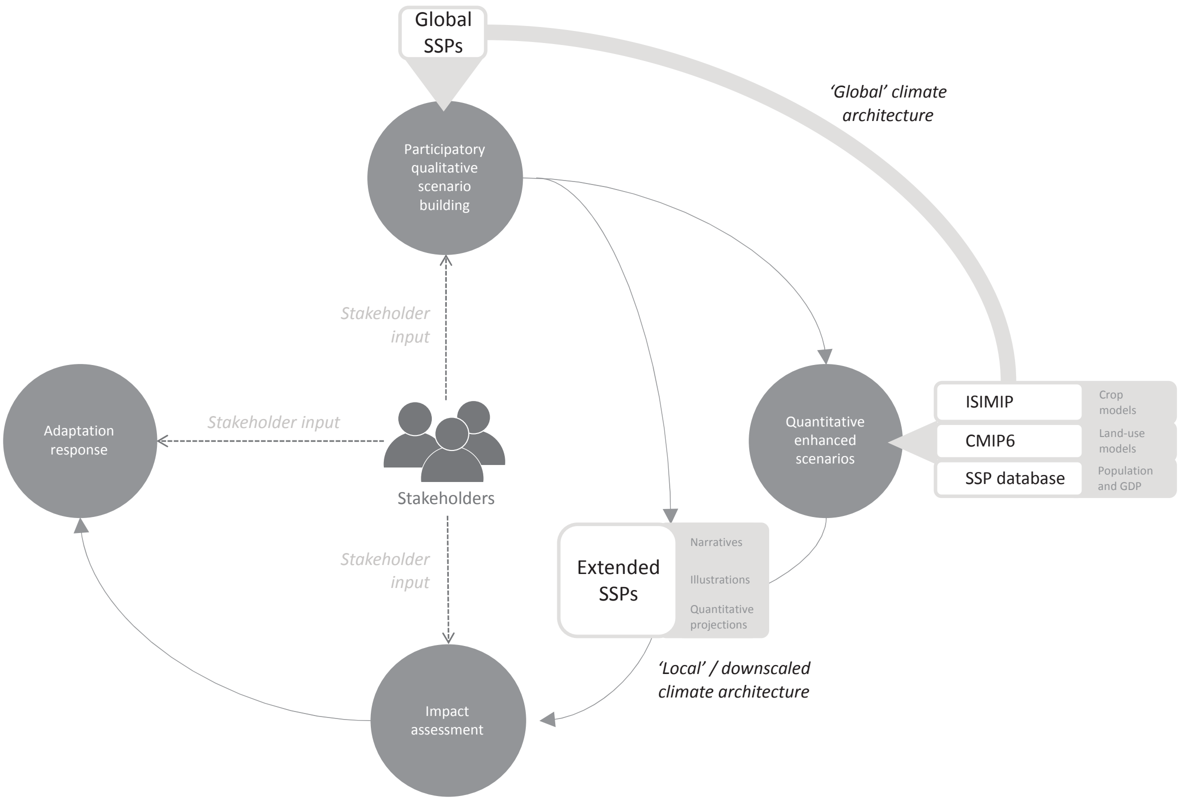

Fig. 1. Overview of cross-scale scenario approach. For abbreviations, please see main text. Source: Authors' own.

2.1. Qualitative scenario development: Building local narratives linked to global SSPs

To develop cross-scale scenarios, we linked local scenarios to the global SSPs. The SSPs offer a systematic exploration of possible socioeconomic futures in terms of widely different predispositions of challenges to mitigate and adapt to climate change at the global scale (Ebi et al., 2014; O'Neill et al., 2017; van Ruijven et al., 2014; van Vuuren et al., 2014). We see two main arguments for using the SSPs as the global scenario set in our approach.

First, SSPs were originally designed to be 'extended' to local and regional scales (Wilbanks & Ebi, 2014). An initial objective of developing the SSPs was "to guide regional and sectoral extensions of the scenarios … that fit within the overall global picture" (O'Neill et al., 2017). These scenarios are sufficiently generic narratives of future possibilities at the global scale, and provide a global context for processes at lower geographical scales that seek to use scenarios to guide regional, national or sub-national planning (Kriegler et al., 2014). In this study we aim to assess this design criterion of the SSPs.

Second, the application of the SSPs in sub-global IAV studies could facilitate and increase comparability between different studies. SSPs are beginning to be used and applied to a range of regional and national case studies. Absar & Preston (2015) develop sub-national and sectoral extensions of the global SSP narratives in order to identify future socioeconomic challenges for adaptation in southeast U.S. Reimann et al. (2018) extend the SSPs to the Mediterranean coastal zone and develop regionalized scenarios that include region-specific elements and differentiate between geographical regions. Nilsson et al. (2017) use a combined top-down and bottom-up approach to create SSPs extensions for the Barents' region. Frame et al. (2018) combine participatory processes and quantitative modelling to construct nationally relevant socio-economic scenarios for New Zealand, nested within SSPs. Zandersen et al. (2019) utilize the SSPs as boundary conditions for creating extended SSPs for the Baltic Sea region. Kok et al. (2018) develop European SSPs storylines by mapping the global SSPs onto an existing set of European scenarios. Palazzo et al. (2017) link a set of regional scenarios for West Africa to the SSPs by using and adapting SSP assumptions made for the region. And Rohat et al. (2018) reuse existing scenario knowledge to develop and quantify extended SSPs of human vulnerability in Europe. We want to extend this list to also include use of SSPs to support assessment of cross-border climate impacts.

When developing national socioeconomic scenarios there are almost always existing scenarios that need to be acknowledged and sometimes included in the analysis; and this was certainly also the case for Kenya. However, while we identified a number of socioeconomic scenarios developed at national scale for Kenya, they were either normative and functioned as agenda setting policy documents (e.g., Kenya Vision 2030 (Government of Kenya, 2007)) or constructed under a time horizon incompatible with the SSPs (e.g., Kenya at the Crossroads (IEA/SID, 2000)). Hence, we did not use any of the existing scenarios for the construction of the explorative scenario set for Kenya, but we assessed the normative Vision 2030 across the set of developed scenarios (see section 3.1.1).

In this paper, we used a combined top-down and bottom-up approach (Nilsson et al., 2017) to develop Kenyan scenarios linked to the SSPs, where the top-down element is the SSPs, and the bottom-up element includes stakeholder-generated local and regional knowledge concerning future vulnerability to cross-border climate impacts. To constrain the number of scenarios for consideration and decrease the complexity of the process, it was decided to use only four out of the five SSPs. As SSP2 (Middle of the Road) storyline lacks a certain level of diversity in relation to the other SSPs and represents a business-as-usual scenario, we decided to exclude SSP2 from our scenario set.

Local scenarios for Kenya were developed through a participatory co-production process implemented in a workshop in Nairobi involving a diverse range of local and regional stakeholders including planners, government officials, private sectors representatives, researchers, and civil society members. The workshop took place in January 2019. In total, 44 stakeholders with knowledge and/or experience working with adaptation issues were invited to this workshop. With a response rate of 25%, 11 stakeholders from national government (2), local government (2), research organizations and policy think tanks (3), academia (2), private sector (1), and NGOs (1) participated in the workshop. supplementary material

The process started with the bottom-up element where stakeholders generated information on relevant socioeconomic drivers for understanding future cross-border climate impacts. Drivers, also called as driving forces, are the key 'elements' that create the skeleton of a future scenario (Schwartz, 2012). Participants were asked to think specifically about risks generated from climate-impacted global flows that are transmitted across space. The time horizon was set to 2040–2060. In a prioritisation process, stakeholders were then asked to assess the level of importance (to the understanding of future cross-border climate impacts) and uncertainty, i.e., the extent to which the future development of a driver is unclear, vague or least-predictable. The drivers that scored high on both importance and uncertainty were selected as the key drivers for the scenarios and used as input to the top-down element of the process. Note that so far in the process, the generation and analysis of drivers were independent of the global SSPs.

To operationalize the top-down element, the global SSPs were introduced into the process as 'boundary conditions' (context scenarios) for the future development of the key drivers. The overarching question to guide the process was "How could driver × unfold at the local and regional level in a world as described in SSP1,3,4, and 5?". Stakeholders were asked to assign alternative states to each driver given the world described in each alternative SSP becomes materialized (Fig. 2).

The combination of key drivers and their associated states given each SSP provide the skeleton for the local and regional extensions of the respective SSP. In the next step of the scenario process, the research team created short storylines for the extended SSPs using the scenario skeletons co-produced with stakeholders.

After developing narratives for the extended SSPs, we took onboard Kenya Vision 2030 which is the most important future-oriented policy document in the country and assessed possible future conditions of this vision in the context of the alternative extended SSPs. Kenya Vision 2030 is the country's development blueprint visioning a set of goals and targets to be achieved by 2030. It is based on three 'pillars': the economic pillar aims to improve Kenya's prosperity through economic growth, the social pillar is set to build a just society through equality, social cohesion and secure environment, and the political pillar seeks to realise a democratic political system

	Global SSPs			
Local and regional drivers	**SSP1: Sustainability**	**SSP3: Regional rivalry**	**SSP4: Inequality**	**SSP5: Fossil-fuelled development**
Key driver 1	Local interpretation of key driver 1 given global SSP1	Local interpretation of key driver 1 given global SSP3	Local interpretation of key driver 1 given global SSP4	…
Key driver 2	Local interpretation of key driver 2 given global SSP1	Local interpretation of key driver 2 given global SSP3	…	…
Key driver 3	Local interpretation of key driver 3 given global SSP1	…	…	…
…	…	…	…	…
	Skeleton of Extended SSP1	**Skeleton of Extended SSP3**	**Skeleton of Extended SSP4**	**Skeleton of Extended SSP5**

Fig. 2. The skeletons for the local and regional SSPs ().
adopted from Nilsson et al., 2017

(Government of Kenya, 2007). We evaluated the condition of Kenya Vision 2030 given the alternative extended SSPs and assessed whether or not the future development targets within the three pillars might be attained on the way towards 2040–2060.

2.2. Quantitative enhanced scenarios

Since the scenarios were constructed to inform adaptation planning to cross-border climate impacts, we also wanted them to include elements of links to outside Kenya. To this end we opted for illustrating such links with global climate impacts modelling outputs. We reviewed the future drivers of importance at local and regional scale identified by stakeholders and assessed which drivers could be investigated and quantified by global models.

We selected food imports as the key future driver for developing quantitative enhanced scenarios. Food security and especially imports of food and essential crops was identified as an important local and regional driver and emphasized several times by stakeholders. Stakeholders emphasis on food security as an important challenge for Kenya is supported by scientific literature. Estimates from the Global Report on Food Crises (FSIN, 2018) show that 2.2 million Kenyans were considered food-insecure people in 2017 with a significant and constant increase over a-10-year period. According to a case study on aspects of food security in Kenya, 10 million people (close to 25% of the country's population) do not have access to sufficient food in terms of quantity and quality at any given year. (Sibhatu et al., 2015).Moreover, food security in Kenya significantly depends on the imports of food and essential crops. Reports show that since 2013 agricultural production in Kenya has not kept rapidity with population growth rate which lead the country to become a net importer of maize and wheat (Mohajan, 2014). Long periods of droughts have ever since decreased agricultural production significantly and if the present trends persist, Kenya will face more severe drought events, and challenging reductions in food security in future (Awange et al., 2007).

For the analysis here we used data generated within the ISIMIP[1] project, more specifically within its second round ISIMIP2b (Frieler et al., 2017). The crop model data employed here are from the three crop models GEPIC (Izaurralde et al., 2006; Liu et al., 2007; Williams et al., 1989), LPJmL (Bondeau et al., 2007), and PEPIC (Liu et al., 2016). One of the hallmarks of ISIMIP is that all impact models use the same streamlined input data, both for climate and socioeconomics, and thus can be used for a coherent and sound analysis across impact models. In particular, the ISIMIP2b climate scenarios entail both RCP2.6 and RCP6.0 from four Earth system models (GFDL-ESM2M, (Dunne et al., 2012) HadGEM2-ES, IPSL-CM5A-LR (Boucher et al., 2020) and MIROC5 (Watanabe et al., 2010) that were run in the context of the CMIP5 project (Taylor et al., 2012). As socioeconomic input (e.g., on land use) we would ideally use SSP1, 3, 4 and 5 in order to be consistent with the qualitative scenario building described in section 2.1. However, in the current design of ISIMIP only one scenario is used, SSP2. This introduces an inconsistency in our approach, but since SSP2 represents a middle-of-the-road scenario we think it provides a reasonable approach when linking the qualitative and the quantitative parts of the socioeconomic scenarios.

[1] The ISIMIP (Inter-Sectoral Impact Model Intercomparison Project, http://www.isimip.org collects cross-sectorally consistent climate-impacts simulations by providing common climate scenarios (daily, gridded data), common data sets describing socio-economic conditions (population, GDP, land use etc.).

The crop models calculated potential yields, i.e., in the models each crop was grown everywhere and yields [t/ha] were given as results. There are two kind of yields calculated, rainfed yields and yields with full irrigation. To obtain production values, we further needed the areas where the crops are grown. Data on crop areas was sourced from LUH2 land use data (Hurtt et al., 2020) developed for the CMIP6 project. Data on future crop areas was based on MagPIE simulations (Popp et al., 2014; Stevanović et al., 2016). Matching the crop models, the land use data provides rainfed as well a fully irrigated crop land area. Additionally, for each extended SSP, we used the SSP quantifications database (Riahi et al., 2017) to add quantitative projections on economic development (GDP) and population growth (Crespo Cuaresma, 2017; Kc & Lutz, 2017).

2.3. Exploring future cross-border impacts and adaptation options

In the next step, we used the scenario set as an analytical tool to identify with stakeholders possible future cross-border climate impacts and potential adaptation options to address them. This participatory process took place during a second workshop in Nairobi in October 2019. In total, 68 stakeholders with knowledge and/or experience working with adaptation issues, including the firs workshop participants, were invited to this workshop. With a response rate of close to 25%, 17 stakeholders from national government (3), local government (1), research organizations and policy think tanks (4), academia (4), private sector (1), and NGOs (4) participated in the workshop. supplementary material.

To operationalize the process, the extended SSPs and the risk pathways (Hedlund et al., 2018) were structured according to Table 1. The guiding question was “What are the most important future cross-border climate impacts (for Kenya) in the People, Biophysical, Trade and Finance risk pathways given the extended SSP1,3,4 and 5?”. The time perspective was the same as the one governing the scenario development, i.e., 2040–2060.

In the next step, participants were invited to generate adaptation options to address the identified cross-border climate impacts. Participants were encouraged to consider adaptation options that could be undertaken in the present and near future. On an overarching level, participants were asked to produce adaptation options that supported Kenya Vision 2030 targets on the way towards 2040–2060 (Government of Kenya, 2007).

The adaptation options generated were then analysed given the risk pathways and the alternative extended SSPs. We also clustered the adaptation options using a set of existing typologies (see Smit & Wandel, 2006) which categorize adaptation activities based on their themes or topics (Biagini et al., 2014), spatial scope – national and transnational (Smit et al., 2000) – and the level of adaptation activity – recognition, groundwork and action (Lesnikowski et al., 2011, 2013). Finally, we identified the main areas of adaptation options and activities that were echoed along all four risk pathways and across several extended SSPs and recommended those key areas of adaptation activities to national and local adaptation planners and policy makers.

3. Results

3.1. Extended SSPs for Kenya

3.1.1. Overview

The extended SSPs for Kenya were positioned on a scenario cross (Fig. 3). A scenario cross shows two main drivers and their associated states as polarities, hence a two-by-two matrix is produced. The main reason for using a scenario cross was to better communicate the Kenyan scenarios and associated climate change to stakeholders. Accordingly, we dedicated one axis to level of climate change for the region with polarities ‘Medium/high-end’ (RCP6.0) and ‘Low-end’ (RCP2.6) and one axis to regional collaborations within the East African Community (EAC) with polarities ‘high-level’ and ‘low-level’. The EAC is comprised of Burundi, Kenya, Rwanda, South Sudan, Tanzania, and Uganda. When picking the second axis, we aimed to select a driver that represents a key socioeconomic dimension most relevant to the focus of the case study, i.e., challenges to Kenya with regards to cross-border climate

Table 1
Structured approach for identifying future cross-border impacts.

Risk pathway	Scenarios			
	Extended SSP1: Sustainability	**Extended SSP3: Regional rivalry**	**Extended SSP4: Inequality**	**Extended SSP5: Fossil-fuelled development**
People	Future cross-border climate impacts in the People pathway given extended SSP1	Future cross-border climate impacts in the People pathway given extended SSP3	Future cross-border climate impacts in the People pathway given extended SSP4	Future cross-border climate impacts in the People pathway given extended SSP5
Biophysical	Future cross-border climate impacts in the Biophysical pathway given extended SSP1	Future cross-border climate impacts in the Biophysical pathway given extended SSP3	Future cross-border climate impacts in the Biophysical pathway given extended SSP4	…
Trade	Future cross-border climate impacts in the Trade pathway given extended SSP1	Future cross-border climate impacts in the Trade pathway given extended SSP3	…	…
Finance	Future cross-border climate impacts in the Finance pathway given extended SSP1	…	…	…

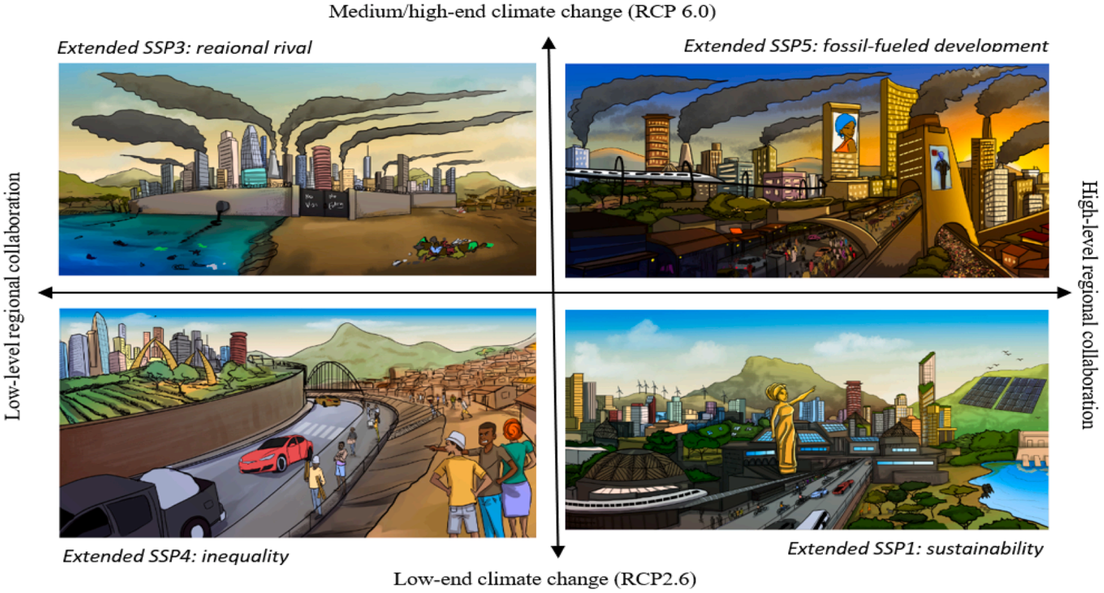

Fig. 3. Extended SSPs for Kenya across climate change and regional collaboration axes. The visualizations were developed by Leti Arts (www.letiarts.com).

impacts.

Creative visualizations for the extended SSPs (Fig. 3) were developed in collaboration with a team of digital comic designers at Leti Arts studio based in Kenya and Ghana. The design was based on scenario descriptions for the extended SSPs and aimed to reflect on the alternative storylines given the specifics of Kenyan geographical and cultural context.

Short versions of the narratives are provided here (full versions are provided in supplementary materials, .

Sustainability is a scenario where regional collaborations towards sustainable development improves within the EAC. Collaborations on natural resource management between Kenya and neighbouring countries ensure preservation and sustainable use of resources and make progress toward resolving cross border conflicts over access to and use of shared resources, especially transboundary water. Clean energy is accessible for a larger share of Kenyan population.

Inequality is a scenario where regional collaboration in the EAC is fragmented and unstable. While Kenya attempts to maintain collaboration, an upsurge in traditional values in the region leads neighbouring countries to enhance militarization and pursue more securitized societies. Transboundary water resources are used unequally by shareholders, as only a few countries have the capacity to expand agricultural sites and power plants. As a result, regional conflicts between Kenya and neighbours increase. Kenya – like most low-income countries – struggles to bridge the gap between rich and poor.

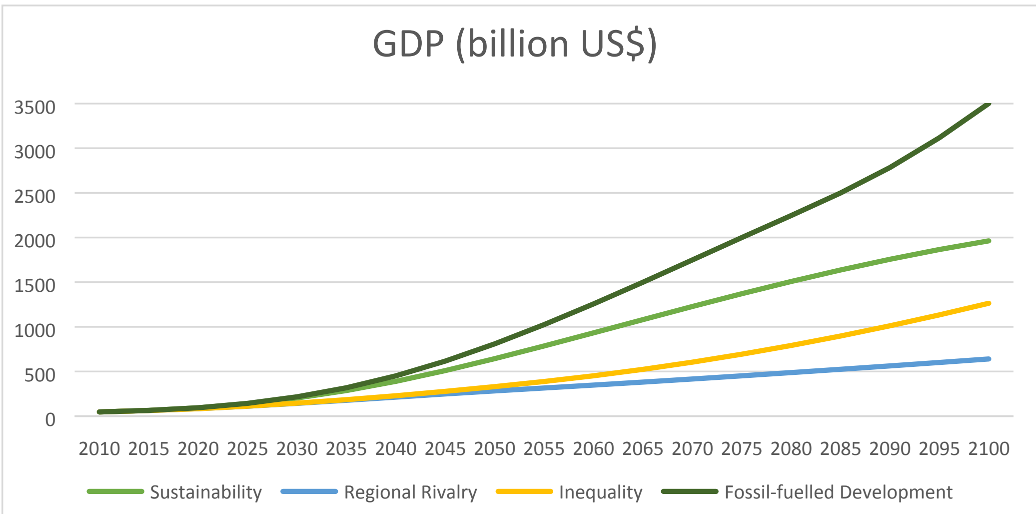

Fig. 4. Projections of GDP for Kenya, based on the SSP database hosted by the IIASA Energy Program at https://tntcat.iiasa.ac.at/SspDb.

Regional rivalry is a scenario where Kenya cooperates with neighbouring countries around common interests and together, they aim to compete against other regional blocs. However, growing nationalist values and intense competition over the scarce resources intensifies rivalry within the EAC region and securitizes relationships between EAC countries. Access to the technological innovations becomes extremely difficult for Kenya because knowledge sharing practices are securitized, and innovations are strictly patented and expensive.

Fossil-fuelled development is a scenario where regional collaboration in EAC increases with a focus on economic growth and increasing competitiveness in global market. Kenya and neighbours agree on the maximum use of the shared natural resources, but environmental policies including, climate adaptation are not priorities. As a result, climate-induced border conflicts decrease.

Future GDP projections for Kenya (Fig. 4) show highest growth under the *Fossil-fuelled development* scenario and lowest under the *Regional rivalry* scenario. While both scenarios are associated with medium/high end climate change, increasing regional collaboration and partnership coupled with technological advancements in fossil-fuelled development assist Kenya in economic growth. GDP growth in the *Sustainability* scenario increases gradually due to transition to a green economy and prioritizing of sustainable development over economic growth. The *Inequality* scenario shows significantly slow GDP growth, indicating overall dysfunctional economic performance.

Projections of future population (Fig. 5) show significant population growth in Kenya given the *Regional rivalry* and *Inequality* scenarios. Stakeholders mentioned several times that there will be a significant discrepancy in lower-income and higher-income population growth. In both these scenarios, increased population coupled with slow GDP growth leads Kenya into technological backwardness, worsened inequalities, and escalating vulnerability to climate impacts. On the contrary, population remains steady in mid-term future and decreases slowly in the long-run under the *Sustainability* and *Fossil-fuelled development* scenarios. Decreased population together with increasing GDP growth results in improved livelihood in these two scenarios, albeit in different forms.

As mentioned, we assessed the future conditions of the social, economic, and political pillars of Kenya Vision 2030 against the four scenarios to evaluate in whether or not the targets described in the vision will be attained on the way towards 2040–2060. The result of this process is shown below (Table 2). The *Sustainability* scenario will guarantee achieving the vision's social and political targets by 2030. However, economic targets will be re-directed from economic growth to sustainable development. In the *Fossil-fuelled development* scenario, political and economic targets will be achieved by 2030. But those social targets focused on secure environment and natural resource preservation will be removed from the national agenda as climate actions and environmental policies are not priorities in this development pathway.

3.1.2. Food security in low- and medium/high-end climate scenarios for Kenya

Kenya significantly depends on import of essential crops, including wheat, corn, and rice. In 2017, imports accounted for 29% of total wheat consumption, 27% of corn and 19% of rice. Of the total imported wheat, 30% came from Russia, 19% from Argentina, 12% from Ukraine, and 9% from Canada. 45% of the imported corn came from Mexico, 19% from South Africa, and 11% from Uganda. And of the total rise imported to the country, 67% came from Pakistan and 25% from Thailand (Harvard University, 2019).

Running crop models under low-end and medium/high end climate change (RCP2.6 linked to ESSP 1 and 4 and RCP6.0 linked to ESSP 3 and 5 (van Vuuren et al., 2014)), we developed alternative projections of crop production in the mentioned countries for two time-slices, 2035–2064 and 2070–2099 (Data is provided in supplementary materials). We translated increases and decreases in total production as changes in those countries' export potential and respectively Kenya's opportunities and challenges to import essential crops from those countries. Finally, we interpreted these changes with respect to the socioeconomic conditions of Kenya in each

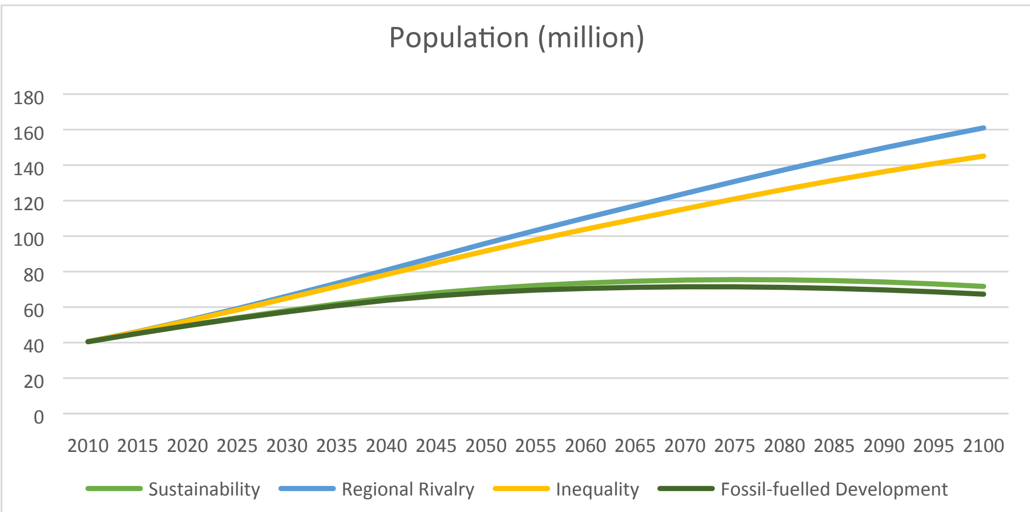

Fig. 5. Projections of population growth for Kenya, based on the SSP database hosted by the IIASA Energy Program at https://tntcat.iiasa.ac.at/SspDb.

Table 2
Future conditions of the social, economic, and political pillars of Kenya vision 2030. (This table shows whether Kenya achieved the social, economic, and political targets of the Vision by 2030, given the country is on the path towards each extended SSP. The ✓ symbol represents 'achieved goals' and the ✗ symbol represents 'failed to achieve goals').

	Extended SSP1 Sustainability	Extended SSP3 Regional rivalry	Extended SSP4 Inequality	Extended SSP5 Fossil-fuelled development
Social pillar	✓	✗	✗	✓, ✗
Political pillar	✓	✗	✗	✓
Economic pillar	✗ ✓	✗	✗	✓

extended SSP. As stated before, we do not compare the models' results with current numbers. We only look at crop production trends in countries exporting essential crops to Kenya between the two time slices under which our models were run.

Separating the results by different crops, models show that corn production decreases in all exporting countries given RCP2.6 between 2035 and 2064 and 2070–2099, with South Africa encountering the highest production decrease (54%). Given RCP6.0 however, South Africa as an exception produces 21% more, while Mexico which is the top corn exporter to Kenya faces more than 11% of production decrease (Fig. 6).

In Pakistan, rice production almost remains the same, while Thailand experiences dramatic decrease (more than 31%) given RCP2.6, but insignificant decrease given RCP6.0 (Fig. 7).

Wheat production decreases significantly in all exporting countries given RCP2.6. Ukraine and Canada decrease their annual production by more than 30% while Russia and Argentina also produce close to 20% less wheat annually. Given RCP6.0, wheat production marginally grows in Argentina with 3% (Fig. 8).

Overall, results show that annual crop production decreases are expected in all countries exporting essential crops to Kenya given

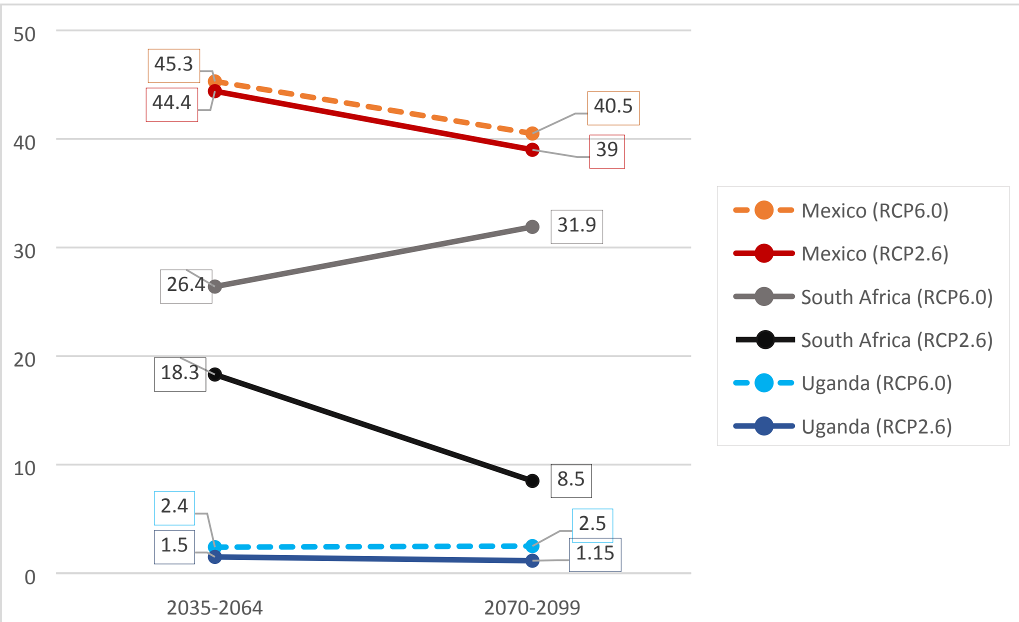

Fig. 6. Change of corn production (unit million ton) in key exporting countries to Kenya given RCP6.0 and RCP2.6.

low to medium global warming (RCP2.6) between 2035 and 2064 and 2070–2099 which results in a shrink in their export capacity. Production of wheat, corn and rice either remains steady or faces insignificant changes in most countries exporting essential crops to Kenya given high global warming (RCP6.0) between 2035 and 2064 and 2070–2099. Exceptions are Russia with close to 21% decrease in wheat production and South Africa with close to 21% increase in corn production.

3.2. *Future cross-border climate impacts for Kenya*

Using the extended SSPs and four risk pathways as the analysis framework in the second workshop, stakeholders identified 15 future cross-border climate impacts for Kenya (Table 2). Looking across the risk pathways, five future cross-border climate impacts were identified under the people pathway, five under the biophysical, two under the trade pathway and three under the finance pathway. Future cross-border climate impacts transmitted through the trade and people pathways were recognized by stakeholders as the most important challenges and were repeatedly mentioned in the context of several scenarios (Table 3).

3.2.1. *People pathway*

Stakeholders identified five important future cross-border impacts under the people pathway. Climate-induced migration across borders to Kenya was mentioned across extended SSPs 4 and 5. This refers to movement of people driven by extreme or progressive changes in the weather or climate, as well as the impact of climate change on the economy and subsequent increases in unemployment in neighbouring countries. Stakeholders discussed climate-induced migration to Kenya as a cross-border climate impact that could affect the Kenyan socioeconomic context in a number of ways, i.e., labour market, border security, and social cohesion. In addition, cross-border disease transmission was mentioned under extended SSP4 as a potential future cross-border climate impact strongly correlated with the movement of people across borders.

Increased regional conflict was identified as a cross-border climate impact transmitting through the people pathway in all scenarios except extended SSP1. This was primarily due to climate change impacting Kenya's neighbouring countries in the shape of job losses, damage to infrastructure and settlements and scarcity of natural resources. Stakeholders believed that as vulnerable groups cross the borders and enter Kenya in search of better livelihoods, regional conflicts, especially between local communities living along borders, will be intensified. These conflicts could be driven by competition over jobs, access to resources, better life conditions, or opportunities for fossil fuel extraction given alternative socioeconomic conditions, but in most cases, intensified conflicts in the EAC was emphasized as a possible future cross-border climate impact.

Stakeholders highlighted unsustainable tourism in Kenya's neighbouring countries as a future cross-border climate impact. Kenya has shared ecosystems with its neighbours, with many national parks and reserves being interconnected and dispersed along two or even more countries (e.g., the Serengeti-Mara ecosystem between Tanzania and Kenya). Expansion of nature tourism in neighbouring countries without considerations for environmental conservation and evidence-based environmental policies was identified as a future cross-border climate impact that might severely affect Kenya and its parts of the shared ecosystems. On the other hand, reduced tourism in the region was also seen as a potential cross-border climate impact. Stakeholders mentioned that shrinking tourism industries in the EAC member countries might also reduce the revenue from tourism in Kenya and impact the country's tourism and

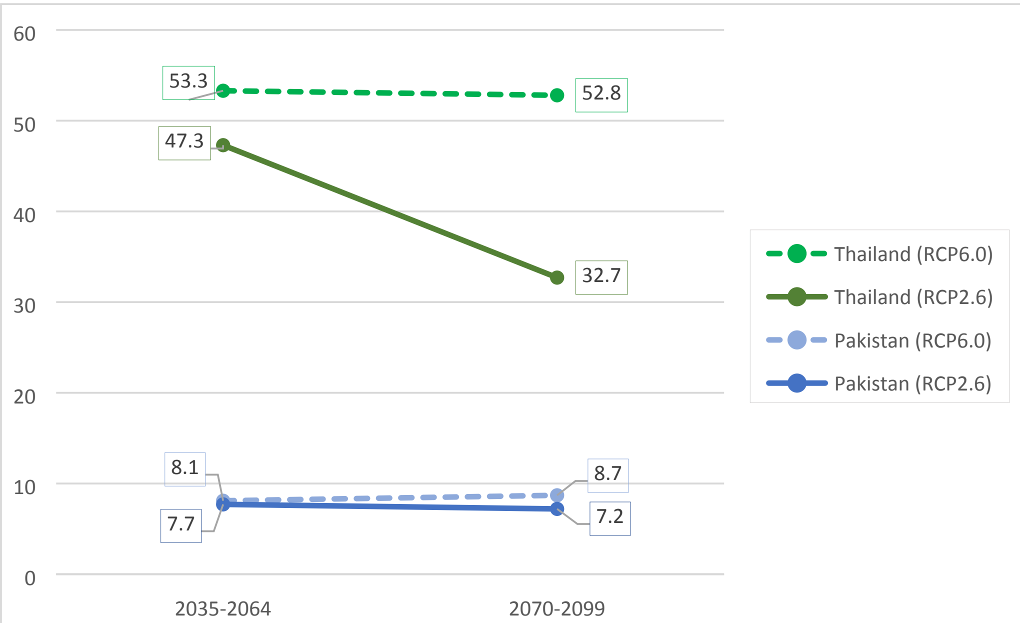

Fig. 7. Change of rice production (unit million ton) in key exporting countries to Kenya given RCP6.0 and RCP2.6.

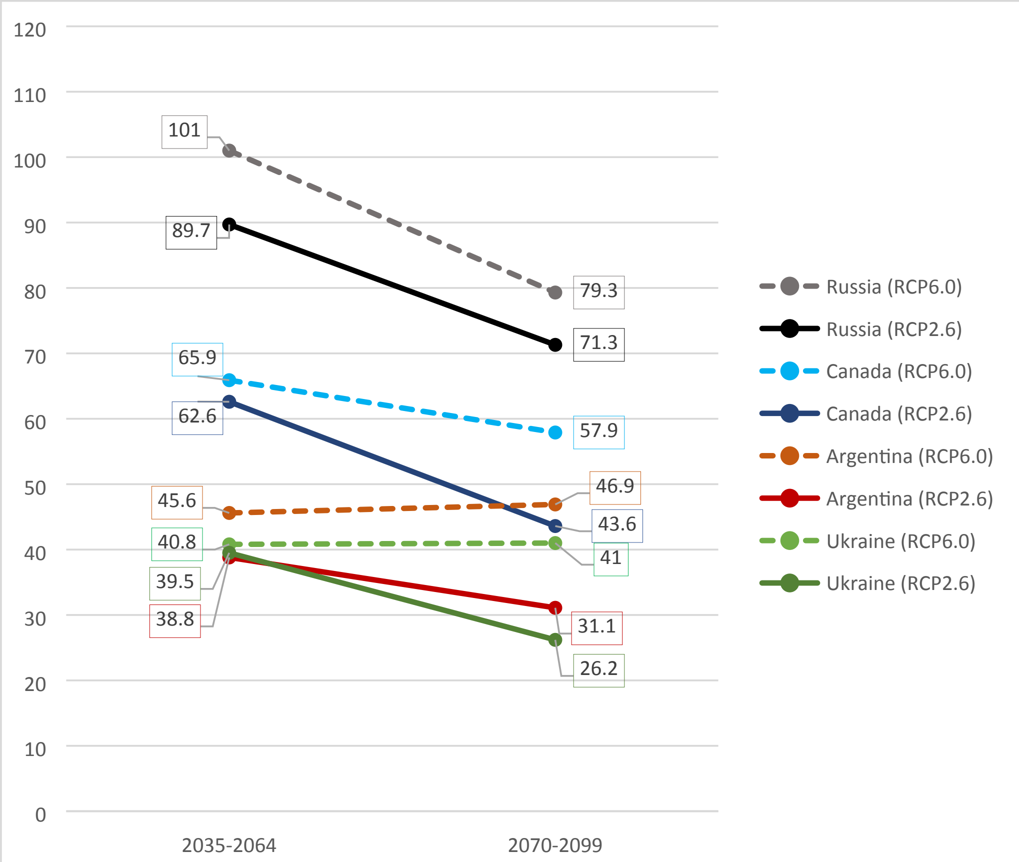

Fig. 8. Change of wheat (unit million ton) production in key exporting countries to Kenya given RCP6.0 and RCP2.6.

Table 3
Future cross-border climate impacts for Kenya across four risk pathways and four scenarios.

Risk pathway	Scenarios			
	Extended SSP1: Sustainability	**Extended SSP3: Regional rivalry**	**Extended SSP4: Inequality**	**Extended SSP5: Fossil-fuelled development**
People	–	Regional conflicts Reduced tourism	Climate-induced economic migration Regional conflicts Reduced tourism Cross-border disease transmission	Climate-induced economic migration Regional conflicts Unsustainable tourism
Biophysical	–	Increased water use by neighbouring countries	Increased water use by neighbouring Migration of invasive species Migration of wildlife Seasonal migration of livestock	Increased water use by neighbouring countries Pollution
Trade	–	Limited import and export markets	Reduced demand for high carbon exports	Reduced demand for high carbon exports
Finance	Reduced official development assistance (ODA) Reduced green climate funds	Reduced official development assistance (ODA) Reduced foreign direct investments (FDI)	Reduced foreign direct investments (FDI)	Reduced official development assistance (ODA)

economy at large.

3.2.2. Biophysical pathway

In the biophysical pathway, stakeholders identified five cross-border climate impacts related to transboundary water resources, pollution and the movement of livestock, wildlife, and invasive species. Increased use of shared water resources by neighbouring countries was one of the most significant future cross-border climate impacts emphasized by stakeholders. Water resources, like Lake Victoria, are important and, in some cases, controversial shared natural resources between Kenya and neighbours. Stakeholders raised concerns that in non-collaborative future scenarios (extended SSPs 3 and 4) where disputes arounds the ownership and management of shared resources are prominent and climate policies are either de-prioritized or only implemented locally, there will be impacts of over-use and degradation of transboundary water resources, which could result in more cross-border conflicts and increased water security issues.

Stakeholders discussed that Kenya might be impacted by air pollution in the neighbouring countries, especially in the context of fossil-fuelled based development in the neighbouring countries (extended SSP5).

Finally, the movement of wildlife, livestock, and invasive species was mentioned as future cross-border climate impact under the biophysical pathway in extended SSP4. While the movement of wildlife outside Kenya could potentially impact the country's tourism industry, cross-border movement of livestock could pose impacts to agricultural industry and food security. Migration of invasive species was mentioned by stakeholders as a kind of future 'wildcard' which could impact Kenya and other countries in the shape of agricultural challenges, health crisis, etc.

3.2.3. *Trade pathway*

In the trade pathway, two cross-border climate impacts were considered. Reduced demand for high carbon exports was mentioned as a trade-related future cross-border climate impact for Kenya across all scenarios except extended SSP1. Concerns were raised that new climate policies and legislation (e.g., carbon border adjustment mechanisms and carbon taxation) in countries that import goods from Kenya will most likely impose significant barriers to the country's export capacity. Potential carbon taxation and reduced demand for high carbon exports affect Kenya in both extended SSP4 and 5, but with different implications and timelines. Extended SSP4 is linked to global SSP4 and low-end climate change (RCP2.6) where there is a discrepancy in countries' commitment to climate actions. In extended SSP4, countries committed to climate actions reduce imports from countries with energy intensive production processes, including Kenya, in 2050. In extended SSP5 linking to global SSP5 and high-end climate change (RCP6.0), although societies are on a fossil fuel intensive path in 2050, it is anticipated that in the long run, many countries start moving toward sustainability, given the increasing high-end climate impacts and extreme events. In this scenario, concerns were raised that Kenya is most likely not among the forerunners of change for sustainability, and in the transition period where some countries start reducing high carbon imports, Kenya might be significantly affected and lose competitiveness in the global market. At the same time, under conditions of regional rivalry (extended SSP3) it was quite possible that imports might be restricted as countries sought to meet domestic demands first or trade with more 'friendly' nations.

In addition to these cross-border climate impacts identified by stakeholders, future changes in crop production in key exporting countries for Kenya could also impact the country through the trade pathway. We projected these changes using quantitative enhanced scenarios (see section 3.1.2), and here, we interpret them with respect to the extended SSPs for Kenya. The *Sustainability* (extended SSP1) is a scenario where Kenya can cope with challenges to import essential crops. As technology transfer to Kenya is specifically focused on smart agriculture solutions, Kenya manages to increase local agriculture production through alternative sustainable solutions. Accordingly, dependency on food imports decreases and food security improves despite a decline in imports. On the contrary, in the *Inequality* (extended SSP4) scenario, the decrease in the production of essential crops in exporting countries to Kenya results in a significant decline in food imports, while the country substantially depends on import of food, due to long periods of droughts and lack of smart irrigation technologies. Decreased food imports coupled with population growth exacerbates risks to food security. Imported foods to Kenya are distributed and consumed unequally. While higher-income communities and urban areas benefit from luxury imports, many cannot afford to acquire essential food crops.

In *Regional rivalry* (extended SSP3), Kenya reduces food imports even though the exporting countries could maintain their export capacities. In this scenario, Kenya aims at reducing dependency on food imports, especially from outside the EAC bloc, by encouraging local producers to increase production. Ever-increasing demand for essential crops by growing population in Kenya results in an upsurge in agricultural production and, consequently, excessive land use and water resources degradation. Energy intensive and fossil fuel-based agricultural technologies also exacerbate air pollution, and risks to public health. In a different path, in *Fossil-fuelled development* (extended SSP5), Kenya aims at expanding imports of food to improve food security in the face of decreasing local agricultural productions. As population growth is significantly reduced toward 2070, demand for essential crops stops growing. Being well connected in global markets, Kenya manages to import needed crops either from direct exporter countries or from a mix of products in intermediary markets and maintain food security at large.

3.2.4. *Finance pathway*

In the finance pathway, three cross-border climate impacts were identified. Reduced official development assistance (ODA) was identified as a cross-border climate impact for Kenya across all scenarios, with the exception of extended SSP4. It was anticipated that under conditions of reduced global and regional collaboration, climate change impacts in ODA donor countries would lead them to redistribute resources domestically. In extended SSP2 and 3, the flow of foreign direct investment into Kenya was expected to decrease as shareholder pressure forced investors to focus investments on green technologies in political stable environments. Lastly, in a more sustainable world (extended SSP1), stakeholders envisaged access to ODA and dedicated green climate funds would diminish, given that Kenya would be expected to have become a middle-income country with less access to such concessional finance.

3.3. Adaptation options addressing future cross-border climate impacts

In total, 41 adaptation options were identified (a list of all adaptation options can be found in supplementary materials). Looking across scenarios, the *Sustainability* scenario was associated with the least number of adaptation options (6), due to a small number of future cross-border climate impacts. Most adaptation options were identified for the *Regional rivalry* scenario (17). Stakeholders associated many adaptation options with regional collaboration and multi-governmental resource management. This explains the identification of fewer adaptation options in the *Inequality* scenario (9) compared to the *Regional rivalry* scenario. In the *Inequality* scenario, the lack of regional collaboration excessively undermines the possibility for planning and executing adaptation options. While, on the contrary, in the context of the *Regional rivalry* scenario, regional collaborations between the EAC countries facilitate efforts for adaptation planning and resilience building. The *Fossil-fuelled development* scenario generated 9 adaptation options.

Clustering the adaptation options, six themes of adaptation activities were identified, including energy-based, information-based, policy-based , infrastructure-based , industry-based , and technology-based . Energy-based and infrastructure-based adaptation options were focused on tangible actions, specifically energy reform and development of climate resilient infrastructures to adapt to future cross-border climate impact. Technology-based options emphasized the development or adoption of technologies necessary for adaptation practices (e.g., climate-smart technologies for agriculture, water efficiency, etc.) and industry-based options highlighted the role of private sector and industries in adaptation to climate impacts. Policy-based options called for policy implementation as a crucial part of adaptation planning, while information-based options underlined the necessity for recognition and raising awareness about adaptation actions targeting cross-border impacts.

Looking at different spatial scales, most adaptations options were identified at the national level. As climate adaptation has been mostly studied and understood at national levels, many options were naturally considered to be implemented at the national level. However, a significant share of the identified adaptation options were in fact transnational adaptation activities.

After synthesizing the generated adaptation options, three key areas emerged across several scenarios. We encourage Kenyan policy makers to focus on these areas of adaptation now and in the near future in order to improve the country's adaptive capacity and adapt to future cross-border climate impacts in 2040–2060 time horizon.

3.3.1. Fostering transnational collaboration and governance

A large number of adaptation options identified in this study were in fact transnational (regional, international) adaptation activities suggesting that despite the historical trends, stakeholders believe that, in order to be effective, adaptation should be a collaborative process achieved through transnational governance and transboundary cooperation.

Transnational and intergovernmental co-management of shared natural resources (i.e., transboundary water and shared ecosystems) were considered an effective adaptation option to prepare Kenya to resolve future regional conflicts and transboundary water disputes. Transnational policy frameworks and legal programs for adaptation could assist Kenya and neighbouring countries to tackle common cross-border climate change impacts in a collective effort.

3.3.2. Increasing research on cross-border climate impacts and transboundary adaptation

Lack of future-oriented research on transnational climate impacts was the main point of departure in this study. When co-producing adaptation options, stakeholders addressed this issue once again by pointing out that investing in research on cross-border climate impacts is necessary to prepare adaptation planning in Kenya.

Several adaptation options encompassed urgent needs for investing in research and development and financing climate-smart technologies especially in regions more vulnerable to cross-border climate impacts. This option would help Kenya to adapt to reducing climate finance and ODA coming from outside of the country. Although most adaptation options relevant to research were national, advocating for international knowledge sharing and technological collaborations were also mentioned.

3.3.3. Building public–private partnerships for resilience building

Preparing the economy, building resilient infrastructure, technological collaborations, and collective efforts in creating resilient trade networks are only a few examples of adaptation activities which need private sector participation. Options relevant to public–private partnership were a mix of policy- and industry-based adaptation activities, suggesting that while private sectors need to get involved in adaptive capacity building for their own future benefits, policy makers are also required to incentivise private sector participation. Co-managing business activities in shared ecosystems was another role for private sector that would address the impact of decreasing economic activities in sectors such as tourism.

4. Discussion

Extending the global SSPs to local and regional contexts is an essential component of the current climate change scenario architecture. Local and regional studies are invited to use the scenario framework and apply the SSPs to sub-global contexts. However, the lack of detailed information on local and regional contexts is a significant challenge to using the SSPs in sub-global studies. Our approach to extending the SSPs through a combined top-down and bottom-up approach provides an opportunity to address this challenge by combining local and regional socioeconomic factors with global scenario information, and expand the relevance of the SSPs for application across sub-global studies.

Our approach to extending the SSPs could create up to five plausible states for each locally identified driver and respectively up to five sub-global scenarios. We believe this approach, which could be considered a variation of morphological analysis (Ritchey, 2018;

Zwicky, 1969), has advantages compared to the 'scenario-axes' technique (van 't Klooster and van Asselt, 2006) which is mostly used in the climate change community (e.g., see Nakicenovic et al., 2000; Rounsevell & Metzger, 2010). When using scenario axes as the scenario development technique, two main driving forces with two plausible polarities are identified and build the overall structure of the scenario set. In contrast, Morphological analysis is a structured scenario development technique which allows the user to utilize all key driving forces in the scenario structures and assign any number of plausible future states to each driver. We believe that using a larger number of key drivers to build scenario structures (instead of emphasising two dominating drivers) allows for a more diverse and comprehensive scenario set where many drivers are considered important for driving future changes. Moreover, having the structural possibility to assign each driver with a larger number of plausible states (instead on only two polarities) also adds to scenario diversity and assists in reflecting on a wider space of future possibilities (). However, after the development of scenarios, we used the scenario-axes technique for presentation purposes. This allowed us to better communicate the extended SSPs to local stakeholders and also add the climate dimension to the qualitative narratives.

We used a mix of storylines, visualizations and quantitative insights derived from climate impact models to communicate the extended SSPs for Kenya to stakeholders involved. Such a mixed approach provides an opportunity to create comprehensive images of alternative futures and assists in better communicating different components to different groups of experts and stakeholders. We observed that visualizing the storylines could significantly facilitate stakeholder discussions on different characteristics of the extended SSPs and assist in better distinguishing different socioeconomic contexts. Moreover, we believe that integrating the qualitative narratives with quantification of some scenario drivers by global impacts models would provide stakeholders with an opportunity to see the extended SSPs in a global context more clearly, which is key when studying cross-border climate impacts. Adding quantitative components to local and regional scenario sets is recommended specially to investigate the impacts of different global flows on regional conditions. However, our observation when engaging with stakeholders was that the results of quantitative impact modelling was useful to stimulate the co-production process and the identification of future cross-border climate impacts, rather than deriving specific decision processes. For example, modelling results motivated stakeholder discussions about food imports and food security in future.

As mentioned above, cross-border impacts of climate change are often conceptualised as either transboundary impacts from neighbouring areas or more remotely teleconnected impacts. Hence, for addressing such impacts countries need to engage with partners both regionally but also globally. This creates challenges for how to focus the development of the socioeconomic scenarios, which can be seen in our study since 'regional collaboration' was selected as a key socioeconomic driver (see Fig. 3), while food security (one of the most important cross-border risk) is mostly concerned with countries outside the region. The reason to select regional collaboration as a key socioeconomic driver despite this theoretical mismatch was that is of huge importance for most other cross-border climate risks. A narrower study on one selected cross-border risk, like for example food security, would have selected another key socioeconomic driver for the scenario cross.

Finally, a word of caution about quantitative enhanced scenarios. Crop modelling is inherently difficult. In the words of Rosenzweig et al. (2014), "agriculture is arguably the sector most affected by climate change, but assessments differ and thus are difficult to compare." Not only do they require future climate scenarios, models differ in what processes they implement. For instance, some models might include CO_2 fertilization while others might not. Furthermore, to project yields, assumptions about progress in technology must be made. The land use modelling is dependent on many assumptions as well. Populations, market prices and so on all play into the land use patterns that finally emerge. For these reasons, we cautiously only look at trends given by the models, not the absolute numbers.

More specifically, there is a gap in models and modelling processes dedicated to investigating cross-border climate impacts at sub-global scales. Addressing this gap would require the development of further impact models focused on exploring and projecting future aspects of these impacts. Moreover, increasing applications of extending the SSPs to local and regional levels, as well as potential attempts to study cross-border climate impacts, magnify the needs for developing and running relevant impact models.

We argue that our framework could be used by sub-global IAV studies to take the transnational environment and global socio-economic conditions into account and develop a comprehensive baseline for the study of future cross-border climate impacts originated from global flows. However, a shortcoming of the present case study is that our analysis is confined to the development of Extended SSPs only for the 'receiving' country (i.e., country at risk). We propose future development of this framework in a way that conducts a more detailed study of the 'sending' countries (i.e., countries exporting potential climate risks) considering the exploration of different drivers and conditions of those socioeconomic contexts as well. However, in any such endeavour it will be of utmost importance to balance level of detail with the ability to build comprehensible and tangible scenarios.

As part of this case study, we assessed the effectiveness and robustness of the current adaptation planning in Kenya to address future cross-border climate impacts. Stakeholders collectively indicated that the current adaptation landscape in Kenya makes almost no references to future cross-border climate impacts and identified new measures and adaptation actions that are necessary to address those impacts. Stakeholders suggested that the design and implementation of many adaptation actions addressing cross-border climate impacts would primarily require regional and global cooperation. Increasing awareness about climate impacts transmitting across borders, and the fact that adaptation to climate change in one country could reduce impacts and vulnerabilities in other countries could encourage stakeholders to initiate stronger collaborations on adaptation and develop collective actions.

We believe stakeholders' emphasis on the necessity of collaboration for adaptation planning could call for new actors and contributors to enter the adaptation arena. Implementing intergovernmental agreements and reinforcing transnational adaptation governance would require engagement with a diverse group of policy makers in different areas. This perhaps necessitates decision makers not only from environment ministries, but also from different government branches, e.g., ministries of finance and foreign affairs, to contribute to adaptation governance. For better implementing the multi- and inter-governmental mechanisms and facilitating transnational governance of adaptation, lessons could be learnt from coherent mechanisms for implementation of the sustainable development goals (SDG), and proposals and frameworks for global adaptation governance (Biermann et al., 2017; Meuleman & Niestroy, 2015; Persson, 2019; Persson & Dzebo, 2019).

In addition to the call for collaboration between the key actors, there is an urgent necessity for linking adaptation options at different spatial scales and across different governance levels. Stakeholders discussed policy implementation as an important challenge to adaptation planning in Kenya. We believe linking adaptation options for cross-border climate impacts to the existing adaptation initiatives that address domestic climate impacts is crucial for fostering coherence across policy domains and governance levels and developing integrated local, national and transnational adaptation strategies.

We also believe that local and regional context-specific scenarios will provide the global scenario community with a feedback loop evaluating the relevance of global scenario sets to the regional and national studies and adaptation assessments. There are socio-economic drivers and conditions at the local and regional scales that influence vulnerability, impacts, and adaptive capacity, and exploring these drivers could significantly inform and improve global scenario processes.

5. Conclusion

Conventional climate change impacts, adaptation, and vulnerability studies, including national risk assessments, tend to confine their attention to impacts and adaptation within the same geographical region, which could result in major blind spots concerning cross-border climate impacts originating outside the region. In this paper, we propose a stakeholder-driven scenario framework for the study of cross-border climate impacts from a future-oriented perspective.

Understanding the development of socioeconomic conditions is necessary for identifying future climate impacts, including such future cross-border impacts. In this paper, we combined the emerging literature on cross-border impacts of climate change with the global SSPs of the climate change scenario framework. When studying impacts emerging inside a country's borders it might be feasible to develop socioeconomic scenarios only for that particular country (and hence not necessarily using the SSPs), while studies of impacts that cross borders need to develop scenarios that relate to the socioeconomic development outside that region.

Using cross-scale scenarios linked to global SSPs as the analytical framework allowed us to take into account the global socio-economic context where impacts are transmitted across spatial dimensions. We used a combined top-down and bottom-up approach to extend the SSPs through a stakeholder-driven participatory processes and co-produced locally relevant socioeconomic scenarios. Our approach to extending the SSPs provides an opportunity to expand the relevance of the SSPs for application across sub-global studies and facilitate comparability in the sub-global literature. Moreover, linking local and regional levels to the SSPs could provide the global scenario community with a feedback loop that could significantly inform and improve global scenario processes. For local adaptation planning this novel framework provides a means for understanding how the socioeconomic development and climate change interact to produce cross-border climate risks. It is a different thing to understand the role of the socioeconomic development for domestic climate risk compared to imported climate risks.

Results from the present case study in Kenya show that participatory processes and engaging with local and regional stakeholders could raise awareness about the significance of future cross-border climate impacts and call for collaboration to improve adaptation planning. More studies on future cross-border climate impacts would be an important step towards better understanding of how cross-scale scenarios and specifically extended SSPs could improve future adaptation planning.

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.

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Appendix A. Supplementary data

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