Understanding the new generation of climate change scenarios
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Assessment of existing scenarios and co-production techniques

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Contents

Chapter I: BASICS

1. Introduction

On a very general level a scenario can be described as a plausible description of how the future may develop based on a coherent and internally consistent set of assumptions. This very broad description includes an extremely wide array of types of scenario and uses of scenarios. The overarching goal of the SENSES project (Climate Change Scenario Services: Mapping the future) is to develop a tailor-made, user-determined Climate Change Scenario Toolkit (the "SENSES" Toolkit) connecting the wide array of scenarios developed by the climate change research community to selected user and stakeholder groups.

The Toolkit will include a unique collection of user-centred scenario visualization tools, include practical guidelines and manuals, and build on co-production techniques of relevant and useful climate change knowledge for three key user groups: i) national and international climate policy makers, ii) businesses and financial sector actors, particularly those with long term planning horizons, and iii) regional climate scenario users.

The project will translate complex scientific scenario information into relevant knowledge for these user groups enabling them to gain relevant insights into adaptation to climate change, mitigation of climate change and residual climate impacts.

This deliverable reports on task 2.1 *Assessment of existing scenarios and co-production techniques.* The task should take stock of the state-of-the-art of existing climate change scenarios through the lens of user needs, including the needs of regional users participating in the case studies in the Netherlands and Kenya. Hence, this deliverable is informed by an earlier SENSES deliverable, D1.1 *Report on user needs.* As summarised in Deliverable D1.1, various stakeholders, in consultations, confirmed that the project would already be a success if the toolkit managed to translate the fundamental basics of scenarios, i.e. what do they mean and how can they be used. Many stakeholders feel unsure about the 'entire logic and assumptions' behind scenarios. Although many of the stakeholders have decent experience with scenarios it seems many important details remain hidden or unclear to them. It was concluded that many of the information tools for existing scenarios are not fit for purpose for the different stakeholder groups.

Stakeholders, furthermore, ask for orientation of types of scenarios and characteristics of scenarios. Specific areas of interest are the linking between short term actions and long term impacts, exploratory vs. normative scenario elements, linkages between emissions and outcome (in terms of e.g. temperature increase), as well as how to understand input vs.

outputs from scenario exercises. Another point was that many scenario tools are experiences as black boxes, i.e. it is hard to follow how outputs are related to inputs.

This report is organized as follows. The next chapter aims a providing the reader with a consistent terminology in order to navigate the complex landscape of scenarios. We see this chapter as a key contribution of this report because a common language could substantially increase uptake of scenarios produced by the climate change research community. Chapter three provides a comprehensive review of 'co-production' techniques for scenario analysis. A key message here is that the different sub-communities within the broader climate change scenario community use the term differently, with a wide variety of interpretations. In SENSES, we use the term co-production either to describe the co-development of scenarios between researchers and stakeholders, or as the iterative interaction process of better identifying user needs and to understand how the various user groups want to use the scenario information. This mode is often used for global scenarios. Chapters four to six covers existing scenarios of relevance for SENSES; the first of which covers global scenarios and the two others covers scenarios for the Netherlands and Kenya respectively. Chapter seven concludes the report.

2. Terminology

The term "scenario" is used by many different communities across scientific domains, scales, as well as in policy and practice. The scenario literature is, therefore, vast, rapidly increasing, and in partial disagreement on what a scenario is, what it can be used for, what methods are most appropriate, and what results it generates. A common terminology on these and other issues will be important for communication and user uptake of scenario information. Synchronising the use of terms by the global climate change community and the regional scenario practitioners proved only partly possible. Yet, despite differences in terminology, there is broad agreement on how scenarios need to be used, how different types of scenarios can be combined, and the overall methodology to operationalise this. In this chapter, we will provide a detailed overview of scenarios, where possible providing a common terminology and where necessary highlight differences in terminology between global and regional scenario applications.

2.1 Definitions, concepts and frameworks

The literature provides many different definitions and frameworks attempting to classify scenarios (e.g. van Notten et al. 2003, Bradfield et al. 2005, Börjeson et al. 2006, Amer et al. 2013). One conceptualisation (Börjeson et al. 2006) is based on three fundamental questions that may be posed about the future:

1. What will happen?
2. What can happen?
3. What should happen? (or: How can a specific target be reached?)

These three questions can be related to for instance weather predictions (#1), climate change projections (#2) and mitigation pathways for reaching a specific temperature goal (#3). In this conceptualisation, the term scenario could be related to either predictions, projections or – in the case of a goal-oriented scenario – pathways.

Another way to frame this is to ask whether the goal of the exercise is to explore probable (#1), possible or plausible (#2) or preferable (#3) futures (Amara 1981). The question what will happen is typically addressed for shorter time-scales, when systems dynamics are relatively well understood and probabilities of future outcomes can be estimated. These techniques often have to assume the broader context is relatively fixed or has no influence on the dynamics of the system under study. The resulting forecasts or predictions are rarely called scenarios, and will not be included in the remainder of this chapter. Note that it is useful in most scenario development exercises to take stock of what is not uncertain, and ensure that this is included if needed. Most scenario exercises address the second and third question, and relate to futures with largely unknown probabilities.

The two other categories related to questions #2 and #3 above are recognised by both global and regional scenario developers. Importantly, both communities also stress the added value of using both types of scenarios in combination, recognising that the question what is preferable is intricated linked to the question what is possible. Scenarios that address the question on what can happen are built to explore plausible alternative developments that allow for assessment of a range of future conditions. They usually cover less understood, multi-faceted systems and longer time-frames, sometimes up to 100 years. Scenarios that address the question what should happen start with a target future (sometimes called a vision), then work backwards to construct pathways to achieve the goals. Policy scenarios are often goal-oriented.

Terminology for scenarios focussed on “What can happen?”

- For quantitative model-based scenario approaches, often deployed on the national to global scale, the term ‘*projection*’ is frequently used to refer to scenarios that address what can happen, for example in ‘climate impact projections’ or ‘baseline projections’. We suggest to use this term in instances, where the quantitative part dominates the scenario content, even if underpinned by a secondary narrative element.
- For regional scenario approaches, the term ‘explorative scenario’ is commonly used. Here the term ‘projection’ is restricted to model-based, quantitative elements of explorative scenarios which are based on the qualitative narrative elements at their core.

Terminology for scenarios focussed on “What should happen?”

- In many cases, e.g. in quantitative scenario applications on the national to global scale, scenarios that address what should happen are referred to as ‘*goal-oriented scenarios*’ or pathways.
- In other, more often regional, scenario applications, the common term is ‘*normative scenario*’. At regional level there is a clear and strong dichotomy between exploring what can happen and designing what should happen, mostly reinforced by a difference in scale with normative scenarios being developed for smaller regions and shorter time horizons, also building on different methods and tools. The explorative scenarios are built for opening up the imagination amongst stakeholders on what can happen, while the normative scenarios are built after the explorative ones in order to

cope with challenges. For model-based scenario approaches, both types of scenarios are more intertwined and often are developed with the same (modelling) tools.

As said, both communities use both types of scenarios to address the same questions, and both see value in combining them.

A useful characterisation of scenarios is provided by van Notten et al. (2003). They divide scenarios into overarching themes. These are the project goal (why?), process design (how?) and scenario content (what?). The project goal can be exploring plausible futures or decision support, the process design intuitive or formal and the scenario content complex or simple. The overarching themes are then further divided into more detailed characteristics according to table 1.

Table 1. Scenario themes and characteristics (table based on van Notten et al. (2003))

Project goal - identifying possible futures versus decision support
I. Inclusion of norms?: exploring / projecting vs goal orientation
II. Vantage point: forward-looking vs backcasting
III. Subject: issue-based, area-based, institution-based
IV. Time scale: long term vs short term
V. Spatial scale: global/supranational vs national/local
Process design – intuitive versus formal
VI. Data: qualitative vs quantitative
VII. Method of data collection: participatory vs desk research
VIII. Resources: extensive vs limited
IX. Institutional conditions: open vs constrained
Scenario content - complex versus simple
X. Temporal nature: chain vs snapshot
XI. Variables: heterogeneous vs homogenous
XII. Dynamics: peripheral vs trend
XIII. Level of deviation: alternative vs conventional
XIV. Level of integration: high vs low

Focusing more specifically on climate change scenarios there are three aspects that are particularly relevant:

Goal-orientation versus exploring / projecting (cf. project goal and I and II above). Are scenarios goal-oriented or do they explore diversity of current trends? This is usually closely related to the method with which scenarios are developed (starting from the present situation or backcasting from the endpoint), and more often than not to their most important use. Goal-oriented scenarios are often used for supporting decision-making, while a set of explorative scenarios / projections map out different possible futures. As stated above, the two types of scenarios are and should be used in concert, as the question of what is preferable cannot be separated from the question what is possible. The combination of a projection of existing trends (often called 'baseline') with a normative scenario can be used to identify actions to bend the current trajectory towards the desired future, thus informing the question of what should happen.

Spatial and temporal scale (cf. project Goal and IV and V above). At the local and regional (spatial) scale we find both short-term (a few decades) and more longer-term (temporal) scenarios while the global scale often uses longer-term scenarios.

Qualitative versus quantitative (cf. Process design and VI above). Are scenarios qualitative stories (sometime called storylines) or quantitative (model based)? This is closely related to the main method of scenario development. Qualitative scenarios are often participatory and co-produced, while quantitative scenarios are often developed by modellers or other scientific experts. As with the project goal, the process design often aims at combining different types of scenarios. In this case, state-of-the-art approaches (e.g. Story-And-Simulation; see Alcamo, 2008) often combine qualitative stakeholder-determined qualitative scenarios with model-led quantitative scenarios.

2.2 Categories of climate change scenarios

We distinguish seven categories of climate change scenarios (or scenario components) that are used individually or in concert to provide actors with climate change information. They are the basic objects for climate change scenario services. The extent to which they are referred to and used in global and regional scenario approaches differs by scenario category. Below a short description is given of what is understood by the seven categories, where needed separated for global and regional scenario approaches.

2.2.1. Socio-economic scenarios

Given the long-term nature of climate change and the large uncertainty about distant socio-economic futures, climate change research naturally has to consider a large range of socio-economic scenarios (Clarke et al. 2014; Kriegler et al. 2016; Moss et al. 2010; Nakicenovic et al. 2000; Raskin 2005; Riahi, Grübler, and Nakicenovic 2007,). Moreover, socio-economic changes drive emissions and thus climate change, while also determining the extent to which systems are vulnerable for the impact of these climate changes and the possibilities for action. Given their elevated role, the SSPs provide an important point of departure for constructing socio-economic scenarios, although unrelated socio-economic scenarios are used as well – both globally and for the regional case studies.

Regional use

Scenario development is typically nested, resulting in multi-scale socio-economic scenarios consisting of newly constructed, co-produced regional scenarios that are similar to a set of pre-existing higher-level scenarios. The degree of matching can differ, as can the method of developing them. In all cases, socio-economic scenarios serve the purpose of exploring what futures are possible, often with stakeholders and often yielding qualitative products. Socio-economic scenarios are a product in its own right, and often those that are most used by policy makers and other stakeholders. They can also contextualise normative scenario development or feed to models to explore changes and impacts quantitatively. Socio-economic scenarios are referred to as explorative. Typically, regional socio-economic scenarios are qualitative narratives, where necessary supported by quantitative modelling.

Global use

Global climate change scenarios have always considered a large range of socio-economic futures, but also relied on a core set of socio-economic scenarios to co-ordinate socio-economic assumptions between climate change, climate impacts, mitigation. and adaptation studies (Moss et al. 2010; Nakicenovic et al. 2000; Riahi et al. 2017). The core set of the current generation of socio-economic scenarios for climate change research builds on the Shared Socio-economic Pathways (SSPs) (Kriegler et al. 2012; O'Neill et al. 2014; Riahi et al. 2017). The SSPs comprise narratives of world futures (O'Neill et al. 2017) and associated population, education (KC and Lutz 2017), urbanisation (Jiang and O'Neill 2017) and economic output projections (Crespo Cuaresma 2017; Dellink et al. 2017; Leimbach et al. 2017).

Additional notes on terminology

The SSPs and RCPs are referred to as "pathways". The term pathway was introduced to characterise them as scenario components. It is important to note, though, that this meaning of pathway is very different from the definition of pathway as goal-oriented scenario (see above and further below). While both definitions co-exist in the literature, only the latter is consistent with the common use of the term "pathway" for mitigation, adaptation, and more broadly sustainable development and transformation scenarios. We will therefore refer to the SSPs as building blocks for climate change scenarios rather than as scenarios themselves.

2.2.2. Greenhouse gas emissions, concentration and climate forcing scenarios.

Emissions scenarios translate assumptions about socio-economic developments and associated projections of energy and land use into projections for greenhouse gas emissions and short-lived climate forcers (SLCFs) such as aerosols. They are typically generated with integrated assessment models (IAMs) covering all world regions and emissions sources using socio-economic scenarios as inputs (Riahi et al. 2017). The emissions projections are converted into projections of future atmospheric carbon dioxide and other greenhouse gas concentrations as well as atmospheric aerosol loadings, using carbon cycle, atmospheric transport and atmospheric chemistry models (Lamarque et al. 2011; Meinshausen et al. 2011). These projections are then used to derive projections of the future anthropogenic forcing of the climate system using radiative transfer models. A core set of concentration and radiative forcing scenarios used across different domains of climate change research are the Representative Concentration Pathways (RCPs) (van Vuuren et al. 2011). As for the SSPs, the term ‘pathway’ was used here to characterise them as scenario *components*. Given their prominent role, the RCPs are another important point of departure for the SENSES project.

Global use

The RCPs, and more broadly emissions, concentrations and forcing scenarios, can be associated with a large range of socio-economic scenarios (and SSPs in particular) and vice versa (van Vuuren et al. 2012). Thus, a combination of SSP and RCP is needed to define a comprehensive integrated scenario describing consistent socio-economic, emissions, and climate outcomes (see below) (van Vuuren et al. 2014).

Regional use

Regionally, global emission and forcing scenarios are often not considered explicitly as most regions are too small to significantly influence global emissions. Rather, climate change projections (see below) are used as a starting point. Those, however, are based on specific forcing scenarios, typically the RCPs. Studies often do not go beyond 2050, which reduces the sensitivity of scenario development to the choice of RCP. Therefore scenario developers often opt for a single RCP (with different GCMs/RCMs[1] to include model uncertainty).

2.2.3. Climate change scenarios

These scenarios are derived from climate models. They comprise the modelling of global and regional climate change, including downscaling activities. Coupled climate models required anthropogenic forcing scenarios as input for climate change projections.

[1] GCMs (Global circulation models) and RCM (Regional circulation models) are climate models at different scales.

Global use

The RCPs were used as input for the 5th coupled climate model intercomparison project (CMIP5) (Taylor, Stouffer, and Meehl 2011) whose climate change projections informed the latest (5th) assessment report of the IPCC (Collins et al. 2013). A new generation of Earth system models (ESMs) includes carbon cycle and atmospheric chemistry components and thus can directly use emissions scenarios as inputs for climate change projections. Nevertheless, radiative forcing projections will continue to be used as inputs for the next round of climate change projections (scenarioMIP as part of CMIP6) (Eyring et al. 2015; O'Neill et al. 2016) to inform the next (6th) assessment report of the IPCC. The reason is to maintain consistency between projections from different types of climate models. Globally, these climate change scenarios are referred to as climate projections.

Regional use

GCMs are downscaled to produce Regional Climate Models (RCMs), through CORDEX (Coordinated Regional Climate Downscaling Experiment), analogue to CMIP. The aim is to downscale global information, and to match regional climate specifics. Regional models typically cover relatively large areas, with most countries having national climate scenarios, related to national issues, e.g. sea-level rise, or extreme events (floods, droughts).

2.2.4. Climate impact scenarios

These scenarios encompass all (modelling) efforts to quantify climate change impacts for a range of projections of future climate change (see above). Climate impact scenarios are derived with a broad array of sectoral and/or integrated models that assess the effect of climate change. While in the past socio-economic conditions were often kept fixed to present conditions, climate impact models increasingly uses socio-economic scenarios (see above) to reflect changing societal conditions. Climate impact models are also employed to assess the effect of mitigation and adaptation scenarios (see below).

Global use

Efforts are coordinated in the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP, Frieler et al. 2017), covering a large range of sectors. A main design motivation of the SSPs was to further facilitate the uptake of socio-economic scenarios in climate impact modelling (Kriegler et al. 2012).

Regional use

The use of impact models strongly depends on the availability of models, data, and modelling knowledge. A very large number of models has been developed in relation to climate change impacts, notably related to crop growth, hydrology, water quality, agriculture and land use, and biodiversity. Particularly the availability of reliable data of sufficient spatial resolution can be problematic. For larger regions, results of global models are sometimes employed.

2.2.5. Mitigation scenarios

Mitigation scenarios are related to assessing the effect of climate change mitigation options. They are usually developed after other types of scenarios are developed, with the goal to reduce emissions and therefore climate change (and impacts). They can be either goal oriented (achieving a specific goal, e.g. 1.5 degree global warming) or projecting current policy trends (assessing the effect without specific long-term goal), and either model-based, or qualitative.

Global use

With the adoption of the Paris Agreement, mitigation scenarios relating to the goal of limiting warming to 1.5°C and 2°C are becoming more and more important. Goal-oriented mitigation scenarios are referred to as 'mitigation pathways'.

Regional use

Regionally, for many sectors (agriculture, water, biodiversity) the focus is on climate adaptation (see below) and not on climate mitigation. Mitigation scenarios are important related to energy but are – relative to adapatation – not very common. The most common manner to include them is through global mitigation aspects that influence regional change, e.g. biofuel production and other land-based mitigation options, or demand for green energy. These are included, much like global socio-economic scenarios, as contextual changes. However, there is a body of literature on mitigation scenarios which is now rapidly expanding to include mitigation scenarios at national level, particularly for OECD countries. Furthermore, now when most countries also have NDCs, including national mitigation plans, the regional use is rapidly expanding.

2.2.6. Adaptation scenarios

This includes all scenarios of adaptation measures. Contrary to mitigation scenarios, the majority of adaptation scenarios is developed sub-globally, addressing specific climate change impacts and specific solutions. Regional adaptation scenarios are mostly goal-oriented and referred to as pathways.

Global use

The function of adaptation scenarios is similar to the regional use, but because of the non-global specifics of many of the climate change impacts, the number and variety of adaptation scenarios is less. They relate to climate change impacts that have global implications, such as ocean acidification.

Regional use

After completion of climate change (impact) and socio-economic scenarios, regional adaptation scenarios are the most common last step in assessing future changes. They are typically developed based on risks of extreme events sometimes in combination with socio-economic scenarios, and sometimes based on existing (non-climate) policies. Almost all countries have a National Adaptation Plan (NAP) as a means of identifying medium- and long-term adaptation needs and developing and implementing strategies and programmes to address those needs. It is a continuous, progressive and iterative process.

2.2.7. Integrated scenarios

Given the many different ways in which a scenario can be used depending on the goal and method of the exercise, there are different types of efforts to integrate some of the scenario categories. Adaptation and mitigation scenarios are already integrating socio-economic scenarios, emissions and forcing scenarios and climate change projections, and in the case of adaptation scenarios also climate impact projections. The highest degree of "integrated scenarios" is achieved in combined mitigation and adaptation scenarios that integrate mitigation and adaptation measures. See Figure 2 for an overview on the relation between the different scenario categories.

Table 2 provides a summary of the main characteristics of the seven types of scenarios as identified in SENSES.

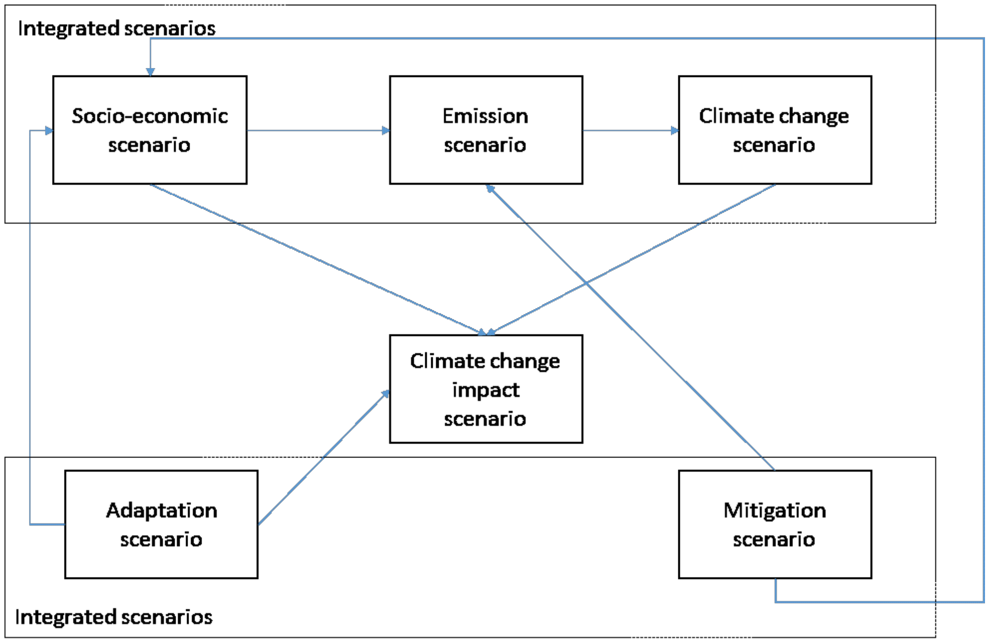


Figure 1. Overview of main connections between types of scenarios

Table

Table 2. Summary of seven types of scenarios as identified and characterised in SENSES

Type of scenario used in SENSES	Inclusion of goal	Key question addressed	Spatial scale	Temporal scale	Data collection	Co-production
Socio-economic scenarios	Globally partly; regionally no	What can happen?	Multi-scale	Long. Globally 2100; regionally 2050	Qualitative narratives and quantitative data	Yes
Emission scenarios	Globally: partly; regionally: no	What can happen?	Global	Long (often 2100 or beyond)	Quantitative	No
Climate change scenarios	No	What can happen?	Global and downscaled to Europe	Long (2100 or beyond)	Quantitative	No
Climate change Impact scenarios	Both	What can/should happen	Global and regional	Variable	Quantitative	No
Adaptation scenarios	Yes	How to reach a specific target?	National (and global)	Medium to long (often 2030 or 2050) with short-term actions	Qualitative and quantitative	Yes
Mitigation scenarios	Yes	How to reach a specific target?	Global (and regional)	Medium to long (often 2030 or 2050) with short-term actions	Qualitative and quantitative	Yes
Integrated scenarios	Both, depending on what is integrated	Depends on what is integrated	Global and regional	Depends on what is integrated	Qualitative and Quantitative	Yes

2.3 Some additional considerations

2.3.1. Scenarios and models

There is often (terminological) disagreement on the role of models in scenario development, as it raises the question whether a scenario is a model input, model output, or even unrelated to models? Carter (2001) states that many assessments treat scenarios *exogenously*; the scenarios are qualitative constructions that are intended to challenge people to think about a range of alternative futures that might go beyond conventional expectations. The scenarios exercise itself is not dependent on the use of models, however models can be used the improve consistency of the storylines and project various quantified changes simultaneously. These qualitative constructions include elements that are difficult to grasp in variables required for models. These scenarios can be used as *input* to modelling exercises. However some key elements of the scenarios will attenuate or be disregarded in the modelling exercise.

Other assessments—especially those that use integrated assessment models (IAMs)—treat scenarios *endogenously* as outcomes, with only requiring prior specification of the key driving variables (e.g., economic development, population). These scenarios are mainly quantitative, derived by running models on the basis of a range of different input assumptions. From this perspective scenarios are the model output.

The perspective if a scenario is model input or model output is often influenced by the background and experience of person. From a modeller's point of view, scenarios are the output of a model. From a social narrative point of view, a model is a single perspective on how the system works that can be used to illustrate the story. Certainly at the regional level, scenarios are not always constructed with the aim to combine them with quantitative models. From a regional planner's perspective, models are a quantification of a scenario (scenario being model input), that can help contextualising decisions to make e.g. adaptation plans. As stated, given the pivotal role of quantitative modelling efforts in the products that we consider within SENSES, the term scenario is used to include modelling input and model output.

2.3.2. An introduction to the process of developing the RCP x SSP scenarios

The climate change research community recently developed a new set of global integrated scenarios, the RCP x SSP scenarios, describing future climate, societal, and environmental change (Van Vuuren et al., 2014, Riahi et al., 2015. This process started with the development of representative concentration pathways (RCPs) that describe a set of alternative trajectories for atmospheric concentrations of key greenhouse gases (Van Vuuren et al., 2011). Based on these, climate modellers produced a number of simulations of possible future climates over the 21st century (Taylor et al., 2012). In parallel, other researchers produced a new set of alternative pathways of future societal development, described as shared socio-economic pathways (SSPs). Integrated assessment models (IAMs) were used to produce additional quantitative elements based on them, including future emissions and land use change for every SSP. A conceptual framework has been produced for the development of SSPs (O'Neill et al., 2014) and for how to combine IAM scenarios based on them with future climate change outcomes and climate policy assumptions to produce integrated scenarios (Ebi et al., 2014; Vuuren et al., 2014; Kriegler et al., 2014) and support other kinds of integrated climate change analysis.

Table 3 shows the basic lay-out of the compartments and how they can be assembled to develop "integrated scenarios" (see Chapter 2.2): The rows represent four RCPs that correspond to certain greenhouse gas concentration developments. These are being used by the climate modelling community to link them to certain ranges of temperature, precipitation and sea level. As such, the rows represent the biophysical system dynamics and the effects on climate change. The columns represent five SSPs that correspond with distinct paths of development of the socio-economic system, focusing on mitigation and adaptation potential. The SSPs do not include adaptation/mitigation options or climate policies, those are covered by the SPAs. Finally, the cells are the integrated scenarios where assumptions on climate, the socio-economic system and adaptation, mitigation and climate policies come together. The scientific community is now facing the challenge of how to integrate the separately developed products over a range of scales to assess climate change impacts, vulnerability, adaptation and mitigation.

Table 3. Scenario development approach showing the connection between RCPs, SSPs and SPAs in the new global scenarios

RCP (W/m^2 in 2100)	**SSPs**				
	SSP1	**SSP2**	**SSP3**	**SSP4**	**SSP5**
2.6					
4.5	SPA				
6.0					

8.5					

3. Co-production techniques

3.1. Introduction

3.1.1. Different perspectives of co-production in SENSES project

For the regional scenario users within SENSES, co-production techniques will be used to develop regionally relevant scenarios for the two case studies (Kenya and the Netherlands). For the other user groups (national and international climate policy makers, businesses and financial institutions), co-production will be mainly used for an iterative interaction process, to better identify the user needs and to understand how the various user groups want to use scenario information.

These two approaches of co-production imply that different perspectives exist regarding what co-production is and how it should be used. Bremer and Meisch (2017) observed multiple meanings of co-production in climate research which add richness to the concept and specify different uses. They identified eight overlapping but distinct perspectives (constitutive, interactional, iterative interaction, extended science, public service, institutional, social learning, and empowerment) (see figure 2). Understanding the various perspectives on co-production clarifies which approach best addresses the purpose and goals of a given task and its associated constraints. Here we focus on two perspectives for the purposes of SENSES.

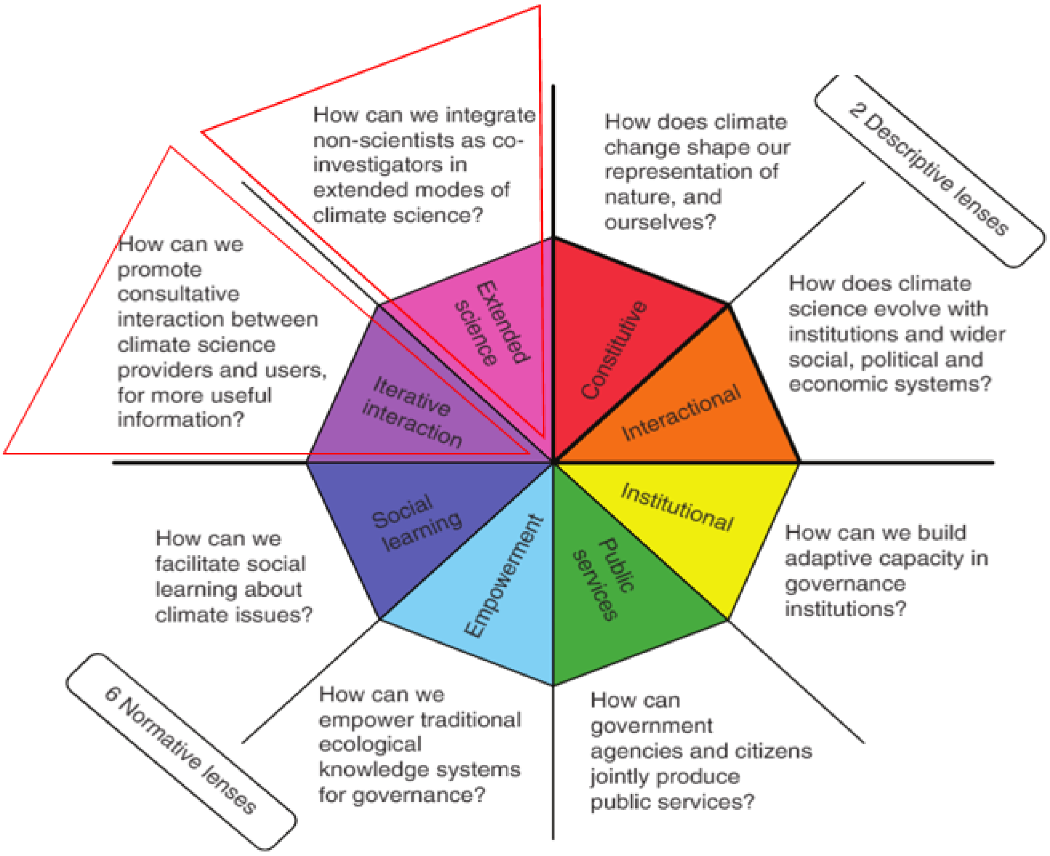


Figure 1. Co-production prism comprising eight perspectives on climate change co-production (Bremer and Meisch, 2017)

The perspective of the "**Iterative Interaction"** lens reflects best the co-production process envisioned to develop climate information products tailored to user needs in SENSES:

> *"This lens promotes the iterative interaction of science providers and users along an interdisciplinary research process designed to* ***produce more useable climate information****; … Its emphasis is on ways of tailoring scientific information to the decision-making context through* ***regular consultation****" .... "More recently, this lens has become a starting point for thinking about how to transform climate science into value-added 'climate services,'* ***climate information products tailored to clients' needs****."* (Bremer and Meisch, 2017)

The perspective of "**the Extended Science"** lens is closest to the co-production process envisioned for developing participatory scenario:

> *"This lens looks at ways of doing science differently by including the* ***knowledge and values of nonscientists as integral to the process of scientific knowledge production****. It begins from an assumption that complex environmental challenges such as climate change cannot be adequately dealt with by normal disciplinary science alone but*

> *need new extended forms of scientific practice...All stress the importance of* ***creating a more robust and socially accountable science that is problem-driven, better reflects complexity and uncertainty, and includes a diversity of perspectives****. Co-production in this sense is supposed to overcome the knowledge–action gap by creating useful and place-based knowledge."* (Bremer and Meisch, 2017)

The various approaches of co-production can also apply to different stages in an exploratory or decision-making process. In considering climate policy, co-production of knowledge for policy-making purposes may be based on climate scenarios, but does not necessarily include the scenario production process as part of the exercise. Science has long played a role in informing policy. Merton (Merton, 1945) offers critiques of the process and its inherent assumptions. More recently, Sarkki et al. (2014) describe the tradeoffs of science-policy interfaces, including the personal time of those involved, speed vs. quality of outputs, clarity vs. complexity of recommendations, and demand vs. supply-led exploration (further explored by Lövbrand (2011)).

The SENSES project recognises the applicability of co-production techniques both for developing scenarios and facilitating learning. This document, however, mainly describes the use of co-production for participatory scenario development, taking an 'extended science' perspective. Since scenario development occurs earlier than co-production through scenario analysis, the activity addresses two of Sarkki (2014)'s identified trade-offs of science-policy interfaces. Information can be communicated more with complexity because the decision is still under exploration (clarity vs. complexity). Additionally, because the scenario exercise is further removed from the actual policy-making, more time exists for horizons scanning to anticipate that policy decisions that will need to be made in order to provide high quality results at the time when they are needed (time vs. quality).

3.1.2. Motivation for co-production in scenario development

Co-production can be defined as collaboration among scientists, and stakeholders, who, after identifying specific decisions to be informed by science, jointly define the scope and context of the problem, research questions, methods, and outputs, make scientific inferences, and develop strategies for the appropriate use of science (Beier et al., 2017).

The definitions of co-production and co-creation are related and often used interchangeably (Voorberg et al., 2015). Generally, co-production is more often discussed in socio-environmental science to allow end-users and citizens, to participate in policy making activities. Co-creation describes a similar process but grounded in the business world with the aims of incorporating customers in developing products for profit. Although businesses are one of the three user-groups targeted in the SENSES project, we will be exploring their opportunities and risks in operations related to climate-impacted sectors such as energy and transport, so the term "co-production" is appropriate.

An extended peer community can be mobilized to contribute contextualized local knowledge to scientific exploration (Ravetz, 1999). We will examine co-production as a methodology that invites a diverse set of participants to develop scenarios. The notion of "post-normal science" (Funtowicz and Ravetz, 1993) supports co-production of policy design (Voorberg et al., 2015) and science for policy (Beier et al., 2017). Co-production features a blend of expert and non-expert input; scenario initiatives may include scientists, policy makers, and potentially affected citizens in exploring possible future development pathways. The common nomenclature juxtaposes these actors as experts and stakeholders, even though both groups contribute expertise to the co-production process.

A scenario definition is often two-fold: that it is about the future, and that it is internally consistent/plausible (Guivarch et al., 2017; Kok et al., 2014). Co-production contributes to salience, legitimacy and credibility (Cash et al., 2003; Kunseler et al., 2015) (see also Alcamo, 2008). Note that all three features are subjective, with salience determining whether a scenario can be applied to a question, and legitimacy and credibility measuring perceptions of the appropriateness of applying said scenario. Truth is always subservient to perceptions, but validity of a suite of scenarios can never be known, since only one future can possibly arise. However, these perceptions have value; social constructs are nevertheless "real" in Bhaskar's (2010) sense, because images of the future (Morgan, 2002), can cause material change in the world through their influence on individual behavior. Scenarios perceived to be salient, legitimate and credible are well positioned to galvanize action. Here we examine these features to understand their value in scenario development and how it is supported by co-production techniques.

Salience refers to the extent to which the particular concerns or needs of users are addressed (Cash et al., 2003). For terms of the co-production purpose, it asks *for what* we are producing knowledge. Participatory approaches recognize that including the actual actors in the development process will produce more relevant insights that are well positioned for successful uptake and action (Johnson et al., 2012; Vervoort et al., 2014). Broader participation should expand the concerns under examination and extend the usefulness of the produced knowledge.

Legitimacy refers to the trustworthiness of the process in the eyes of various audiences and whether that messages of the scenarios are politically fair. In the co-production process, it addresses *how* and *with who* are we producing knowledge. Ravetz (2011) discusses the malaise surrounding the perception of science as an elite culture with restricted membership. Perceived disconnects between scientific and citizen perspectives are particularly important in democratic settings where decision-makers require citizen support to continue their work. Participatory methods can directly involve policy makers and other stakeholders in assessing possible futures to help shape the future or adapt to changing conditions (Kok et al., 2014). Both a practical and a moral case can be made that scenarios should be constructed by those who are expected to act; when this is not done then those who develop the scenarios construct an image of the "other" on their behalf (Adesida, 1994; Sardar, 1993). Legitimacy in micro-level decision can avoid "policy resistant" situations in which a system's response counteracts the policy's original purpose (Elsawah et al., 2015). In the search for robust and socially accountable science, including the voices of those impacted will give the process and its products more legitimacy(Bremer and Meisch, 2017).

Credibility refers to the trust audiences put in the scientific and technical quality used to generate plausible views of the future**.** It relates to the co-production outcome; *what* knowledge are we producing? To plan for culturally diverse populations, intuitive, experiential and local knowledge will offer planners more information than reliance on technical-rationality and scientific methods alone (Chakraborty, 2011). The human elements of a system tend to be more difficult to predict (Dessai and Hulme, 2004) because of their ability to reflect critically and adjust based on new understandings (Berkhout et al., 2002; Dessai and Hulme, 2004). Characterizing both biophysical (stochastic) and social (reflexive) uncertainty expands the analysis of unknowns in the context of climate change (Dessai and Hulme, 2004). Since social constructs shape action, those who live within those constructs should be allowed to say how they believe them to operate. Thus, the coherent and internally consistent set of assumptions about key relationships and driving forces that define scenarios (Guivarch 2017) should be clarified by the actors immersed in them. The resulting knowledge offers more creditability among those actors and their compatriots.

The next section examines how these three concepts guide the initiation of a co-production process.

3.2 Framework for Co-Production of Scenarios

Gramberger et al. (2015) identify various challenges to engaging stakeholders, including a) Linking stakeholder contributions to the overall research questions b) Difficulties in identifying and selecting representative stakeholders; and c) doubts about whether stakeholders are qualified to provide credible contributions. These concerns relate to salience, legitimacy and credibility respectively, and can be addressed through a deliberate process. The preparatory steps for below are adapted from Reed (2013)'s methodological framework for participatory scenario development.

1. Define context and establish whether there is a basis for stakeholder engagement in scenario development
2. Systematically identify and represent relevant stakeholders in the process
3. Define clear objectives for scenario development with stakeholders including spatial and temporal boundaries
4. Select relevant participatory methods for scenario development
5. Commence scenario co-production

Steps 1-3 support a process to satisfy salience, legitimacy and credibility while imposing sufficient constraints to keep the exercise focused. We examine each in turn.

3.2.1. Define context and establish whether there is a basis for co-production

Any co-production scenario development activity for informing decision-making must be initiated by a specific actor, whether they are a stakeholder, the decision-maker, or an external project participant such as an expert advisor or a funder. This actor will decide whether co-producing scenarios will add value to the process or the information derived from it. Lebel et al. (2005) note stakeholder participation is often motivated to engage the stakeholders in understanding their local environment, achieve buy-in for decision made and explain the assessment findings. Less frequently expressed reasons include learning from the stakeholders.

Criteria for relevancy may differ between actors (Hegger et al., 2012), and co-production will be useful in a system where decision-maker interests are sufficiently aligned with the various stakeholder interests and vice versa. Ultimately, the decision maker will determine whether to implement any decisions based on co-produced scenarios. Vested interests or unstated priorities in decision-making may jeopardize the subsequent decision's implementation and diminish the value of the co-production exercise altogether. Postnormal science (Funtowicz and Ravetz, 1993) assumes that such values are made explicit and inform an interactive dialogue.

There are balances that must be accommodated, for example, an overly focused scope can reduce the opportunity for critiques from other perspectives, reduced legitimacy and credibility (Sarkki et al., 2014). However, in order for scenario co-production to be useful, stakeholders must be able to contribute salient information.

3.2.2. Selection of representative stakeholders

Following the decision to include stakeholders, individuals must be sought who can provide context-specific knowledge to inform and improve the imagined interventions. While Step 1 establishes that stakeholders can contribute salient knowledge and objectives, the derived decision's legitimacy depends on who participated and who did not, the processes applied, and how information is produced, assessed, and disseminated (Cash et al., 2003).

The composition of stakeholders in a co-production exercise can significantly affect the outcome in terms of what knowledge, interests and personalities are present in the discussions, although iteration may mitigate some of these effects (Kok et al., 2014). Actors must have some incentive to participate, some expectation of a favorable outcome (Hegger et al., 2012). A key challenge in transdisciplinary research lies in understanding the stakeholder environment, knowing who the stakeholders are, and identifying the population from which the sample of stakeholders can be drawn (Leventon et al., 2016). The entire population of persons potentially affected by a decision must be reduced in size to a group of people that offer representative (legitimate) and salient information to the decision at hand. The smaller the scale of the problem, the more responsive the socio-ecological dynamics (Zurek and Henrichs, 2007), and thus the more relevant the stakeholder input and responses.

Various methods exist to identify, analyze and select representative stakeholders. The stakeholder analysis typology of Reed et al. (2009) describes the main methods for: i) identifying stakeholders; ii) differentiating between and categorizing stakeholders; and iii) investigating relationships between stakeholders. Selection criteria may include quotas for age, gender, organizational affiliation, key sectors, and/or geographical scope of activity. Identifying stakeholders can be an iterative process, during which stakeholders can be added as the analysis continues (Godet, 2006, page 250). The stakeholder groups should be sufficiently large that individual stakeholders can together characterize the most important responses for the system under different scenarios.

The goal is to include salient and credible stakeholders, but even if a list of such individuals were definitively known, their attendance remains subject to constraints of availability, distance, funding, and their own priorities. In identifying and inviting various stakeholders to participate in co-production it is important to recognize that one of the great tenants of science – reproducibility – regarding stakeholder contributions is beholden to very human subjectivities. The products of group processes depend on assumptions and mental models which remain unstated (Morgan, 2014). Furthermore, Morgan and Keith (2008) recognize that human cognition biases such as over-confidence and constrained imagination about the future, to which Kok et al. (2014) adds insufficient context or relevant expertise, can reduce the plausibility of scenarios produced. However, the advantages of a participatory process include challenging the perceptions of those in authority to influence attitudes and agendas, therein encouraging policies better suited to serving the needs of those concerned (Patel et al., 2007) (Patel) and increasing the legitimacy of the process in the eyes of the stakeholders.]

Reproducibility is thus not necessarily possible in determining which individuals attend a co-production activity, but should be sought in the concerns and priorities that are elicited with respect to the decision under examination. Even so, storylines are difficult if not impossible to reproduce, but transparency in the generation process will allow future researchers to reconstruct how storylines arose (Alcamo, 2008, Carlsen et al. 2017).

Various stakeholders may bring preferred tools with implications for the transparency of the scenario generation process. Transparency can extend to perceptions of models used for decision making. If the end users cannot see how the model relates to their reality because the model is opaque or conflicts with their understanding of their environment, stakeholders may not trust the model or the results that it generates (Elsawah et al., 2015). Without a clear exposition of assumptions and approach it will be difficult for audiences to make sense of the results, or to trust them sufficiently to use them in their own decisions (Berkhout et al., 2002). This relates to the process' credibility, which can be assured with sufficient constraints.

3.2.3. Define clear objectives for scenario development with stakeholders including spatial and temporal boundaries

Following the establishment of a representative and salient group of stakeholders, the futures analysis begins by defining the research objectives and the boundaries of the system under examination. The objective of the analysis should be clearly stated so all parties understand the purpose of the co-produced scenarios.

Jurisdictional authority will constrain the scope of proposed solutions, since global factors or driving forces outside of the local or regional governance system will constitute boundary conditions (Zurek and Henrichs, 2007) as will the constraints that the stakeholders bring to the co-production process, such as local economics, cultural practices and existing human capital. The more stakeholders included, the more constraints may emerge concurrent to the proliferation of ideas. This helps to ensure that the knowledge produced is credible.

The co-production facilitators may choose to impose additional constraints for the sake of the exercise, like discounting black swan events or limiting the policy changes to a single sector or time frame. Absar and Preston (2015) recognise that unconstrained storylines may become redundant or difficult to manage and communicate.

The constraints must be balanced with the solicitation of creative ideas, where an early or overly deterministic imposition of constraints may prevent ideas from being considered, and a late imposition of constraints may produce an unwieldy decision space.

Chakraborty (2011) explored imposing different constraints on different stakeholder groups and found that increasing the flexibility of the future projections made participants feel more "empowered" in the exercise. The flexibility was justified by the authors because the exercise value was not its technical accuracy. This indicates that a balance must be maintained for requirements for credibility and empowerment through imaginative thinking. Kok et al. (2014) found that some participants doubted the credibility of their responses when they ventured outside their expertise.

3.2.4. Select relevant participatory methods for scenario development

Finally, with the goals, constraints and actors established, the selection of co-production techniques can begin. Godet proposes to select techniques answering the following questions: 1) Choose procedures that will specifically answer distribution questions; 2) Use methods adapted to the time and means available; and 3) select simple, concrete, appropriable tools that encourage reflection and group expertise. A combination of co-production techniques may be selected. The selection and arrangement of these techniques will determine the methodological framework of the co-production process for scenario development. The options and their characteristics are discussed in the following section.

3.3. Typology of co-production techniques for scenario development

3.3.1. Foresight in Climate Scenario Development

Before delving into the co-producing techniques currently employed, we note that almost none have been used in global climate scenario efforts, or in other global environmental scenario studies. The most consistently applied method has been intuitive logics, an easily implemented and highly popular technique (Bradfield et al., 2005; van der Heijden, 2005).

The SRES study featured an "open process" to involve experts beyond the writing team (Nakićenović et al., 2000 Appendix VI). The process involved posting aspects of the scenarios to a public-facing website and inviting comments from target groups of experts. A similar procedure was followed for the SSPs (O'Neill et al., 2017, p. 172). The SSPs also featured consultation with experts in a series of meetings held throughout the scenario development process (Ebi et al., 2014a). The MA scenario team interviewed potential users of the scenarios (the project's "stakeholders") and disseminated the results to selected groups for review (Alcamo et al., 2005).

Within each of the teams, the process for the SRES and MA scenarios were broadly similar, in that they involved narrative development combined with quantitative assessment. The MA scenario team was particularly conscious of this process, which was later formalized by

Alcamo (2008) as the "Story and Simulation" approach. To avoid interdependencies that might slow the time-consuming processes of narrative construction and modelling, the SSPs and RCPs were developed in parallel. Development of the RCPs was an almost entirely quantitative exercise (van Vuuren et al., 2011). The range of RCPs was determined by the existing literature, while intermediate trajectories were determined by requiring an even number of well-separated scenarios. Experts from outside the modelling teams helped to identify the required outputs from the model runs, but not the underlying assumptions.

While the SRES, climate community, and MA scenarios made use of very few foresight tools, some of those tools have been applied retroactively. Schweizer and Kriegler (2012) applied Cross-Impact Balances (CIB) to the SRES scenarios, while Carlsen et al. (2016) applied Scenario Diversity Analysis (SDA). Schweizer and Kriegler were particularly careful to only use information available to the SRES team at the time of writing. Together, the studies found that greater consistency and diversity could have been achieved had these methods been applied in the SRES process. Kemp-Benedict (2012) argued that they could improve the SAS method more generally. Schweizer and O'Neill (2014) applied CIB to the SSPs. They uncovered some dynamics that were missed in the SSP development process, but more importantly they argue that CIB offers a traceable formal process that can benefit global scenario exercises.

In a further study of the SSPs, Lamontagne et al. (2018) drew on a range of techniques, broadly consistent with Robust Decision Support (RDS), to show that the SSPs did not encompass potentially important and policy-relevant scenarios. While their method would have been challenging to implement during the SSP process itself, it shows that using the SSP framework might unhelpfully restrict policy discussions. The consensus view emerging from these studies is that using a broader range of foresight techniques could significantly improve global scenarios. Deploying these techniques will require a better understanding of the various inputs, perspectives and processes available in the field of foresight.

3.3.2. Developing a database for co-production techniques

Various studies have classified techniques that can be used for scenario developments (Bishop et al., 2007a; Börjeson et al., 2006a; Popper, 2008). Depending on the scenario characteristics, the type of co-production can be selected accordingly (van Notten et al., 2003). For this report, a database has been developed to classify over 60 co-production techniques (see figure 5). The starting point for this database is the methodologies discussed in Future Research Methodology (Glenn and Gordon, 2003) extended with frequently used techniques, both in peer reviewed and grey literature. It must be stated that it was beyond the scope of this project to classify all possible co-production techniques. The overall objective of the database is to provide a first overview of possible co-production techniques for scenario development that could guide the selection of suitable techniques. The database is accessible online. To see the full database in an online Excel file, click here.

General characteristics					1. Project goal: 1.1. What is the scenario perspective?		1.2. What is the stage of the scenario development process?					2. Scenario knowledge generation: 2.1. Information Solicited (base for knowledge generation)			2.2. Way of knowledge generation		2.3. Ambiguity		3. Degree of engagement: 3.1. Who are the participants?	3.2. Degree of engagement			
Name	Activity	Description	Time Duration	Grouping	What could happen? (explorative)	What should happen? (normative)	Understand: Understand	Scenario development: Generate ideas	Scenario development: Integrate ideas into whole	Scenario development: Consistency	Decision: Decision	Quantitative	Qualitative	Translation tools	creative	evidence-based (systematic)	allow ambiguity (divergent)	reduce ambiguity (convergent)	Participation	Requires group activity	can be performed in a 1 day workshop	means of interaction	Future Research Methodology
Brainstorming	Technique	Brainstorming is a creative and interactive	short	brainstorming	x	x	x	x	x				x		x		allow	reduce	broad	group	yes	in person	
Affinity diagram (card techniques)	Technique	A tool to generate ideas by organizing qua	short	brainstorming	x	x	x	x	x				x		x		allow		broad	group	yes	in person	
Nominal Group Technique (card technique)	Technique	Individuals silently write down ideas. Ideas	short	brainstorming	x		x	x					x		x		allow		broad	group	yes	in person	
Futures Wheel	Technique	The Futures Wheel is a form of brainstorm	short	brainstorming	x			x	x	x			x		x		allow	reduce	broad	group	yes	in person	FRM
Scenario discovery cluster analysis	Technique	Scenario discover cluster analysis provides	medium	scenario analys	x		x			x		x				x		reduce	narrow	both		desk analysis	
Cross over point	Technique	Crossover points are used to compare (env	medium	comparison		x			x	x	x	x				x		reduce	narrow	both	yes	in person	
Multicriteria analysis	Technique	Multi-Criteria Analysis is a prioritisation a	medium	comparison		x					x	x	x			x		reduce	broad	both	yes	in person	FRM
STEEP analysis	Technique	STEEP (Social, Technological, Economical, E	short	horizon scannin	x	x	x						x			x		reduce	broad	both	yes	in person	
SWOT Analysis	Technique	SWOT is an assessment tool that lists the	short	horizon scannin	x	x	x						x			x		reduce	broad	both	yes	in person	
Environmental Scanning	Technique	identifies early indicators and "weak signa	variable	horizon scannin	x	x	x						x			x		reduce	-	both		desk analysis	FRM
Text Mining	Technique	Text mining is the process of deriving high	variable	horizon scannin	x	x	x						x			x		reduce	-	both		desk analysis	FRM
Cross-Impact Analysis	Technique	Cross Impact Analysis is a tool to calculate	medium	matrix	x					x		x	x			x		reduce	narrow	both	yes	in person	FRM
linked Cross Impact Balance	Technique	linked Cross-Impact-Balance analysis is a	medium	matrix	x	x				x		x	x			x		reduce	narrow	both	yes	in person	
Structural Analysis	Technique	Structural analysis is a tool designed to lin	short	matrix	x		x		x			x	x		x	x		reduce	narrow	group	yes	in person	FRM
Cognitive Mapping	Technique	Cognitive mapping is a causal mapping tec	short	mindmapping	x	x	x	x	x				x		x		allow		broad	both	yes	in person	
Agent Modeling	Technique	Agent-based Modelling (ABM) is one bran	medium	modeling & sim	x	x	x		x	x		x				x		reduce	narrow	both	yes	online	FRM
Modeling to Generate Alternatives	Technique	Modelling to Generate Alternatives (MGA)	medium	modeling & sim	x	x	x	x	x			x				x	allow		narrow	both	yes	in person	
Statistical Modeling	Technique	A statistical model is a mathematical mod	medium	modeling & sim	x	x	x	x		x		x				x		reduce	narrow	both		desk analysis	FRM
Role playing	Technique	A role-playing game is a game in which pl	short	modeling & sim	x	x	x	x					x		x		allow		broad	group	yes	in person	
Simulation-Gaming	Technique	Simulation Gaming is form of role-playing	short	modeling & sim	x	x	x	x					x		x		allow		broad	both	yes	in person/online	FRM
Robust Decisionmaking	Methodology	Robust Decision Making (RDM) is a combir	long	n/a	x	x	x	x	x	x	x	x			x		n/a	n/a	broad	group	>> time	in person	FRM
Story and Simulation	Methodology	Story-and-Simulation (SAS) is an "open" pr	long	n/a	x	x	x	x	x	x		x	x	x	x	x	n/a	n/a	broad	group	>> time	in person	
Multipattern approach	Methodology	Multi-Pattern Approach (MPA) is a theoret	medium	n/a	x		x	x	x	x		x	x			x		reduce	narrow	group	>> time	in person	
Normative Forecasting	Methodology	Normative Forecasting begin with a consic	medium	n/a	x	x	x	x	x	x		x	x		x	x	n/a	n/a	narrow	group	>> time	in person	FRM
Anticipatory Action Learning	Philosophy	Anticipatory Action Learning (AAL) is resec	long	n/a	x		x	x	x	x			x		x				broad	group	>> time	in person	
Causal Layered Analysis	Philosophy	Causal layered analysis (CLA) utility is not	long	n/a	x		x	x	x				x		x		allow		broad	group	>> time	in person	FRM
Syncon (participatory)	Technique	The Syncon process begins with small grou	long	participatory se	x	x	x	x	x				x		x		allow		broad	group		in person/online	FRM
Search conference (participatory)	Technique	A Search Conference is a structured partici	medium	participatory se	x	x	x	x	x				x		x		allow		broad	group		in person	FRM
Workshop (participatory)	Technique	a meeting at which a group of people eng	medium	participatory se	x	x	x	x	x		x		x		x		allow		broad	group	yes	in person	FRM
Charette (participatory)	Technique	Charrette is an intensive face-to-face proc	short	participatory se	x	x	x				x		x		x		allow	reduce	broad	group	yes	in person	FRM
Expert panel (participatory)	Technique	Expert Panels are groups of people dedica	short	participatory se	x	x		x	x		x		x		x		allow		narrow	group	yes	in person	
Focus group (participatory)	Technique	Focus groups are usually conducted by a re	short	participatory se	x	x	x	x	x				x		x		allow	reduce	narrow	group	yes	in person	FRM
Groupware (participatory)	Technique	Groupware is the use of computer softwar	throughout	participatory setting			x					-	-		x		allow		broad	group		online	FRM
Participatory workshop techniques	Technique	Creative techniques that can be used in a	short	participatory te	x	x	x	x	x				x		x		allow		broad	group	yes	in person	
Futures Polygon	Technique	probability of occurence of the future whe	short	probability ma	x				x			x	x			x		reduce	narrow	group	yes	in person	FRM
Trend Impact Analysis	Technique	Trend Impact analysis (TIA) is a tool to est	short	probability ma	x		x	x		x		x				x	allow		narrow	group	yes	in person	FRM
Morphological Analysis	Technique	Morphological analysis (MA) investigates	medium	scenario matrix	x		x	x	x	x		x				x	allow	reduce	broad	group	>> time	in person	FRM
GBN matrix	Technique	The matrix is based on two dimensions of	short	scenario matrix	x		x	x	x				x			x	allow	reduce	broad	group	yes	in person	
Field Anomaly Relaxation	Methodology	Field Anomaly Relaxtion (FAR) is a four-st	medium	scenario matrix	x		x	x	x				x			x	n/a	n/a	broad	group	>> time	in person	FRM
In-depth interviews	Technique	In-depth interviewing is a qualitative rese	short	survey	x	x	x	x					x		x		allow		narrow	one-to-one		in person	
Semi-structured interviews	Technique	As opposed to closed surveys with fixed qu	short	survey	x	x	x	x					x		x		allow		broad	one-to-one		in person	
Survey	Technique	A questionnaire is distributed or made ava	short	survey	x	x	x						x		x			reduce	broad	group		in person/online	
Delphi Techniques	Technique	The Delphi technique uses a series of cons	variable	survey	x	x	x	x	x	x	x	x	x			x		reduce	broad	group	yes	in person/online	FRM
Causal Loop diagram	Technique	A causal loop diagram (CLD) is a causal dia	short	system dynami	x	x	x		x			x	x	x		x		reduce	broad	both	yes	in person	
Fuzzy Cognitive Mapping	Technique	Fuzzy Cognitive Mapping (FCM) is a tool to	short	system dynami	x	x	x		x			x	x	x	x	x		reduce	broad	both	yes	in person	
Group model building	Technique	Group Model building are facilitated sessi	short	system dynami	x	x	x		x			x	x	x		x		reduce	broad	group	yes	in person	
Systems dynamics	Technique	System dynamics (SD) is an approach to ur	short	system dynami	x	x	x	x	x			x	x	x		x		reduce	broad	both	yes	in person	FRM
Bayesian network	Technique	A BN consists of two key components: (i) a	medium	system dynami	x	x			x	x				x		x		reduce	broad	both	yes	in person	
Science and Technology Roadmapping	Technique	Roadmapping is a method which outlines t	medium	timeline		x		x	x		x	x	x			x		reduce	narrow	group	yes	in person	FRM
Substitution Analysis/ Fisher-Pry Analysis	Technique	Substitution analysis is a mathematical te	short	timeline	x		x	x				x				x		reduce	narrow	both	yes	in person	FRM
Technological Sequence Analysis	Technique	Technological sequence analysis is a tool t	short	timeline		x			x	x		x				x		reduce	narrow	both	yes	in person	FRM
Relevance Trees	Technique	Relevance trees is an analytic technique th	short	tree diagram	x		x	x					x			x	allow		broad	both	yes	in person	FRM
Heuristic Modeling	Technique	Heurtistic modeling consist of the use of (s	medium	modeling & sim	x		x		x	x		x	x		x	x	allow		broad	group	yes	in person	FRM
Visioning	Technique	Visioning is the process of creating a serie	medium			x		x	x				x		x		allow		broad	group	yes	in person	FRM
Wild Cards	Technique	Wild cards are low-probability, high-impac	medium		x			x				x	x		x		allow		broad	group	yes	in person	FRM
Genius Forecasting	Technique	Genius Forecasting is an activity carried ou	short		x			x	x				x		x		allow	reduce	narrow	individual	yes	in person	FRM
Multiple Perspective	Technique	Multiple perspectives: Technical (T), Orgar	short		x	x	x	x	x				x		x		allow		broad	group	yes	in person	FRM
Science fiction	Technique	Science Fictioning (SF) is an activity that de	variable		x		x	x				x	x		x		allow		narrow	group	yes	in person	

Figure 2. Database of co-production techniques

The selection of suitable techniques is inherently linked to the project goal, scenario content and degree and form of stakeholder involvement (van Notten et al., 2003). These variables lay the foundation for the selection of the co-production techniques. This chapter describes a selection of questions to guide the compilation of techniques that together can form the scenario methodology. Although, we recommend following this step-by-step approach, it is also possible to select possible techniques that meet just one specific criteria of interest.

Table 4. Overview of main characteristics of the co-production tecnique employed. These are also the main entry points of the database.

General characteristics of co-production technique	
Activity Intensity	*single-step (technique), holistic (methodology), overarching (philosophy)*
Time Duration	*Short (hours), medium (days), long (weeks, months)*
Project goals and scenario stages	
Scenario perspective	*Explorative (What could happen?) / Normative (What should happen?)*
Stage	*Understanding/developing scenarios/decision making*
Stage: Developing scenario specific	*Generate/Integrate/Consistency*
Scenario content generation	
Information solicited	*quantitative/qualitative*
Way of knowledge generation	*creative/evidence-based*
Ambiguity	*Allow (convergent) or reduce (divergent)*
Degree of engagement	
Type of stakeholders	*narrow / broad participation*
Participants	*Individual vs. group activity*
Workshop viability	*One day workshop/multiple activities*
Engagement	*In person / online /desk analysis*

General characteristics

The database distinguishes techniques, methodologies and overarching activities. The definition of methodology and techniques for scenario development are also often used interchangeably. For scenario development, a combination of techniques is often used. The selection and arrangement of various techniques forms the methodological framework of the scenario development process. A methodology thus focuses on the various steps for carrying out the process and technique focusing more in the particular way in which the steps are carried out (Bishop et al., 2007b). The third group, overarching activities, do not refer to specific techniques nor methodologies but describes a deeper level of scenario development knowledge. It describes different layers of knowing that could underlie scenario development and takes a more philosophical point of view.

Selected method should reflect the project goals and scenario stages

What is the scenario perspective?

The first selection criteria to find suitable techniques is related to the type of scenario to be developed. Foresight techniques can be used to develop exploratory scenarios, to answer the question: '*What can happen?*' (cf. above) while other techniques can be used to develop scenarios to answer the question *'What should happen?*'. Some techniques could be applied both for explorative and normative scenario development, which is of particular importance since in many real cases climate change scenarios contain both aspects.

What is the stage of the scenario development process?

The different techniques should assist in reaching the purpose of the various phases of the scenario building process. Understanding the phases in scenario development process can guide in the selection of techniques. Various studies have looked into the phases of scenario development (Kok et al., 2014, Bishop et al., 2007a; Börjeson et al., 2006; Popper, 2008a). Kok et al. (2014) recognizes three stages 1) identifying the main concerns about future developments; 2) selecting key uncertainties and driving forces; and 3) drafting of the actual stories. Börjeson (2006) distinguish three more general phases for scenario development: *generating, integrating and consistency*. Co-production techniques can be grouped around these phases: 1) Generating techniques for generating and collecting ideas, knowledge and views regarding some part of the future, and common data gathering; 2) Integrating techniques integrate parts into wholes, it includes using models based on quantitative assessments of probability or relationship; and 3) Consistency techniques ensure consistency among different forecasts. Popper (2008) further distinguish the generation phase into *exploration, analysis* and *anticipation*. We note that these authors' stages overlap, but are neither consistent the activities covered nor the parsing of those activities. We recognize three main stages that encompass these activities as well as others: 1) Developing a mutual understanding of the system under exploration, 2) Developing and refining scenarios, and 3) Using scenario results to support decision making. Based on these various steps in scenario development, co-production techniques can be selected that fit will with the purpose of the envisioned outcomes. Since methodologies describe a whole scenario development process, they often include all the various stages of the development process.

Selected method should reflect envisioned scenario content generation

What type of information will be used?

Based on the expected project goals and/or available data, techniques can be selected that focus more on quantitative information, qualitative information or techniques that aim to connect qualitative data with quantitative data.

Qualitative information to develop scenarios can be employed where the key trends or developments are hard to capture in variables and simplified indicators, or where such data is not available. In general, these techniques allow for more creative, free thinking and for representing the views and complexity of many different interests that are difficult to capture in quantitative elements (van Vliet et al. 2012).

Techniques that work mainly with quantitative information place greatest reliance on representing scenarios numerically. Quantitative techniques are useful to illustrate storylines and to contextualize the scenarios for decision-making. Although developing quantitative scenarios has many advantages, their use can reduce the transparency of scenario outputs and/or require certain simplification that decreases to capture certain complexity of the scenario.

A third group that can be distinguished are semi-quantitative techniques. Semi-quantitative techniques can serve as a bridge between storylines (qualitative) and models (quantitative). Linking the storylines and models can generate added value by i) Increase consistency of storylines, ii) providing a tool to visualize the spatial consequences of storylines; and iii) to create integrated scenarios (Giaoutzi and Sapio, 2012). Various (semi-quantitative) techniques exists to link qualitative judgement to quantitative models in the scenarios. Despite these techniques, it remains challenging to adequately link storylines with models.

How will knowledge be generated?

This selection is closely related to the type of information but is not always one-to-one relation. Based on the scenario objectives, co-production techniques can be selected that have a creative or evidence-based approach. Creativity refers to the mixture of original and imaginative thinking (Popper 2008). Creative co-production techniques enables creative thinking, to include broader perspectives and multiple viewpoints on how the system under consideration could work. These techniques highly benefits from inventiveness and ingenuity of skilled individuals, such as science fiction writers, artists or the inspiration that emerges from groups of people involved in brainstorming sessions.

Evidence-based approach recognizes that it is important to attempt to explain and/or forecast a particular phenomenon with the support of reliable documentation and means of analysis of, for example, statistics and various types of measurement indicators (Popper 2008). They can be useful to develop trends when sufficient data is available. They are also used to substantiate options addressed in normative scenarios.

Reduce or allow ambiguity

Co-production techniques can inspire to open up and allow to have various interpretations of the system under considerations. These techniques encourage divergent thinking. This is often useful in the initial phases of scenario development to gather as much as possible knowledge and perspectives on system under considerations. Techniques to reduce ambiguity aims to bring various interpretations together and integrate information. It can be a second step in scenario development and often used in the final step on decision making.

Use methods adapted to the time and means available and desired degree of engagement

Who are the participants that co-produce the scenarios?

Integration of both experts and stakeholders requires a transdisciplinary approach. Interdisciplinary studies are co-producing knowledge with experts from particular research domains, while transdisciplinary research involves experts from different unrelated disciplines as well as a broader range of participants, such as user-groups and the general public (Tress et al., 2005). Narrow participation (interdisciplinary) focuses on co-producing scenarios with 'experts', while broad participation (transdisciplinary) engage range of stakeholders. Transdisciplinary research aims to bridge traditional boundaries, both between disciplines and between academia and practice, thereby creating new knowledge and perspectives around a common question. Transdisciplinary approach additionally seeks to create a new, unified direction with a focus on solving problems, engaging a broad range of stakeholders outside academia (Takeushi, 2014). In general, creative and qualitative co-production techniques are more suitable to capture all this information in knowledge when the range of stakeholders is broad. Some co-production techniques are only suitable when the participants have a high level of expertise.

Time and means available

The method selection should be adapted to the time and means available. This may be affected by resources such as: project budget, availability of expertise, political support, technological and physical infrastructure (Popper 2008). The techniques for scenario development can involve individuals working alone or groups of varying membership features working within a single workshop or over the course of several months. The selection of development method should reflect the complexity of the questions asked, which may demand different levels of engagement, and these must accommodate the constraints of the participants.

The methodological framework should take into consideration stakeholder preferences regarding time commitment. A co-production process should a) balance stakeholders' time commitment with maximizing stakeholder involvement in the process; b) but providing enough time to deal with the challenging nature of the thinking involved in building scenarios for research; and c) providing enough time for stakeholders to develop trust and a shared understanding of the problem (McBride et al., 2017). While workshops are very useful for developing trust and shared understanding of the problem, they are resource and time intensive and are therefore often alternated with other techniques (interviews, Delphi method, focus groups) to minimize stakeholders' time commitment.

Selected method should reflect the desired level of social learning

Since participatory scenario development includes structured group processes (Kok et al., 2007), methods can be selected based on the phase a group is in (Gordijn et al., 2018). Both product-oriented scenarios (knowledge generation) and process-oriented scenarios, will benefit if selected techniques consider group processes and learning experiences of the people involved. Depending on the co-production perspectives, the use of co-production can also reflect the desire to build capacity, foster cooperation between stakeholder groups, consensus building and/or improve social learning. The database does not include specifically techniques to cover social learning. In general, when motivation of co-production is focusing on learning processes, the use of using interactive, group exercises and techniques that focus on the various learning phases within the group are essential. Content oriented scenarios are more guided by the various phases of a scenario development.

3.4. Co-Production in climate scenarios

The study of (Bremer and Meisch, 2017) analyzes papers where co-production is used for climate research. They found that most papers are concerned with climate change adaptation (74%), another 8% are equally concerned with adaptation and mitigation, and only 2% have a focus on mitigation. The remaining 16% of the papers deal with other more conceptual issues. Bremer and Meisch (2017) hypothesize that *"As co-production is about creating meaningful knowledge for particular contexts of action, it might appeal more to people interested in adaptation [at a regional and local level]. Yet, basically, there seems to be no reason why co-production should not be interesting for mitigation research."*

3.4.1. Role of co-production in socio-economic scenarios

Socio-economic scenarios can be constructed in various ways and a variety of approaches may be combined (Abildtrup et al., 2006). Socio-economic scenarios exercises should both look at "how does the world work' and "how could the world work". The scenario development practice should therefore enable creative thinking, to include broader perspectives and multiple viewpoints on how the system under consideration could work.

Often the underlying drivers of socio-economic development pathways, (i.e. social values, governance institutions, political stability, environmental awareness) are defined through expert judgement, resulting in qualitative narratives (storylines). Quantitative assessments such as population growth and economic activity, are often based on modelling (Abildtrup et al., 2006).

The Story and Simulation (SAS) (Alcamo, 2008) methodology can be used to develop the narrative storylines and link to dynamic models in an iterative procedure. Stakeholder panels consisting of the relevant actors commonly develop the stories, and models are developed and applied by experts. The two separately-developed products are iteratively revised to increase internal consistency.

3.4.2. Role of co-production in emission and climate scenarios

The development of both emission scenarios and climate scenarios are based on highly complex, quantitative models. These scenarios are generally not co-produced because the determinants are mathematical and statistical in nature. However, for the development of various (national) climate scenarios, climate scenario end-users can be consulted to better understand how the climate scenario information is used by different sectors of society. Climate information often remains unused because it is seen to be too complex, not sufficiently relevant or unusable (Skelton et al., 2017). To narrow this 'usability gap' (Lemos et al. 2012), co-producing climate information might help to improve the salience of the climate scenarios. Although this is not co-production of climate scenarios, this step can be described as co-production of climate information (Skelton et al., 2017), cf. the two perspectives of co-production in SENSES in section 3.1.1.

3.4.3. Role of co-production in mitigation scenarios

Global mitigation scenarios are based on complex model and developed within the IAM community and are generally not co-produced. Decisions about mitigation pathways can be made by weighing the requirements of different pathways against each other. The range of possible measures should suit the system under consideration (spatial scale and/or sector) and comply with the national mitigation targets. National mitigation pathways should look at technical and economic feasibility, synergies and tradeoffs of policy measures and the social acceptability of potential pathways (e.g. nuclear power, wind farms). The pathways involve a range of synergies and tradeoffs connected with other policy objectives such as energy and food security, energy access, the distribution of economic impacts, local air quality, other environmental factors associated with different technological solutions, and economic competitiveness. These trade-off are area dependent. Also the contribution of different countries to global climate mitigation is directly related to the formulation of international climate policies, such as Kyoto Protocol and Paris Agreement. The contributions that each individual country should make in order to achieve the worldwide Paris Agreement goal are determined by all countries individually and called "nationally determined contributions" (NDCs). In terms of scenario development it involves backcasting scenarios to define pathways to reach a certain goal.

Development of global and national mitigation scenarios requires high level of expertise and analytical techniques. Quantitative model-based mitigation scenarios are generally developed by technical experts and their analysis is largely dominated by techno-economic considerations. Limiting global temperature rise to 1.5°C requires far-reaching transformations in human societies, from the way that we produce and consume energy to how we use the land surface (Clarke et al., 2014). In order to generate scenarios that also consider stakeholder preferences, participative approaches to scenario development could potentially be used. In particular, to increase public support in local mitigation scenarios the preferences and social acceptance of citizens could be included.

Participatory approaches can also assist in the deliberation of mitigation scenarios. Actors within the systems are increasingly driven by the need to meet challenging carbon emission reduction goals. This implies radical and disruptive changes to current systems, to be achieved whilst maintaining ‘secure’ supplies and meeting ‘reasonable’ service demands at ‘affordable’ costs. The nature of these changes and what different actors judge to be secure, reasonable and affordable is highly contentious (Foxon et al, 2010).

Examples of participatory mitigation scenarios exists (e.g. Germany, South Africa, UK), but implementation and literature is limited. Mitigation scenarios still have a strong top-down approach. However, developing participatory mitigation strategies could encourage increased awareness of different perspectives among stakeholders, confidence building between stakeholders and ministries, and improve chances to implement mitigation measures due to joint development with stakeholders.

3.4.4. Role of co-production in adaptation scenarios

Adaptation scenarios are normative policy scenarios to identify interventions to adapt to extreme events and climate change. Due to the varying severity and nature of climate impacts between regions, most adaptation initiatives will be taken at the regional or local levels.

Various approaches to develop adaptation scenarios have been developed. A top-down approach, based on large-scale biophysical impacts analyses, focuses on quantifying and minimizing uncertainty by using a large range of scenarios and different climate and impact models. The main problem with this approach is the propagation of uncertainties within the modelling chain. Due to the large uncertainties and the focus on large-scale biophysical impacts others prefer a bottom up approach (Dessai and Hulme, 2004; Dessai et al., 2009). This approach usually focuses at the local level where plans are being developed on which climate change could have an impact. This bottom-up approach focusses much more on reducing vulnerabilities, often at local scale, by developing resilient systems.

4. Existing scenarios on global scale

In Chapter 2 we have already introduced the *types* of climate change scenarios that are considered for the SENSES project. This chapter gives an overview of the actual scenarios on the global scale that are chosen to be integrated in the co-production of scenario knowledge with stakeholders.

In the following we will explain the scope of the chosen scenarios for the co-production exercise and put them into a global context. Again, with climate change scenarios we mean

- climate change projections,
- impact projections and
- (socio-economic) mitigation scenarios.

4.1. Simulation rounds as common organization scheme

The production of the considered climate change scenarios is organized in individual simulation rounds, mostly steered by a set of specific scientific questions. The overview tables (see table 5-8) below summarize all respective simulation rounds for the scenarios relevant to the SENSES project.

The actual outcome of the simulation rounds is then characterized by *factsheets, which can be found in APPENDIX I*. Hereby, great emphasis is applied that factsheets are written from a potential user's perspective, summarizing the most important facts for alleviated access. A factsheet briefly summarizes

- the guiding scientific questions
- the results and key insights
- the source database, where the raw data can be found
- publications
- policy briefs *[optional]*

The benefit of this formalized approach is manifold.

- Using the same template for each scenario study makes them easier comparable for a user. Further, describing each study in the same format supports orientation and comprehension in this diverse spectrum of studies.
- The essential research questions and outcomes can be quickly grasped. They are summed up in a very high-level, abstract manner, no details like technical approaches

or similar are allowed; only the questions to be answered and the results through the eyes of an external person, i.e. a stakeholder.
- The factsheets are stand-alone and can be used in a modular way also allowing to sutilize them in different contexts outside this document.

4.2. Scope of climate change scenarios

Despite the fact that the climate change modelling community has stepped into a new era where the three – climate change, climate impact projections and socioeconomic mitigation scenarios – are increasingly linked through common protocols and intercomparison projects, there are still distinct differences. The ensemble of climate change scenarios and projections all have their respective history and development. Below an overview of the essential characteristics of these scenario types is given.

4.2.1. Climate change projections

For the SENSES project we will focus on the Coupled Model Intercomparison Project (CMIP) in terms of climate change projections. CMIP is a collaborative framework with the aim to understand climate change. The projections for CMIP are computed by general circulation models. CMIP started in 1995 by the Working Group on Coupled Modelling (WGCM) of the World Climate Research Programme's (WCRP). For SENSES, we will restrict the projections to those of global scale by CMIP.

Simulation rounds of CMIP

CMIP simulation rounds are called 'phase'. Since 2013 climate change projections from phase five are available and accordingly, the scenarios used in SENSES will be from CMIP5. CMIP collects model output of about 40 global climate models that assume greenhouse gas concentrations according to four different emission scenarios (RCP2.6- RCP8.5).

Content of CMIP

A main aim of the CMIP5 round is to improve understanding of climate (change) itself, to provide estimates of future climate change. By projecting potential changes the CMIP exercise provides data to those considering possible consequences through climate change. The data comprises meteorological quantities (temperature, precipitation, air pressure, wind, and radiation), oceanic quantities, and land surface quantities (evapotranspiration, vegetation) and can be taken as input for the projections by impact models (e.g. ISIMIP, see below).

CMIP5 promotes a standard set of model simulations for:

- Evaluation of the realism (validation) of the models in simulating the recent past
- Projections of future climate change. Two time-scales are considered, near term (up to about 2035) and long term (up to either 2100 or to 2300)
- Evaluation of the factors responsible for differences in model projections (e.g. key feedbacks involving clouds and the carbon cycle)

Futher alternatives

For the interested reader, it should be added that there exists a simplified pendant to CMIP, called the Atmospheric Model Intercomparison Project (AMIP) which focusses on the atmospheric model without the added complexity of ocean-atmosphere feedbacks in the climate system. Further, as a general drawback of global climate models it should be mentioned that they provide information on rather coarse scales, which in turn can cover strongly differing landscapes (aggregating mountainous and coastal plains in one patch). These landscapes could have strong differences in potential for floods, droughts or other extreme events. To enhance resolution for more detailed questions Regional Climate Models, can help. Here these models are only applied over a subset of the area for more detailed impact and adaptation assessment and planning. The preeminent project for higher resolution climate modelling on smaller scales is the CORDEX project. But, as mentioned above, the SENSES project will focus on global climate change projections by CMIP5.

4.2.2. Climate impact projections

For climate impact projections a multitude of research projects can be named:

- AgMIP | Agricultural Model Intercomparison and Improvement Project
- Aqueduct Water Stress Projections: Decadal Projections of Water Supply and Demand Using CMIP5 GCMs
- WaterMIP
- BRACE | Benefits of Reducing Anthropogenic Climate change
- HAPPI | comparison of impacts between a 1.5° and 2°C warming
- HELIX | High-End cLimate Impacts and eXtremes
- IMPRESSIONS | Impacts and Risks from High-End Scenarios
- ISIMIP | Inter-Sectoral Impact Model Intercomparison Project
- TRENDY | Trends in net land carbon exchange over the period 1980-2010

For SENSES we will focus on the impact projection data by the ISIMIP project. ISIMIP aims to improve global and regional risk management by advancing knowledge of the risks of climate change through integrating climate impacts across sectors and scales in a multi-impact model framework. Currently, it unifies most impact models in its intercomparison project.

Simulation rounds of ISIMIP

ISIMIP is organized into simulation rounds, which are guided by a focus topic. For each round, a simulation protocol defines a set of common simulation scenarios based on the focus topic. Participating modelling groups drive their simulations with a common set of climate input data, and socio-economic data (in some cases unique to one sector) which ensures cross-sectorally consistent impact simulations. Participation is open to all models capable of following the simulation protocol.

Content of ISIMIP

The cross-sectoral and cross-scale consistency of the impact model simulations in ISIMIP is achieved via a single, common simulation protocol that is carefully designed to ensure comparability across the sectors and scales. ISIMIP provides a global archive of consistent impact projections until 2100 or 2300, covering the sectors agriculture, water, biomes, health and coastal infrastructure sectors. Other sectors that are considered include fisheries, energy, permafrost, biodiversity, forestry, and health.

The selection of ISIMIP-specific simulation tasks is guided by a focus topic, an overarching research theme for each ISIMIP simulation round. Given that the focus topic will change with each round, broad thematic coverage will be achieved over time.

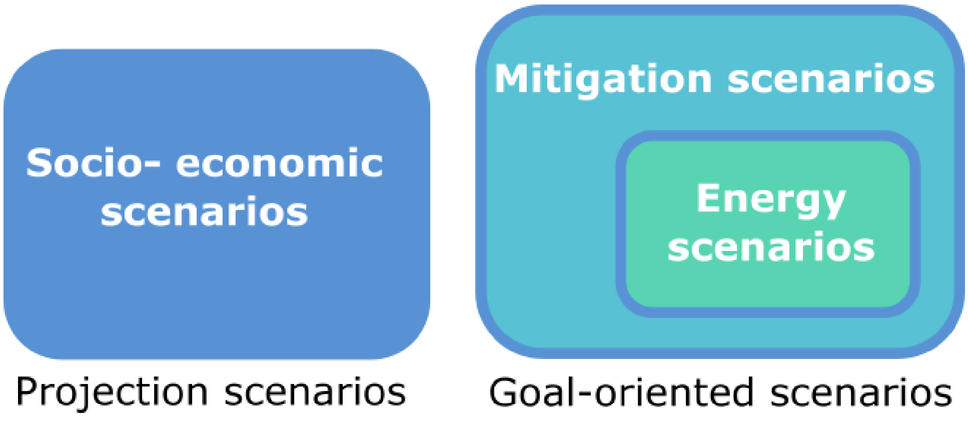
4.2.3. Socio-economic and mitigation scenarios

Socio-economic and mitigation scenarios cover societal, technical, cultural and economic developments. Understanding the implications of a regime pursuing a specific climate target (e.g. max 1.5°C global warming) and associated policies is facilitated by mitigation scenarios. They belong to the group of *goal-oriented scenarios,* as introduced in *Chapter 2.* Also, *projection scenarios* in terms of pure socio-economic scenarios have relevance for this, like the SSPs (Socio-economic pathways). They describe possible futures in terms of population, economic activity, culture, and other socioeconomic factors but leave out a specific climate target (see Figure 6). Decisive parameters of these projection scenarios allow to explore the impact of concepts like lifestyle, technology choices, etc.

A subset of mitigation scenarios would be energy scenarios with an obvious focus on energy, having a reduced set of economic and social aspects. Energy scenarios have a long tradition. In fact, the company Shell started since the early 1970s to use scenarios as response to the oil crisis (Herbst et al. 2012)[2] and even already 1950 macroeconomic energy models were used to support the development of the industrial economy. In the meantime, all of them also include the aspect of climate change mitigation. As examples for the biggest actors for energy scenarios the IEA (International Energy Agency), Shell, BP, Exxon Mobile, EIA (U.S

[2] Herbst, A. et al. Introduction to Energy Systems Modelling. Swiss J Economics Statistics 148, 111–135 (2012).

Energy Information Administration) can be named. For an extensive review of existing energy scenarios with a focus on mitigation please refer to Paltsev (2014)[3].



For SENSES we will focus on socio-economic and mitigation scenarios from a specific community, namely the *IAM community*. With their integrated assessment (IAM) models they are set up more broadly towards society, economy, and nature. They aim to provide policy-relevant insights into global environmental change and sustainable development issues by providing a quantitative description of key processes in the human and earth systems and their interactions. The modelling is integrated, i.e. information from many scientific disciplines is used and both the human and earth system are included. The assessments serve to create useful information for decision-making, even in case of large uncertainties. Since 2007 their importance has grown strongly, e.g. as they were asked by the IPCC (Intergovernmental Panel on Climate Change) to lead the development of new scenarios and have even increased their contribution in this assessment process since then. The energy scenarios of actors like the IEA, Shell, etc are not included in the IPCC process because their outlooks are not in peer-reviewed literature as required by IPCC for inclusion in its assessment.

Simulation rounds of the IAM scenarios

In the IAM community the simulation rounds are called studies, where specific scientific questions are addressed. There are no regular time periods when these studies are launched.

[3] Paltsev Sergey. Energy scenarios: the value and limits of scenario analysis. *WIREs Energy Environ.* 2017, 6: null. doi: 10.1002/wene.242

Content of the IAM scenarios

Most IAMs relate to the goal of not surpassing a maximum global mean temperature increase, either 2° or 1.5°C. Integrated Assessment Models include representations of climate, using models and data generated by the climate modelling and research community, and Earth systems, using models and data generated by the impacts, adaptation, and vulnerability (IAV) modelling and research community. Overarching topics (also summarized in the factsheets) that are investigated by IAM scenario studies are

- the role of individual policies
- timing of mitigation action
- the role of sectors and specific technologies and their availability
- the role of individual emissions drivers
- regional scenario studies

The detailed output of IAM scenarios is manifold. However, under the most important output parameters the following can be named:

- energy & land use
- emissions
- investments
- tech deployment
- prices and
- macro-economic impacts

The complex topic-questions answered by the individual scenario studies are summarized in the factsheets, see Annex 1.

Additionally, the IAM scenarios can in turn also be used as input. For example, IAMs provide to the climate modelling community emissions scenarios of greenhouse gases (GHGs), short-lived species (SLS) and land-use projections. IAMs provide to the IAV modelling community projections of socioeconomic states, general development pathways, and the multiple stressors of climate change[4].

4.3. Overview of simulation rounds

[4] Janetos et al. 2009, Science Challenges and Future Directions: Climate Change Integrated Assessment Research. Report PNNL-18417 - GCIS. Available at: https://data.globalchange.gov/report/pnnl-18417. (Accessed: 7th December 2018)

4.3.1. Climate change projections

Table 5. Climate Change Projections

Study	**Documented in**
CMIP5	https://esgf-data.dkrz.de/search/cmip5-dkrz/

4.3.2. Climate impact projections

Table 6. Impact Projections

Study	**Documented in**
ISIMIP Fast Track	https://esg.pik-potsdam.de/search/isimip-ft/
ISIMIP2a	https://esg.pik-potsdam.de/search/isimip2a/
ISIMIP2b	https://esg.pik-potsdam.de/search/isimip2b/

4.3.3. IAM Scenarios

Table 7. Multi-Model Studies

Study	Documented in
ADVANCE synthesis	Advance database
AMPERE (Assessment of Climate Change Mitigation Pathways and Evaluation of the Robustness of Mitigation Cost Estimates)	Own database / AR-5 database
CD-LINKS	1.5° database
EMF 22 (Energy Modeling Forum 22)	AR-5 database
EMF 27 (Energy Modeling Forum 27)	AR-5 database
EMF-30	1.5° database
EMF-33	1.5° database

Global Energy Assessment	AR-5 database
LIMITS (Low Climate Impact Scenarios and the Implications of required tight emissions control strategies)	AR-5 database
SSPs	1.5° database
RoSE (Roadmaps towards Sustainable Energy futures)	AR-5 database

Table 8. Single-Model Studies

Study	Documented in
IIASA LED	1.5° database
IMAGE 1.5	1.5° database
IEA ETP	1.5° database
UBA (EMC)	Selected in 1.5° database
PIK CEMICS	1.5° database
IIASA GGI	GGI database
PIK PEP1p5	1.5° database
UBA (SMP)	1.5° database

5. Existing scenarios in the Netherlands

This chapter provides an overview of existing scenarios in the Netherlands on national scale, and regional scale scenarios relevant for the Dutch case study: Overijsselse Vecht. It describes the main characteristics, the development of the scenarios, and its relation to the RCP x SSP architecture. Information is obtained from articles, grey literature and interviews with experts in the field.

5.1. Overview of scenarios in the Netherlands

Over the past decades, the development and use of scenarios have evolved in the Netherlands. Scenarios have been used in the Netherlands already since the 1950s for water management planning (Haasnoot and Middelkoop, 2012). National scale scenarios for the Netherlands have been developed by governmental agencies and are being updated periodically (about once every 5-10 years). The main national explorative scenarios include KNMI'14 climate scenarios, WLO'15 socio-economic scenarios and delta scenarios (see table x). The socio-economic scenarios look ahead to 2050, the climate and delta scenarios have a time horizon up to respectively 2085 and 2100.

Next to a number of explorative scenarios, national normative scenarios have been developed. These normative scenarios consist of long-term visions that outlines the Dutch policy. These visions are elaborated with strategies using backcasting. Most of these types of scenarios have visions developed for 2030/2050.

For the region of the Dutch case study, the national climate and socio-economic scenarios have been downscaled to the regional level. Next to these scenarios, various regional scale scenarios exists. They mainly describe visions (normative) with a time horizon of 2030.

Table 9. Overview of Dutch scenarios

Theme	Name	Institute	Year	Scenario Type	Nr	Time horizon	Link to RCP/SSP	Output	Co-production
Socio-economics	*WLO2015*	*PBL and CPB*	*2015*	*Explorative*	*2*	*2030/ 2050*	*- final results compared to SSP architecture (SSP1 and SSP3/4)* *- use of SSP data for international developments and climate policy*	*Quantitative and qualitative*	*Yes*
Climate	*KNMI'14*	*KNMI*	*2014*	*Explorative*	*4*	*2050/ 2085*	*- Based on AR-5, CMIP5 models* *- compared to RCP 4.5, 6.0, 8.0* *- RCP2.6 NOT included*	*Mainly quantitative*	*Yes*
Climate	*High end climate scenarios*	*KNMI*	*2009*	*Explorative*	*2*	*2050/ 2100/ 2200*	*- based on AR-4*	*Mainly quantitative*	*no*
Water	*Delta scenarios*	*PBL, CPB, KNMI, Deltares, WUR*	*2013*	*Explorative*	*4*	*2050/ 2100*	*- include bandwidth Paris agreement* *- use of AR-5/CMIP5 models to bring 2013 version up-to-date*	*Quantitative and qualitative*	*Not clear*
mitigation and adaptation	*Climate agenda*	*Government*	*2013*	*Normative*	*1*	*2030/ 2050*	*- targeted to reach Paris agreement*	*Qualitative*	*No*
Adaptation	*Climate Adaptation strategy*	*Government*	*2016*	*Normative*	*1*	*2030/ 2050*	*- no direct link to RCP/SSP* *- targeted to reach Paris agreement* *- based on -> AR-5 model*	*Qualitative*	*Yes*
Mitigation	*Exploration climate goals (emission reductions)*	*PBL and ECN*	*2017*	*Normative*	*2*	*2030/ 2050*	*- no direct link* *- targeted to reach Paris agreement*	*Quantitative*	*Yes*
Energy (mitigation)	*Energy Agenda*	*Government*	*2016*	*Normative*	*1*	*2030/ 2050*	*- no direct link* *- targeted to reach Paris agreement*		*no*
Environmental vision	*Omgevingsvisie (NOVI)*	*Government*	*2019*	*Normative (vision)*	*1*	*2030/ 2050*	*- no link*		*no*
Economy	*Transition agenda*	*Government*	*2016*	*Normative*	*1*	*2050*	*- no link*		*no*
Water (adaptation)	*Dutch Delta Programme*	*Delta Programme Commissioner*	*2018 Since 2010 every*	*Normative*		*2050*	*- AR-5 /CMIP-5* *- Paris agreement*		*yes*

Theme	*Name*	*Institute*	*Year*	*Scenario Type*	*Nr*	*Time horizon*	*Link to RCP/SSP*	*Output*	*Co-production*
			year						
Nature, landscape and biodiversity	*Nature Outlook*	*PBL*	*2011*	*Normative*	*4*	*2040*	*- no link*	*- Qualitative*	*yes*
Climate	*Based on KNMI'14*	*-*	*-*	*-*	*-*	*-*	*-*	*-*	*-*
Socio-economics	*Based on WLO'15*	*-*	*-*	*-*	*-*	*-*	*-*	*-*	*-*
Regional Environmental Vision	*Omgevingsvisie Overijssel*	*Province of Overijssel*	*2017*	*Normative*	*1*	*2030*	*No direct RCP/SSP link*	*Mainly qualitative*	*no*
Water (adaptation)	*Room for the Vecht (programme)*	*Province of Overijssel*	*2010*	*Normative*	*1*	*2050*	*No direct RCP/SSP link*	*Qualitative and quantitative*	*Yes*
Energy (mitigation)	*Nieuwe Energie Overijssel*	*NEO, Province of Overijssel*	*2017*	*Normative*	*1*	*2023/ 2035*	*No direct RCP/SSP link*	*- quantitative*	*yes*

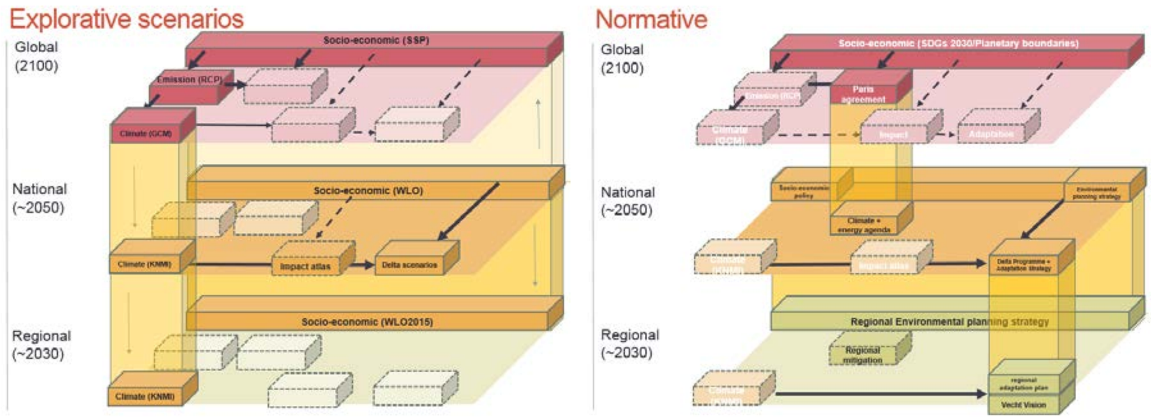


Figure 3. Overview of multiscale explorative and normative scenarios relevant for the Dutch case study. Some multiscale connections are well established which can be seen with the vertical connection. The horizontal arrows show connection between scenarios, with dashed lines weak connections.

5.2. National explorative scenarios

The main national explorative scenarios include KNMI'14 climate scenarios, WLO'15 socio-economic scenarios and delta scenarios. The main characteristics, the development of the scenarios and relation to the RCP x SSP architecture are described in this chapter. In figure x these national exploratory scenarios are mapped on RCP x SSP architecture. It provides an overview of the range of existing scenarios for the Netherlands.

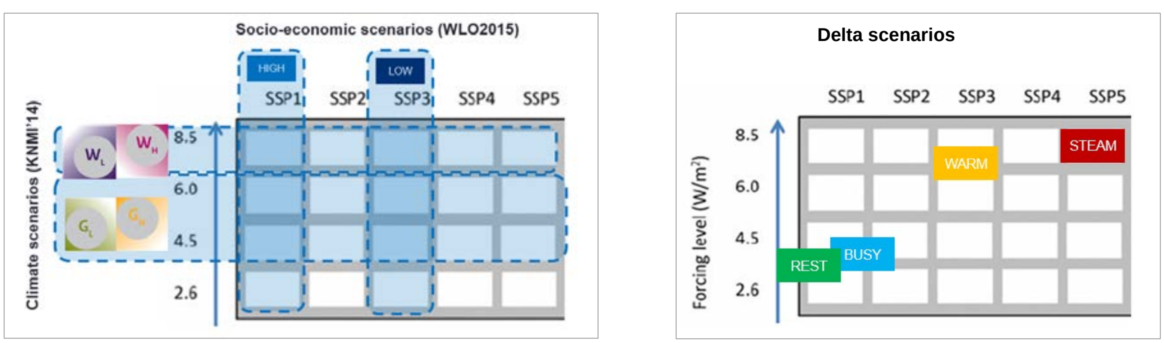


Figure 4. Socio-economic, climate and delta scenarios mapped on the RCP x SSP framework

5.2.1. Socio-economic scenarios

PBL (Netherlands Environmental Assessment Agency) and CPB (Netherlands Bureau for Economic Policy analysis) developed socio-economic scenarios for the Netherlands: *Nederland in 2030-2050: twee referentiescenarios – Toekomstverkenning Welvaart en Leefomgeving' (WL0215). (English: 'Netherlands in 2030-2050: two reference scenarios – Foresights of*

Prosperity and the Living Environment'). The two reference scenarios, 'low' and 'high' look ahead to the 2030s and 2050s. Scenario 'high' combines a relatively high population growth with a high economic growth of around 2% per year. In the 'low' scenario, a limited demographic development coincides with a moderate economic growth of around 1% per year.

In both scenarios, developments of the natural and built environment were investigated with a focus on four broad themes: regional development and urbanization, mobility, climate and energy, and agriculture. The scenarios describe a future situation assuming unchanged national policy. As such, the scenarios provide insights in future challenges and opportunities and build a framework for (future) policy. In addition to a general basis for policy development, the study forms a reference for area-specific policy scenario studies. The scenarios are updated once in a while, the previous national scale socio-economic scenarios were developed in 2006.

Brief narratives of the two scenarios:

Scenario high: *Scenario high describes a globalized world where international developments continue, including international trades and liberal markets. It assumes successful international collaboration, rapid technological developments and high economic growth. Energy prices are not hampered by geopolitical tensions. The GDP for all countries will increase with 2% due to technological and demographic developments. The world manages to make binding climate agreements as a result of which the temperature rise is limited to 2.5 to 3 degrees compared to 1990.*

Scenario low: *Scenario low describes a world with more international conflicts and tensions. International trust decreases, which hampers adoption of international agreements. There is less international trade, and a less liberal and globalized world. This also leads to less (technological) innovation and the overall world economic growth will decrease. Oil prices increase due to geopolitical tension.*

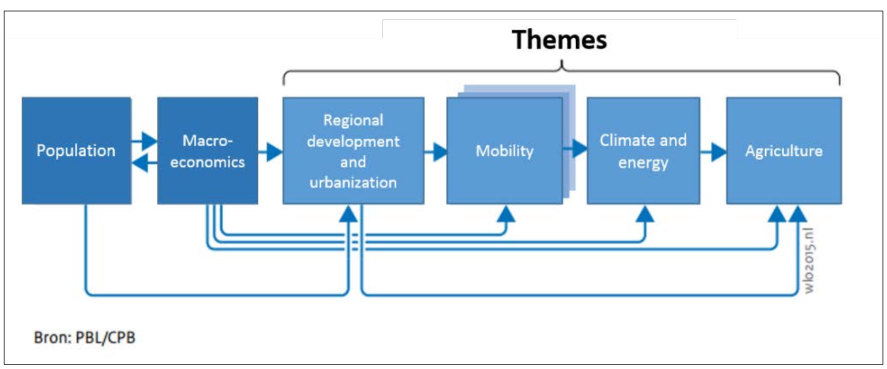


Figure 5. Themes and modules in the socio-economic scenarios

User needs for socio-economic scenarios

The ministries responsible for natural and built environment policies are the main and most important users of the scenarios (Ministry of Infrastructure and Environment, Ministry of Economic affairs and Climate Policy, Ministry of the Interior and Kingdom Relations). Based on their experiences with the previous socio-economic scenarios (WL02006, 2006) they have indicated their desires and needs. They highlighted the importance of integrated scenarios, and their desire to put more emphasis on the uncertainties. The ministries also requested calmer (moderate) scenarios that are easy to work with.

Development of scenarios

Based on the user needs, PBL and CPB have chosen to develop only two, calm scenarios without too much extremes. Working with only two scenarios has been experienced as positive in policy practice. The interpretation of the low and high scenarios is based on an analysis of the current state of affairs, developments in the past, literature research and insights from experts.

The scenarios consist of a modular approach. The scenarios were first developed in the demography and macroeconomics module. The output of these two modules is used as input for the four themes. The modular structure offers the possibility to make theme-specific explorations, and to explore relevant uncertainties per theme.

Relation to RPC x SSP architecture

The two scenarios cannot be linked one-to one to the SSP architecture. However, the quantitative data of the scenarios were compared with the SSPs. Only quantitative data were compared, not the storylines connected to these scenarios. The demographic development was selected as the most important criteria. Based on this approach, scenario 'High' is compared to the SSP1. Scenario 'Low' is in between SSP3 and SSP4.

Information from exogenous factors, such as (global) climate policies and population/GDP of other countries, is based on the Shared Socio-Economic Pathways (SSP) and the quantitative elaboration by the OECD (2013). For the 'High' scenario, country data from SSP1 scenario is used; the average of SSP3 and SSP4 is used for input data for the 'Low' scenario.

In the module 'climate and energy' international agreements play an important role. Within this theme, they specifically mention the use of input data from SSP1 information for scenario 'High', and SSP3 for scenario 'Low'.

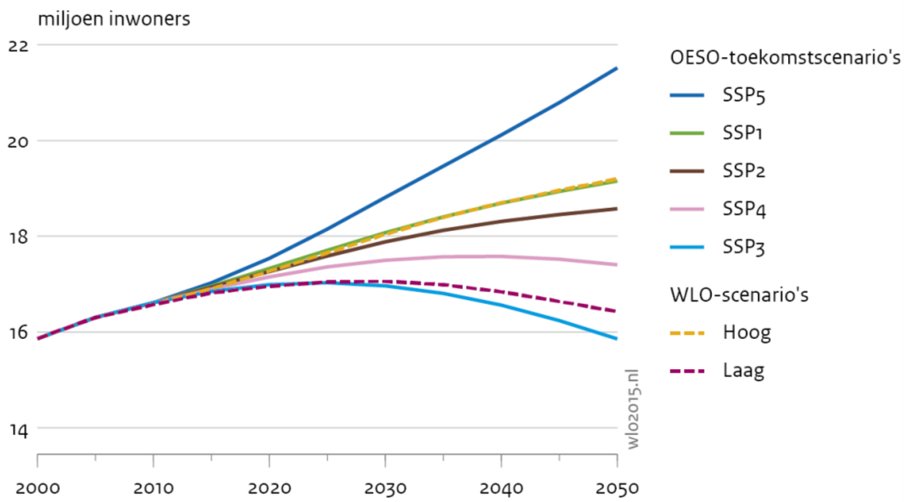


Figure 6. Population growth, form the WLO scenarios and OECD scenarios

Limitations

The WLO'15 scenarios have a number of limitations.

1. There are only two calm, moderate scenarios developed

   By developing only two calm scenarios, the scenarios might underrepresent the (many) fundamental uncertainties about future developments. By developing calm, policy poor scenarios, it confirms the existing state of affairs to a certain extent.
2. Limit the number of policy areas that were included

   Not all policy areas are covered and some areas are underdeveloped, for example the analysis of commodity markets, air quality issues, (regional) housing markets, nature and water are limited.
3. No foreign scenarios were developed

   This WLO did not develop international scenarios for other countries. OECD research (O'Neill et al, 2014, Kriegler et al., 2012) forms the basis for the interpretation of the international picture.
4. No extensive sector analysis was carried out

   The WLO follows approximately the same sector developments from previous WLO sector analysis or use information from other existing scenarios (national energy scenarios)

5.2.2. Climate scenarios

Climate scenarios on national scale are developed by the Royal Netherlands Meteorological Institute (KNMI). KNMI is the national data and knowledge institute for climate science. KNMI contributes to international climate research and represents the Netherlands in the Intergovernmental Panel on Climate Change (IPCC).

The KNMI'14 climate scenarios (KNMI, 2014) are the most recent climate scenarios available for the Netherlands. These scenarios translate the global findings in the IPCC 2013 report (AR5) to the situation in the Netherlands. The KNMI climate scenarios are updated from time to time. Previous climate scenarios include KNMI'06 (2006) and WB21 (2000). The next update is expected in 2021 and will be based on IPCC AR6 report.

The KNMI'14 climate scenarios consist of four scenarios and show the change for 2050 and 2085 compared to the climate in the period 1981-2010. The scenarios show a snapshot for these periods. Additional information on climate change interval are provided (see chapter tailor made climate information). The four scenarios differ in the extent to which the global temperature increases ('Moderate' and 'Warm') and the possible change of the regional air circulation pattern ("Low value" and "High Value"). Each scenario provides a consistent picture of the changes in 12 climate variables, including temperature, precipitation, sea level, and wind. The KNMI'14 scenarios are intended as a tool to support impact studies, to enable the consideration of climate change in decision-making processes and to develop adaptation options and strategies.

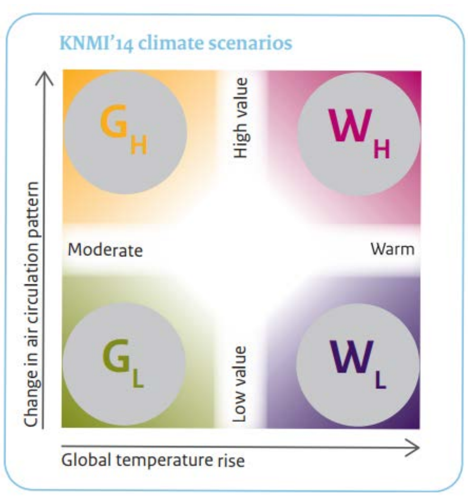


Figure 7. KNMI'14 climate scenarios. One axis depicting different values of the projected global mean temperature increase, and one axis expressing the response to an (uncertain) regional circulation response.

User needs climate scenarios in the Netherlands

The KNMI climate change scenarios (KNMI'06, KNMI'14) were constructed in response to a strong request from multiple stakeholders in the Netherlands, particularly in the water management sector. The development of the KNMI'14 scenarios included an assessment of user requests for climate information. The process benefitted from the experience that users have gained with the KNMI'06 scenarios. This experience allowed them to formulate clear and specific needs and requirements. An overview of the user requirements for climate information for professional use (climate impact studies, climate adaptation and to a lesser extent also climate mitigation in the Netherlands) is documented in the report of Bessembinder and Overbeek (2011)

According to van den Hurk (2014) the stakeholder consultation improved the relevance of the scenarios. Based on these consultations, variables were selected for which a wider community showed interest. Compared to KNMI'06, the KNMI'14 scenarios provide more variables, more spatial detail, spatial differentiation between coastal area and land inward, and information about natural variability.

Table 10. User requirements of climate scenarios. Information is based on interviews with key stakeholders that used the 2016 KNMI climate scenarios.

User requirements based on experience on the KNMI'06 scenarios. • *Need for more climate variables* • *more information on natural (year-to-year) variability* • *information on the relation between scenarios and observed trends* • *scenarios for 2030* • *more regional detail in the climate change information* • *sub-daily (hourly) extreme conditions* • *visual illustration of the manifestation of climate change and its possible impacts* • *time series associated with the scenarios.*

Development of scenarios

The climate scenarios for the Netherlands are based on observation data, the global climate models (CMIP-5), augmented with calculations performed using the KNMI Regional Climate MOdel for Europe (RACMO2). A principal components analysis was applied on all the CMIP-5 models, which indicated two main drivers of climate change in the Netherlands: global mean temperature and regional large scale air circulation. These drivers are used to distinguish the 4 scenarios (see figure x). Additional model calculations have been performed using the KNMI climate models EC-Earth (EC-Earth is also one of the CMIP-5 models). EC-Earth data were downscaled using the regional climate model RACMO2. All climate change scenarios have been evaluated against recent trends in the observations.

Co-production in climate scenarios

Extensive stakeholder interaction has taken place to understand the different perspectives and interpretations of the role of climate change in different sectors of society. During each stage of the KNMI'14 climate scenario development, users were involved. Regular workshops and newsletters informed the potential users about the construction process in an early stage. Information on user demands for climate information for professional use (impact, adaptation, mitigation) were collected. In separate meetings for policy makers and research institutes interactive sessions/workshops were held, which confirmed and detailed the main topics of concern of the stakeholders for a sustainable delta in the Netherlands.

Relation to the RCP architecture

Calculations of the KNMI'14 scenarios are based on RCP4.5, RCP6.0 and RCP8.5 scenarios. However, the RCP emission scenarios used by the IPCC cannot be linked one-to-one to the four KNMI'14 climate scenarios, because the KNMI scenario classification is based on the spread in climate model calculations, which in the short term contributes more to the different outcomes than the spread in greenhouse gas and pollutant emissions. Figure x shows how the global temperature increases for the KNMI'14 scenarios agree with the global temperature increase in 2050 calculated for the different emission scenarios. The G_L and G_H scenarios match the lower end of the scenarios RCP4.5 and RCP6.0. The W_L and W_H scenarios match the high emission scenario RCP8.5. For 2085, this relationship is the same. The lowest emission scenario, RCP2.6, was not used to develop the KNMI'14 scenarios. To describe the effect of this lower limit on climate change in the Netherlands an additional scenario is necessary, consistent with a strong worldwide reduction of the use of fossil fuels.

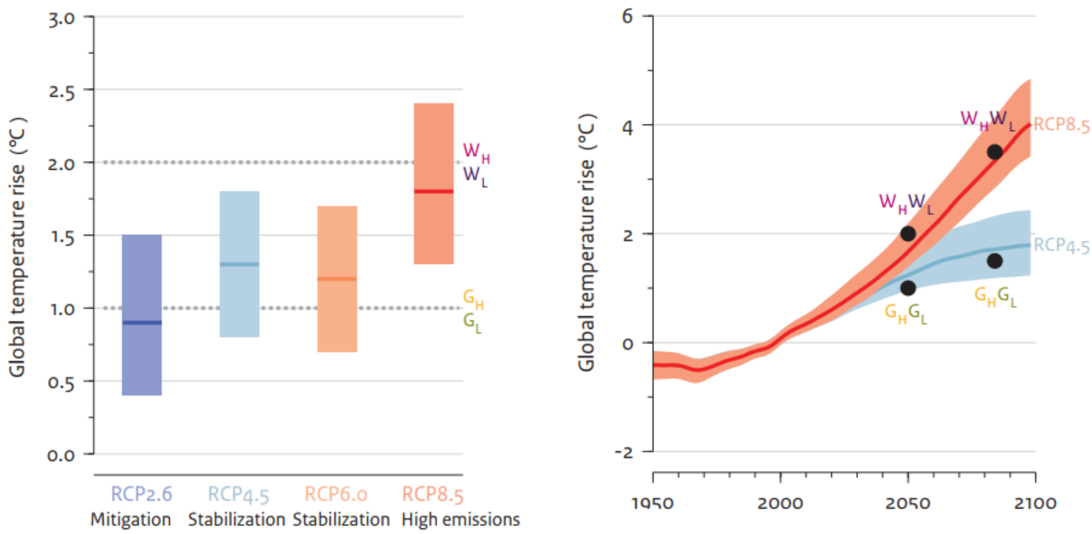


Figure 8. a) Global temperature rise around 2050, relative to 1981-2010, as adopted in the KNMI'14 scenarios (horizontal lines) and calculated for the four IPCC emission scenarios (RCPs; vertical bars for model spread, with a line for the central estimates). b) b) Global temperature rise relative to 1981-2010 based on climate model calculations performed for the IPCC 2013 report. Two different IPCC emission scenarios: RCP4.5 (stabilization) and RCP8.5 (high emissions). Coloured bands: model spread; lines: model means; dots: global temperature rise determined for the KNMI'14 climate scenarios for the Netherlands.

Tailor made climate information

KNMI'14 provides a general scenario framework, that includes an internally consistent set of model simulations for each scenario. This allows to tailor climate information for specific objectives. For many applications the information provided by KNMI'14 is still too general and additional tailoring of the scenarios is needed. The KNMI'14 scenario framework was designed to make this tailoring process easier than before, by generating an internally consistent set of explicit model simulations for each scenario. As such, the scenarios provide a reference to which a broad set of sectors- or area specific climate assessments can be related and compared. The option to further tailor the scenarios to the user needs increases the relevance of the scenarios. The report by Bessembinder and Overbeek (2011) provides additional information and examples on tailor made climate information.

To increase temporal detail, KNMI also developed the time series transformation tool. The aim of the time series transformation tool is to generate time series consistent with the KNMI'14 climate scenarios. The tool applies the changes in averages and variability for the selected KNMI'06 climate scenario and selected time horizon to a given historical time series for temperature or precipitation.

Extreme scenarios

KNMI scenarios provide outputs in changes in the mean climate, but also changes in the extremes such as the coldest winter day and the maximum hourly precipitation per year. However, the KNMI models EC-Earth and RACMO, are not well capable of representing non-hydrostatic effects that could result in extreme climate change and events. Therefore output from global climate models (EC-Earth) and Regional Climate Models (RACMO) give limited information on the occurrence of extreme events such as extreme precipitation, thunderstorms and fog. The development of extreme scenarios is beyond the scope of KNMI'14.

In 2009, the KNMI developed high-end climate scenario, to explore low probability/high impact scenarios. The scenarios describe plausible upper limits of sea level rises in 2100 and 2200. The assessment has been carried out at the request of the Dutch Delta Committee, to explore the high-end climate change scenarios for flood protection of the Netherlands. The assessment is based on insights from KNMI'06 and IPCC AR-4 report.

Limitations

1. The low-end emission scenario, RCP2.6 was not used to develop the KNMI'14 scenarios.
   - To describe the effect of this lower limit on climate change in the Netherlands an additional scenario is necessary, consistent with a strong worldwide reduction of the use of fossil fuels (might be covered by the next KNMI'21 scenarios).
2. Extreme events (scenarios) are not included

5.2.3. Delta scenarios

The delta scenarios are developed as part of the Dutch Delta Programme. The Delta Programme is working on an integrated strategy to prepare the Netherlands for the consequences of climate change. It concerns changes in river discharge, extreme precipitation, sea level rise, land subsidence and salinisation.

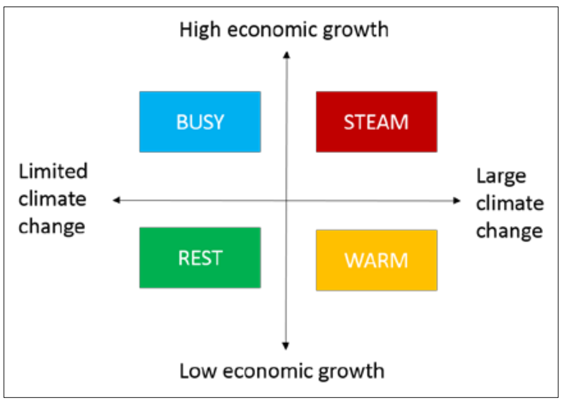


Figure 9. Delta scenarios

The delta scenarios explore possible futures by looking at both climate change and socio-economic scenarios developed for the Netherlands.

The delta scenarios describe 4 storylines for 2050 and 2100. It provides qualitative and quantitative data on climate, water systems, water consumption, and the use of land. Each storyline provides a consistent description of the possible future climatic, socio-economic and other developments. It includes developments that take place on a global, European and national level. In addition, they describe the impacts of these developments on a number of sectors that are relevant to water policy in the Netherlands and the challenges for flood risk management and freshwater supply. These sectors are: urbanization, agriculture, nature, shipping, energy and drinking and process water.

The scenarios are mainly intended for national water policy, in particular in the field of flood risk management, flooding and fresh water supply. The databases are specifically intended to be used in the quantitative model instruments for long-term policy choices (National Water Model) and the National Hydrology Tools (NHI). The delta scenarios could be used to raise awareness for long-term planning, to facilitate strategy development, to test alternative strategies, and to facilitate communication.

User needs delta scenarios

At this moment it is not clear if, and to what extent users were involved in the development of these scenarios. There is no information on co-production processes or the degree in which stakeholders have been consulted for user needs. However, the delta scenarios are developed for the Dutch Delta Programme (stakeholder) with the general ambition to shift from designing and implementing adaptation measures in response to past climatic events to shaping the Dutch Delta while anticipating to possible future conditions.

Development of scenarios

The first set of delta scenarios were developed in 2012. The hydrological conditions are based on the KNMI'06 climate scenarios and the WLO2006 socio-economic scenarios. Note that these scenarios are the precursors of the KNMI'14 and WLO'15 described earlier in this document.

In meantime, both the national scale climate and socio-economic scenarios for the Netherlands have been updated. The Delta Programme has explored the consequences of these updated scenarios as well as the consequences of the Paris agreement for the delta scenarios. The KNMI'14 and CMIP-5 datasets were down-scaled to the sub-catchments of the hydrological rainfall - runoff models (HBV). It was concluded that these new insights still fall within the bandwidth of the delta scenarios, and that the impact of the Paris agreements will not be manifest in the water taskings until 2050 at the earliest. The preferential strategies currently still constitute the proper basis for the selection of measures.

Relation to RCP x SSP architecture

The four scenarios can be put into a RCP x SSP architecture. Figure x show a rough comparison of the various scenarios into the RCP x SSP architecture.

Limitations

Possible improvements for the delta scenarios include

- Explore mutual impacts of the system, the subsystems, and the environment
- Relate future developments to the past and the present
- Pay more attention to future uncertainties
- Visualize the scenarios more adequately
- Apply stakeholder participation

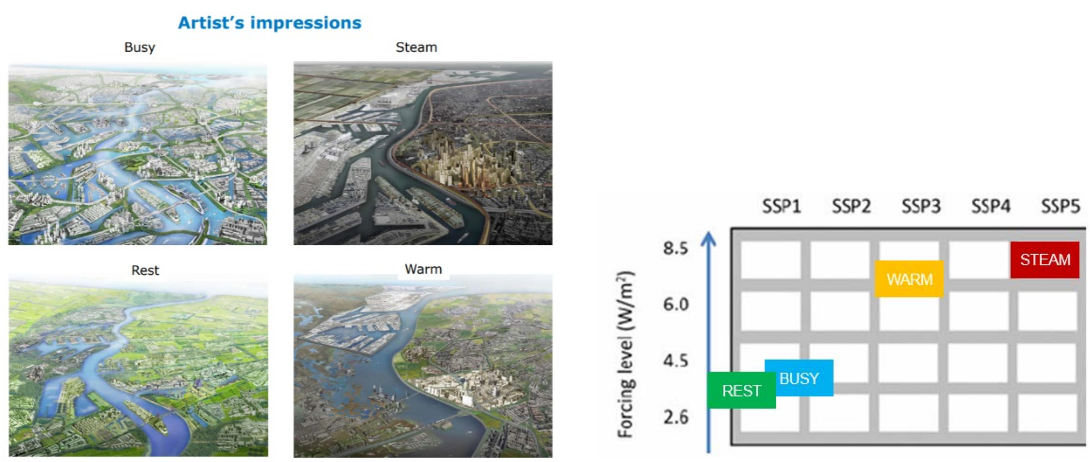


Figure 10. Mapping of the Delta scenarios onto the RCP x SSP architecture

5.3. National normative scenarios

This section briefly summarizes other national scale, normative scenario studies for the Netherlands.

5.3.1. Climate agenda

The Netherlands is party to a number of international climate agreements, including the United Nations (UN) convention on climate change, the Kyoto Protocol and the Paris agreement. These agreements form the basis of Dutch policy on climate change. The climate agenda describes goals and ambitions for 2030 and 2050 and outlines the government's plans for dealing with climate change.

5.3.2. Climate mitigation

In 2017, *The policy brief – Verkenning van klimaatdoelen. Van lange termijn beelden naar korte termijn actie* (english: Exploration of climate goals: from long-term visions to short-term actions) (PBL & ECN, 2017) was published. Based on the integral vision and goals developed in the Energy agenda, this document use back casting to define the short term action to reach that long term vision. Transition pathways for reducing emission in five themes are investigated (power and light, low temperature heat, high temperature heat, transport, and nature & food). Two visions are elaborated: the technical options and costs for an emission reduction of 80% and 95% by 2050.

Relation to RCP x SSP architecture

Calculated emissions in the exploration of climate goals are in compliance with IPCC AR-5. The emission reduction of 95% is corresponding to the Paris agreement goals.

5.3.3. Adaptation Strategy

National Climate Adaptation Strategy

The National Climate Adaption Strategy (2016) describes the impacts of climate change in the Netherlands and the high impact risks that need to be addressed. The strategy includes the launch of new adaptation initiatives and to support and accelerate existing adaptation initiatives and practices. Strategy is aligned with the Dutch Delta Programme and the National Safety and Security strategy.

5.3.4. Energy sector

The Netherlands has committed itself to the Paris agreement. The vision of the Netherlands is to gradually grow towards a low-carbon economy in 2050. Recent years, the Dutch energy sector has made significant steps for the transition to clean energy. Below a brief description of

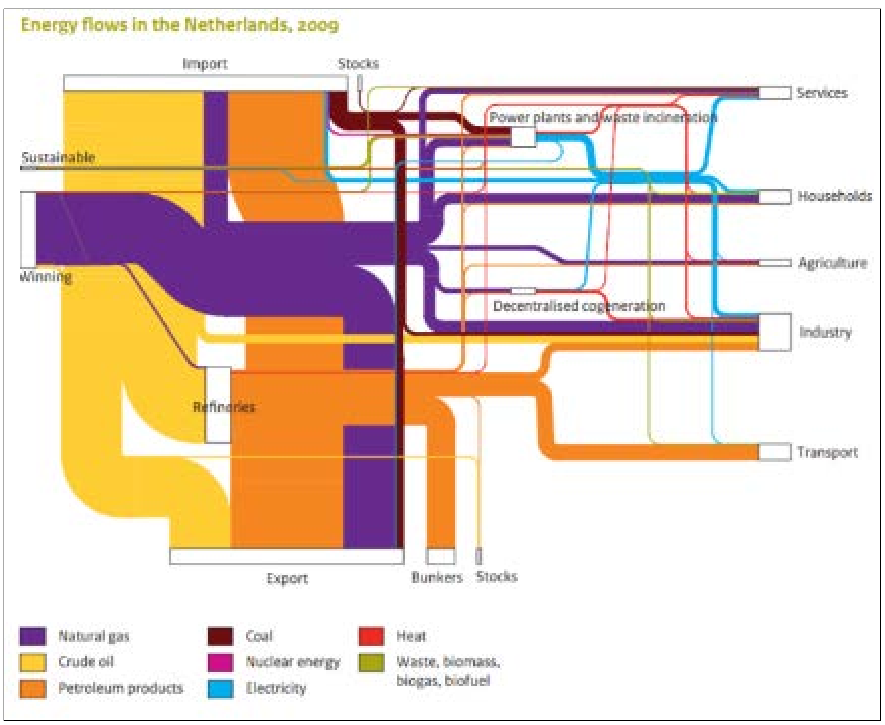


Figure 11. Energy flows in the Netherlands, showing the total dependency on fossil fuels.

the main

developments.

In 2011, PBL (Netherlands Environmental Assessment Agency) and ECN (Energy Research Centre the Netherlands) developed the report: "Exploration of pathways towards a clean economy by 2050. How to realise a climate-neutral Netherlands". The Dutch Ministry requested a roadmap towards a cleaner country by 2050, similar to the EU roadmap on how greenhouse gas emissions in Europe could be reduced by 80% by 2050. The report gives a summary of the opportunities and technical possibilities, and which steps to take to reach that goal (normative). In 2015, the Government published the *Energy Report - Transition to Sustainable*. The report provides an integral vision of the future energy supply of the Netherlands. In 2016, the Government published the *Energy agenda*. The agenda describes the ambitions and goals for the energy transition. The overall goal is to reduce the CO_2 emissions to 80-95% by 2050.

5.3.5. Nature and landscape visions

PBL has explored the visions and perspectives on nature for 2040. The Nature Outlook presents four perspectives on how nature and landscape could be perceived, including the benefits and possibilities for society. The visions follows the values that people award to nature and the desired future for nature as they see it. This is different from other scenario approaches, that are based on autonomous trends in socio-economic factors, with different futures of nature as an outcome.

5.4. Dutch policy and programmes with long term visions

5.4.1. National environmental planning strategy

The national environmental planning strategy (NOVI) will become the government's long-term vision (2030-2050) of essential and desired developments of the environment. Currently, there are about 80 visions from various departments, such as the nature vision, the environmental policy plan and the National Water Plan. These different visions will be merged and connected within the NOVI. The vision should be ready in 2019, when also the related law (omgevingswet) enters into policy. It will provide an integral view on broad strategic policy. In general, it follows 4 pillars[5]:

- Towards a sustainable and concurrent economy
- Towards a climate-proof and climate neutral society

[5] For more information: https://www.werkplaatsnovi.nl

- Towards a future-proof and accessible live and working environment
- Towards a valuable living environment

5.4.2. Circular economy

In a government-wide program 'The Netherlands Circular in 2050', the government describes how to turn the Dutch economy into a sustainable, fully circular economy in 2050. To achieve this goal, action at all levels and clear milestones are outlined. To accelerate the transition to a circular economy, the government developed five “transition agendas” in which the following chains and sectors have the highest priority: biomass and food, plastics, manufacturing, construction, and consumer goods.

5.4.3. Dutch Delta Programme

The Delta Programme is developed to protect the Netherlands now and in the future against high water and ensure sufficient fresh water. The goal is that water safety, freshwater supplies and spatial planning will be climate-proof and water-robust in 2050, so that the Netherlands is adapted to the greater extremes of the climate. Where traditionally adaptation measures were designed and implemented in response to past climatic events that have had a high society impact, the modern ambition is to shape the Dutch Delta while anticipating to possible future conditions.

The Delta Programme, with various authorities and other organizations, makes plan to achieve these ambitions. The delta programme started in 2010 and each year a new Delta Plan is developed. The aim of the most recent 2018 delta plan is to accelerate and intensify adaptation, so that the Netherlands will be water-robust and climate-proof in 2050.

5.4.4. Room for the River Programme

In the Netherlands, the Room for the River programme was implemented in 2006 under the umbrella of the Water Management of the 21st Century strategy (WB21) along the rivers Maas, Waal, IJssel, and Nederrijn. It is a government design plan intended to address flood protection, master landscaping and the improvement of environmental conditions in the areas surrounding the rivers. The project had been active from 2006–2015. However, the overall philosophy of building with nature and providing more space for the rivers is becoming an integral component in adaptive water management.

5.5. Regional scenarios for the Dutch case study

5.5.1. Background information

The Vecht River (Dutch: Overijsselse Vecht) is the largest of the small and smallest of the largest rivers in the Netherlands. The Vecht flows through the province of Overijssel, located in the east of the Netherlands. The source of the Vecht is located in Germany and flows into the Zwarte Water at Zwolle. The Vecht river covers a distance of 167 km, covers a catchment area of 3785 km^2 and is a part of the Rhine river basin.

Agriculture is one of the main pillars of the economy in the region. The river is used for recreational purposes. The province has the ambitions to improve the identity and experience of the area along the Vecht River and to support the economic development of the Overijsselse Vecht Valley.

The Vecht is managed by two water boards, the eastern part by Vechtstromen and the western part by Drents Overijsselse Delta. Until 2005, the management of the Vecht river was carried out by Rijkswaterstaat. Rijkswaterstaat is the national agency responsible for the management of the main water network and systems, while water boards are responsible for the regional waters.

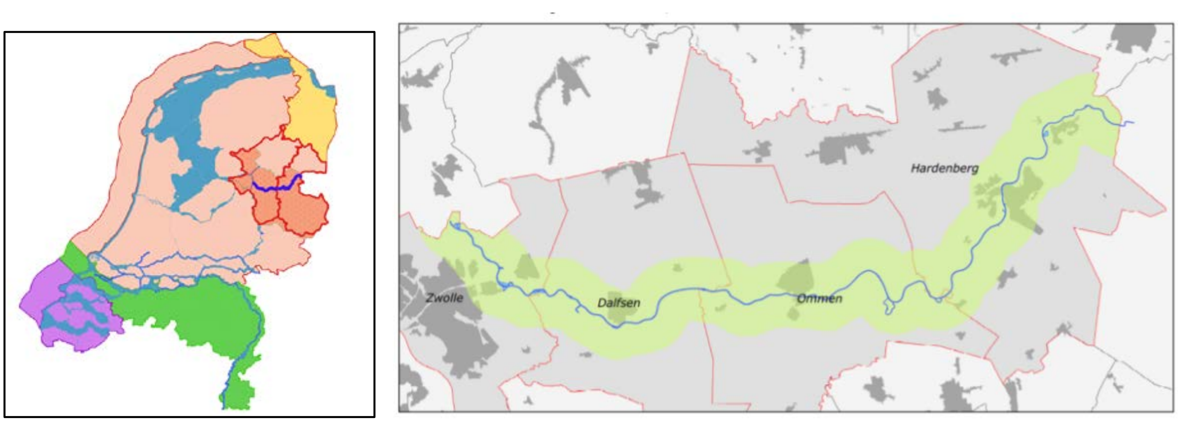


Figure 12. River basins (Eems, Maas, Rijn, Schelde) in the Netherlands. The Vecht (dark blue line) is located in the Rhine River basin, the largest river basin in the Netherlands. The Vecht flows in the province of Overijssel (dotted area). The delineations of the water boards Vechtstromen and Drents Overijsselse Delta are shown in red (status 2018). The two water boards are responsible for the management of the Vecht River. Note that the Vecht on the German border side is not presented. B) zoom in to the Vecht River and the municipalities (source: Province of Overijssel)

In the past, river channel modification was perceived as a necessary task to improve flood peaks discharges and to enhance flood safety. Furthermore, floodplains and riparian zones along the river channel were reclaimed for agricultural use. However, these activities have resulted in severe ecological degradation of the Vecht River. Two major programs - the Vision for the Vecht and Room for the Vecht - have been established to transform the severely modified lowland river into a “semi-natural“ state.

5.5.2. Lumbricus Programme

Lumbricus is a knowledge program (2016 -2020) in which water boards, knowledge institutions and entrepreneurs, together with farmers, conduct research for climate-proof soil and water systems. The program looks at the effectiveness and coherence between various measures that can make the water and soil system more climate-proof. These practical measures are implemented and tested in living labs ‘proeftuinen’ in the sandy soils of East and South Netherlands. The Vecht River is one of these living labs. Lumbricus consists of four interrelated sub-programmes, focusing on a) soil, b) water, c) stream valleys and d) governance. This integrated cooperation program brings together knowledge for fresh water supply, soil management, climate adaptation and water security.

5.5.3. Regional scenarios

Province of Overijssel has its own scenario institute: Trendbureau Overijssel. This is an independent institute that prepares explorative scenarios for Overijssel. Topics range from employment, health, agriculture, energy, landscapes. The regional scenarios are based on national scenario studies and extended for regional situation using stakeholder workshops. Stakeholder workshop consist of a mix of knowledge institutes, relevant actors, artists to increase creativity.

Regional environmental planning strategy

The province of Overijssel has developed a vision for the region: Omgevingsvisie Overijssel (2017). The vision outlines the vision for 2030 for the province of Overijssel. It includes visions on spatial planning, the environment, water, traffic and transport, the subsurface and nature. The vision is available in report and is also made available using an interactive mapping tool.

Regional adaptation plan Overijssel

In 2018 Overijssel published regional adaptation plan. The plan is based on the national visions describes in the Dutch Delta Programme. For each theme it has been stated whether and if so, which additional steps are necessary to become climate robust by 2050. The ambitions for climate adaptation are also connected to other provincial programs and policies, such as the Environmental Planning Strategy (omgevingsvisie). The province of Overijssel is one of the first provinces to have drawn up an adaptation strategy at regional level, in line with the National Adaptation Strategy.

Energy

NEO (2017) Nieuwe Energie Overijssel – provides a vision on the energy transition in Overijssel, with a time horizon of 2035, and ambition to be climate neutral in 2050.

5.5.4. How are scenario studies currently used in the Overijssel?

15 interviews have been conducted with various regional institutes to get an understanding on scenario use in the regions.

Climate scenarios

The KNMI'14 scenarios are used to develop the national climate impact atlas for the Netherlands. The atlas gives a first impression of the future risks of floods, droughts, heat in the area. The calculation are based on KNMI'14 scenario W_h.

The KNMI scenarios are used extensively by water boards, municipalities and provinces for stress test and spatial adaptation. Before 2019, all Dutch municipalities and water boards have to perform a climate stress test. The stress test assists identification of the locations that are prone to flooding, drought, and heat. The stress test can be used as a first precondition for addressing climate adaptation for government, businesses and citizens.

One of the difficulties for the institutes is to select the level of extremes to be used to determine vulnerability. For example, it is difficult to understand if you have to work with an event with a likelihood of return period once in 10, 50 or 100 years.

Water board Vechtstromen uses the KNMI'14 climate scenario (scenario W_h) to analyze the impacts of climate change for the Vecht River. This scenario is only one of the 4 KNMI'14 scenarios that has been developed. Waterboard works mostly with GRADE (Generator of Rainfall and Discharge Extremes) to prepare for climate extremes. GRADE is based on historical data and generates precipitation and discharge series for 50.000 years.

Regional socio-economic scenarios

All interviewees were familiar with national climate, socio-economic scenarios and regional scenarios from Trendbureau Overijssel. Some were involved in previous scenario stakeholder workshops. They indicated that these workshops and scenario studies are inspiring, integrate knowledge and perspectives to gain a better overview where we stand, and how the future might evolve. The scenarios are mostly used to think out of the box, provide policy makers with decision space: what is open? What is possible? However, the advantages of a participatory process include challenging the perceptions of those in authority to influence attitudes and agendas, therein encouraging policies better suited to serving the needs of those concerned.

5.5.5. Relevant portals and visualizations

The portals listed below give an overview of portals related to communicating (climate) information to a range of stakeholders. Next pages show some print screens.

- Web-GIS on national scale climate impact atlas: http://www.klimaateffectatlas.nl
- Story maps on national scale climate impacts: http://www.klimaateffectatlas.nl/en/story-maps
- Interactive website to explore the climate agenda: http://klimaatagenda.minienm.nl/
- Information portal for a range of users - on spatial adaptation: www.ruimtelijkeadaptatie.nl
- Information portal - Climate Adaptation Services. www.climateadaptationservices.com
- Tool to visualise possible energy transitions: https://pro.energytransitionmodel.com/
- Dashboard displaying regional climate monitoring data: https://klimaatmonitor.databank.nl
- https://www.lokaalklimaatportaal.nl/

6. Existing scenarios in Kenya

6.1. Overview of Scenarios in Kenya

Since 2002, the Kenyan government has developed some form of scenarios to inform national and sector-specific development plans (Table 1). At the national level, Kenya Vision 2030 sets out the desired development scenario for the country as a whole. Meanwhile, sector-specific scenarios – featuring a range of goals, plans and strategies – have been developed for sectors, such as: agriculture, livestock and fisheries; energy; environment, forestry, water and sanitation; infrastructure; manufacturing; population, urbanization and housing; tourism; and trade (LTS International/Acclimatise 2012). With climate change, several scenarios (emission scenarios; climate change projections; impact projections; adaptation options; mitigation options) have also been developed over the years. Climate change scenarios have mainly been developed by international consultants with inputs of government agencies, especially the Kenya Meteorology Department and Ministry of Environment and Natural Resources. National development plans, and sector specific plans have been developed by government agencies with input and support of development partners, consultants and other stakeholders within Kenya.

Both national and sector-specific development plans generally focus on a long-term time horizon of 2030, within which intermediate medium-term plans are made covering five-year time periods. Some climate change scenarios also look at a time horizon of 2030, although others have looked to 2050, 2060, 2080 and 2100. Most of national and sector-specific plans are largely normative, with visions of a desired future. For instance, the ambition of Vision 2030 is for Kenya to become "[a] globally competitive and prosperous country with a high quality of life by 2030". Most national plans are similarly normative, such as the country's Sustainable Energy for All Action Agenda or Climate-Smart Agriculture Strategy. Kenya's climate change scenarios focus on both mitigation and adaptation, with plans to address both concerns mostly exploratory. Adaptation and mitigation plans (or scenarios) are incorporated into the medium-term plans for each sector: agriculture, livestock and fisheries; health; infrastructure (energy and transport), manufacturing; environment, water and sanitation; population, urbanization and housing; tourism; trade (see above).

Table 11. Overview of scenarios and plans for Kenya

Theme	Name	Institute	Year	Scenario Type	Nr	Time horizon	Link to RCP/SSP	Output	Level of co-production
Demographic	Population	Kenya National Bureau of Statistics	2009		1	2009; projections to later years	None		Yes
Economic; Social; Political governance	Vision 2030	Government of Kenya	2007	Normative	1	2030	None; but links to MDGs, and SDGs	Qualitative and quantitative (e.g. GDP growth of 10%)	Yes
Adaptation; Mitigation; emissions; climate impacts; vulnerabilities; climate scenarios	2nd National Communication To UNFCCC	National Environment Management Authority	2015	Normative		2030; 2060	None	Qualitative and quantitative	Yes
Adaptation	Kenya National Adaptation Plan 2015-2030 (NAP)	Ministry of Environment and Natural Resources	2016	Normative	1	Short- (1-2yrs), medium- (3-5yrs) and long-term (>6yrs)	Paris Climate Agreement	Qualitative descriptions of planned adaptation actions	Yes
Climate change	NCCRS 2010	Government of Kenya	2010	Normative	1	Not specified, though 2020 implied in some instances	None	Qualitative and quantitative	Yes
Climate change	Climate: Observations, projections and impacts. Kenya	UK Met office	2011	Explorative	2	2100	None	Quantitative	No
Climate change	Government of Kenya Adaptation Technical Analysis Report	LTS International and Acclimatise	2012	Explorative	4	2100	None	Quantitative	No
Adaptation and Mitigation	NCCAP 2013-2017	Government of Kenya	2012	Normative	1	2013-2017	None	Qualitative and quantitative	Yes
Adaptation and Mitigation	INDC	Ministry of Environment and Natural Resources	2015	Normative	1	2030	Paris Agreement; COP 19 and 20 decisions	Qualitative descriptions of mitigation actions	Yes
Adaptation	National Climate Change Action Plan Adaptation Technical Analysis Report	Republic of Kenya	2012	Normative		2018; 2022			Yes
Agriculture	Mainstreaming Kenya's National Climate Change Action Plan into the Agriculture Sector	Republic of Kenya	2013	Exploratory	1	2030	May be RCP	Qualitative and quantitative	Yes
Environment, water and sanotation	Mainstreaming Kenya's National Climate Change Action Plan into the Environment, Water and Sanitation Sector.	Republic of Kenya	2013	Exploratory	1	2030	May be RCP	Qualitative and Quantitative	Yes
Energy	Energy Scale up Program and Rural Electrification: Generation of 23,000 MW and Distributed at Competitive Prices	Republic of Kenya	2013	Normative	1	2050	None		Yes
Infrastructure (Energy and Transport)	Mainstreaming Kenya's National Climate Change Action Plan into the Infrastructure Sector	Republic of Kenya	2013	Exploratory	1	2030	None	Qualitative and Quantitative	Yes
Manufacturing	Mainstreaming Kenya's National Climate Change Action Plan into the Manufacturing Sector	Republic of Kenya	2013	Exploratory	1	2030	None	Qualitative and Quantitative	Yes
Health	Mainstreaming Kenya's National Climate Change Action Plan into the Health Sector	Republic of Kenya	2013	Exploratory	1	2030	None	Qualitative	Yes
Population, Urbanization and Housing	Mainstreaming Kenya's National Climate Change Action Plan into the Population, Urbanization and Housing Sector	Republic of Kenya	2013	Exploratory	1	2030	None, but could be linked to RCPs	Qualitative and Quantitative	Yes
Emissions and mitigation	Mapping of GHG Emissions and Low-carbon Development Opportunities to Government of	Republic of Kenya	2012	Exploratory	1	2030	None, but could be linked to RCPs	Qualitative and Quantitative	Yes

	Kenya Planning Sectors								
Trade	Mainstreaming Kenya's National Climate Change Action Plan into the Trade Sector	Republic of Kenya	2013	Exploratory	1	2030	None, but could be linked to RCPs	Qualitative and Quantitative	Yes
Emission Scenarios and Mitigation Options for different sectors	Low Carbon Climate Resilient Development Pathway: Technical Report	Republic of Kenya	2013	Normative and Explorative	1	2030	None, but could be linked to RCPs, MDGs/ now SDGs.	Qualitative and Quantitative	Yes
Social-economics and politics	Kenya at Cross Roads	?	2000	Exploratory	4	2010; 2020	None	Qualitative	Yes

6.2. Climate Change Scenarios

6.2.1. Key climate scenarios

National-level climate scenarios have been developed by the government of Kenya mainly through consultants. The most cited climate scenarios are those developed by the UK's Met Office (2011) and LTS International/Acclimatise (2012), in collaboration with government agencies (Kenya Meteorology Department, Climate Change Secretariat; Ministry of Environment and Natural Resources) and with input from the IGAD Climate Prediction and Application Centre and other national and international experts and stakeholders. The Met Office (2011) and LTS International/Acclimatize (2012) are the most recent climate scenarios available for Kenya. However, both the Kenya Meteorology Department and IGAD Climate Prediction and Application Centre provide regular climate change forecasts and projections for Kenya and Horn of Africa region.

The LTS International/Acclimatie (2012) climate projections uses the North Carolina State University enhanced version of RegCM310 with input from the Finite Volume Global Climate Model (FvGCM) to make regionally distinct projections for Kenya. The results are based on data from one regional climate model (based on boundary conditions obtained from a single global climate model). It shows projected changes in mean temperatures and rainfall for 2071-2100 compared to 1961-1990 baseline.

Overall, the regional climate model suggest that the whole of the country could warm by between 1°C and 5°C (by 2071-2100). Dry seasons (March to May and October to December) are projected to experience the greatest increase in temperature, particularly in the north of the country, whereas 'long rains' from March to May are projected to experience the smallest increase, particularly in the northeast of the country, where negligible changes are projected in comparison to the baseline period. The northwest of the country is projected to warm by around 1°C more than the rest of the country, whereas northeastern regions, in particular around Wajir County, are projected to experience less warming than the rest of the country, by approximately 1°C-2°C. The Figures below show the projected changes in average rainfall (Figure 1) and temperature (Figure 2) for 2071-2100 (compared to the baseline average of 1961-1990 for the A2 scenario (see LTS International/Acclimatize 2012, pp33-34)).

The Met Office (2011) scenarios use outputs from the Climate Model Intercomparison Project's CMIP3 model ensemble (as used in the IPCC's Fourth Assessment Report Climate, AR4) for climate and climate change impact projections. The CMIP3 model ensemble outputs for temperature and precipitation for the SRES A1B scenario[6] are used for projections in Kenya. The results show changes in average annual temperature and precipitation by 2100 compared to the 1960-1990 baseline. Overall, there is good agreement between ensembles for temperature increases over Kenya of up to around 3°C. The model ensemble projects strong precipitation increases over East Africa, especially Kenya, with increases of over 20% projected with strong ensemble agreement.

The scenarios presented in LTS International/Acclimatize (2012) and Met Office (2011) are intended to support impact studies, enable consideration of climate change in decision-making processes and mainstreaming in different sectors, and facilitate development of adaptation and mitigation options and strategies. For example, the scenarios presented in both documents have been used to assess impacts of climate change and to develop adaptation and mitigation actions presented in the National Adaptation Plan, Kenya's INDC and the 2nd National Communication to the UNFCCC (see below). Further, each of these documents present climate change scenarios, and impact projections for different sectors.

[6] "The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system… [A1B represents] a balance across all sources…(where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end-use technologies)." (See https://www.ipcc.ch/ipccreports/tar/wg1/029.htm#storya1)

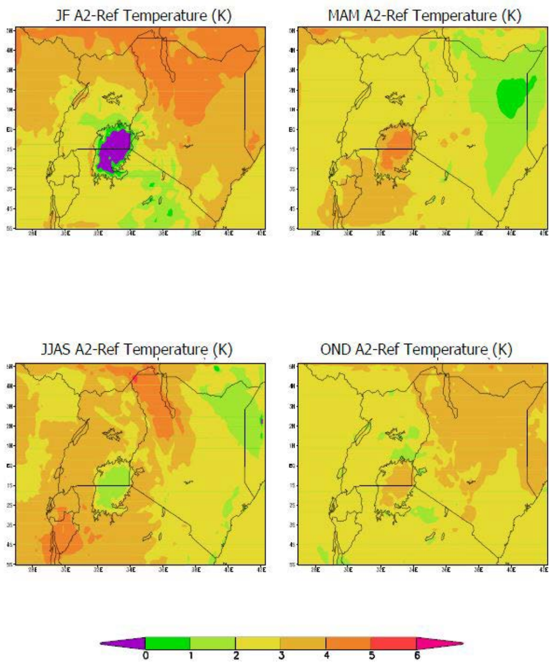


Figure 13. RegCM3 temperature projection results for 2071-2100 (A2 emission scenario; 20km). Source: LTS International/Acclimatize (2012)

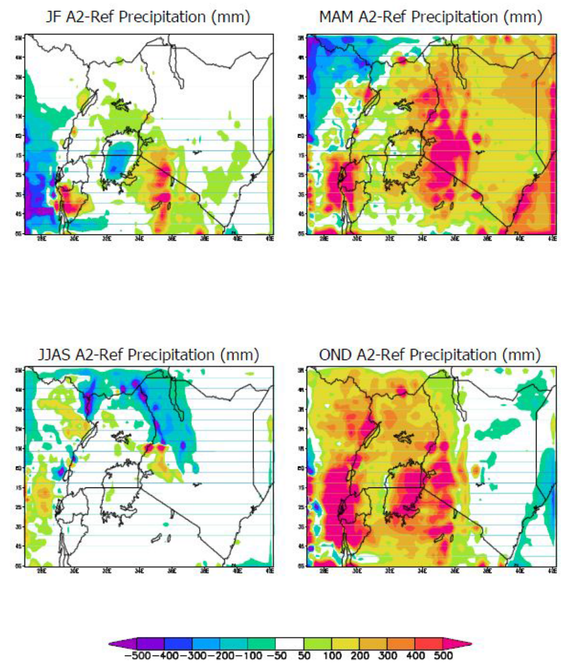


Figure 14. RegCM3 rainfall projection results for 2071-2100 (A2-RF; 20km resolution). Source: LTS International/Acclimatize (2012)

6.2.2. User needs in climate scenarios in Kenya

It is not clear whether the development of the climate scenarios present in the studies by LTS International/Acclimatize (2012) and Met Office (2011) were developed in response to user requirements. However, it is plausible to conclude that information requirements to guide the development of the National Climate Change Strategy, Climate Change Action Plan 2013-2017, Kenya National Adaptation Plan 2015-2030, and climate mitigation strategies (INDC) informed some of scenarios presented in the climate scenarios for Kenya.

6.2.3. Development of scenarios

The climate scenarios for Kenya are based on observations data, global climate models (CMIP3), and regional climate models. These were complimented by regional data such as those of IGAD Climate Prediction and Application Centre. The Met Office (2011) scenarios used CMIP3 model data. The CMIP3 model ensemble outputs for temperature and precipitation for the SRES A1B scenario was used for projections in Kenya. The development of the LTS International/Acclimatize (2012) scenario was guided by the IPCC Revised 1996 Guidelines for

National Greenhouse Gas Inventories (Volumes 1, 2 and 3) and the Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. However, the LTS International/Acclimatize (2012) does not present scenarios in the strict sense of the term. The Met Office (2011) presents only two scenarios for climate projections: one middle of the road scenarios and one aggressive mitigation scenario. Further, there have not been attempts to update the scenarios based on new observations.

6.2.4. Co-production in climate scenarios

Generally, the development of climate scenarios is described as participatory. However, the development of the scenarios in Met Office (2011) were based on only reports and observations provided by national organizations. The authors mention that they engaged with local scientists to better understand the impact of extreme events and received input and advice from reviewers in Kenya. This implies limited consultation and no co-production of knowledge.

The scenarios presented in the Adaptation Technical Analysis Report by LTS International/Acclimatize (2012), on the other hand, can be considered more co-produced. The scenarios – and the associated sector specific adaptation and mitigation plans – were developed through an intensive consultative and participatory process that included a wide array of stakeholders. The team that developed the scenarios consulted with numerous research, academic, private sector, civil society and government institutions. Nine county consultation meetings were organized by the Ministry of Environment and Natural Resources to solicit input. The team developing the report was supported by a thematic working group of eighteen individuals who were selected by the ministry to represent government technical departments, civil society, and academia. The team worked closely with this thematic working group and, in addition to regular formal and informal communication, arranged a series of workshop events, on-line surveys, and discussions to inform and guide the development of the scenarios.

6.2.5. Relation to the SRES and RCP

The different SRES scenarios formed the basis for the climate scenarios for Kenya; there is no direct linkage to RCPs. The development of the scenarios presented in LTS International/Acclimatize (2012) was guided by the IPCC Revised 1996 Guidelines for National Greenhouse Gas Inventories (Volumes 1, 2 and 3) and the Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. These were used to undertake the necessary calculations on GHG Emissions and Removals. Calculation of emissions was assisted using UNFCCC's Non-Annex I National Greenhouse Gas Inventory Software (version 1.3.2). The Met Office (2011) study used the same emissions scenarios across the different impact sectors studied. These are a business as usual (IPCC SRES A1B) and an aggressive mitigation (the AVOID A1B-2016-5-L) scenario. Model output for the scenarios was taken from more than 20 global climate models and averaged for use in the impact models. The impact models are sector specific, and frequently employ further analytical techniques, for instance, pattern scaling and downscaling in the crop yield models.

6.2.6. Tailor-made climate information

Although the projections in the Met Office (2011) and LTS International/Acclimatize (2012) are general, efforts have been made to examine the implications of the climate projections for different sectors. For instance, in addition to climate projections, LTS International/Acclimatize (2012) examines climate change impacts on the thematic sectors within the government's 5-year medium-term plan. The Met Office (2011) study also projects climate change impacts on crop yields, food security, water stress and drought, pluvial flooding and rainfall, fluvial flooding, tropical cyclones, and coastal ecosystem and regions. Based on the projected risks and impacts, the LTS International/Acclimatize study outlines sector-specific adaptation and mitigation options. These are presented in the Adaptation Technical Analysis main report, but also in the Kenya National Adaption Plan 2015-2030, National Climate Change Action Plan 2013-2017, Kenya's 2nd National Communication to the UNFCCC, and the Kenya's Intended Nationally Determined Contribution (INDC), and in sector specific impact analysis and adaptation and mitigation options reports. Similarly, the climate and impact projections in the Met Office study have been used to inform national adaptation and mitigation plans, especially the National Climate Change Response Strategy.

6.2.7. Extreme scenarios

The Met Office (2011) scenarios provide outputs for changes in the average temperature and precipitation. However, the scenarios also project changes in the extremes such as changes in the frequency of cold days and nights and warm days and nights, which are moderate extremes. Cold days/nights are defined as being below the 10th percentile of daily maximum/minimum temperature and warm days/nights are defined as being above the 90th percentile of the daily maximum/minimum temperature. The projections show a trend towards fewer cold nights and days and more warm nights and days. Night-time temperatures (daily minima) show widespread decreases in the frequency of cold nights and increases in the frequency of warm nights with high confidence. Daytime temperatures (daily maxima) show widespread decreases in the frequency of cool days and increases in the frequency of warm days with high confidence. In terms of precipitation, projections are made for droughts and flooding.

The LTS International/Acclimatize (2012) study also examines changes in extreme events. These are considered in terms of changes in number of hot days per year, number of hot nights per year, and number of cold days and nights per year. The projections show that the average number of hot days per year (defined as daily temperature that is in the top 10% of daytime temperatures for that region and season) has increased by 57 (a 15.6% increase) between 1960 and 2003. The average number of hot nights per year (defined as night-time temperature that is in the top 10% of night-time temperatures for that region and season) increased by 113 (a 31% increase) between 1960 and 2003. The average number of cold days and nights (defined as temperatures in the lowest 10% for that region and season) has decreased by 4.4% and 11.5% respectively.

6.2.8. Limitations

The Met Office (2011) impact scenarios have some limitations. First, some impact areas were omitted such as those associated with human health impacts. Second, no attempt was made to include the effect of future adaptation action in the assessment of potential impacts. A limitation of both reports is that they do not really provide a range possible emission and climate scenarios, since only one scenario is presented against the baseline scenarios in both studies.

6.3. Socio-economic scenarios

Kenya's main normative socio-economic scenario is Vision 2030, its national development blue print developed in 2008 outlining the country's socio-economic and political development aspirations. Possible/exploratory socio-economic and political development scenarios for Kenya in 2010 and 2020 were developed by the Institute of Economic Affairs (IEA) and the Society for International Development (SID) in 2000. Meanwhile, while the Kenya National Bureau of Statistics (KNBS) conducts regular socio-economic and population surveys.

Vision 2030 provides a single normative social, economic and political development scenario for Kenya. The overarching vision to make Kenya a "globally competitive and prosperous country with a high quality of life by 2030". The Vision 2030 is anchored on three key pillars: economic; social; and political governance. The economic pillar aims to achieve an economic growth rate of 10% per annum and sustaining the same till 2030. This has, however not been achieved as Kenya recorded a GDP growth of 5.8% in 2016 (KNBS, 2017). The social pillar seeks to create just, cohesive and equitable social development in a clean and secure environment. The political pillar aims to realize an issue-based, people-centered, result-oriented and accountable democratic system. In terms of demographics, Kenya's population was estimated at 38 millions in 2009, and was projected to grow to 40.7 million in 2012 and 45.4 million in 2016 (KNBS, 2009).

The Institute of Economic Affairs (IEA) and the Society for International Development (SID) (2000) study presents four possible exploratory scenarios. The *El Niño* scenario is a state of inaction where confusion and inertia thwart efforts at both economic and political reforms. Under this scenario, the status quo is maintained. Tension heightens and Kenya fractures into ethnic districts with new systems of government within them. The *Maendeleo* scenario is a transformation scenario that concentrates on a re-ordering of the economy while resisting agreements on needed changes in political structures and environment. In this scenario, the economic gains do not last long as political tensions emerge that require sorting out to preserve economic headway. It is a scenario of initial rapid gains but is full of inequalities and instability. The *Katiba* scenario is a transformation scenario focused on institutional reorganization and the creation of democratic and locally accountable institutions while ignoring fundamental economic reform. Although responsive institutions emerge, Kenya does not achieve substantial economic transformation under this scenario. The *Flying Geese* scenario involves a definite departure from destructive politics. Under here, the incumbency realizes its position is untenable and reaches a political settlement with the key adversaries. This leads to a reorganization of the institutions to improve representation and participation that reflects the diversity of Kenya's people. This is accompanied by radical transformation of the economy to spur growth and improve distribution.

6.3.1. User needs for socio-economic scenarios

The Ministry of Devolution and Planning is responsible for overall national development planning. Other sector ministries are responsible for sector-specific plans, but these must be aligned to the overall nation development plan, Vision 2030, and the medium-term plans. Similarly, in Kenya's recently established devolved government system, the various counties are responsible for developing their own specific county integrated development plans which contribute to the overall national development plan. There still appears to be a need to develop socio-economic scenarios to guide and tailor adaptation and mitigation plans at the national and county level. Whether this need is felt across different ministries and departments, and agencies as well as by the private sector and civil society is unknown.

6.3.2. Development of scenarios

Vision 2030 was developed through a consultative and inclusive stakeholders' process carried out between October 2006 and May 2007. The process involved international and local experts, ordinary Kenyans and stakeholders from all parts of the country. Contents of the Vision 2030 were subjected to open consultations in all districts in Kenya, before the finalization of the document. However, since it contains only one aspirational vision, it is difficult to tell how it captures diverse perspectives of different stakeholders on how the future should unfold as well as how it is likely to unfold. Development of the 4 scenarios presented in the IEA and SID (2000) study benefited from intellectual advice and guidance from many Kenyan professionals in their roles as researchers, peer reviewers, members of the scenario-building team and trustees. The process of developing the scenarios is described as a broad collaborative effort of many individuals and institutions. It involved five workshops and other meetings by a group of more than 80 Kenyans of various ages and professions. The scenarios for Kenya were developed by a group of 25 Kenyan professionals from all walks of life. The team worked from material compiled by a team of more than 30 researchers. The development of the scenarios was conducted in a period of over one year, in-between five workshops.

6.3.3. Relation to RCP x SSP architecture

There is no direct linkage between the development scenario present in Vision 2030 and the RCP x SSP. Neither is there a direct linkage between the scenarios presented in the IED and SID (2000) and the RCP x SSP. However, the major social, economic and political development plans presented in Vision 2030 has implications for RCP and SSP. Planned development in social and economic pillar will mean increased energy demand. While this increase will be met from renewable energy source (geothermal, hydro, wind and solar), the planned development of coal and exploitation of coal and oil resources will increase Kenya's emissions. The four scenarios presented by IEA and SID (2000) also have implications for social, economic and industrial development.

6.3.4. Limitations

The main limitation is that Vision 2030 does not really present scenarios in the strict sense. Furthermore, development plans in the Vision 2030 and in the four scenarios in the IEA/SID (2000) study cannot be linked to RCP x SSP on a one-to-one basis.

6.4. Sector-specific scenarios

Kenya has committed itself to the agreements in the Paris Climate Agreement. Although Kenya prioritizes adaptation, the country also aims to achieve a low-carbon development pathway by 2030. Kenya has thus developed several sectoral development, adaptation and mitigation plans. In general, these sectoral development, mitigation and adaptation plans are mostly normative and describe strategies and actions to reach certain goals over specific time horizons. Below, we examine development, adaptation and mitigation plans for selected sectors that feature within the medium-term plans: agriculture; environment, forestry water and sanitation; infrastructure (energy and transport); population, urbanization and housing; and manufacturing.

6.4.1. Agriculture

Kenya has developed the Agriculture Sector Development Strategy 2010-2020 (RoK, 2010). The vision of the strategy is "A food-secure and prosperous nation". It sets the overall goal of the sector as achieving an annual growth rate of 7%. The Kenyan government has also developed the report entitled 'Mainstreaming Kenya's National Climate Change Action Plan into the Agriculture Sector'. Adaptation options considered include: promotion of drought tolerant crops, water harvesting, integrated soil fertility management, insurance schemes, price stabilization schemes for livestock, strategic food reserves, and mainstreaming climate change into agricultural extension services. Regarding livestock, priority low carbon climate resilient actions (mitigation) include improved management of grazing systems, livestock diversification, breeding of animals to improve their ability to adapt to climate change and produce lower methane emissions, and provision of accessible climate information to farmers and pastoralists. Overall, agroforestry has the highest mitigation potential estimated at 4.2 MtCO_2e by 2030. Conservation tillage has the potential to abate 1.1 MtCO2e by 2030. Reducing the use of fire in cropland and rangeland management, has the potential to abate 1.2 MtCO2e by 2030.

6.4.2. Energy

The Government of Kenya has developed the 'Updated Least Cost Power Development Plan' for the period 2011-2031 (RoK, 2011). The updated plan reviews the load forecasts, committed generation and transmission projects, hydro projects, cost of generation plants, and transmission system requirements. Candidate generation resources considered in expansion plan include geothermal, hydro, wind, coal, oil-fired and nuclear fired plants. The optimal development program is dominated by geothermal, nuclear, coal, imports and wind powered plants. Kenya has also developed the 'Energy Scale up Programme and Rural Electrification: Generation of 23,000 MW and Distributed at Competitive Prices' (RoK, 2013a). The plan reviews completed and planned energy developments to 2050.

Kenya's has also developed the document "Development of a Power Generation and Transmission Master Plan, Kenya: Long-term Plan 2015-2035" (Ministry of Energy and Petroleum, 2016). The Plan outlines demand forecasts for 3 scenarios and one sub-scenario: a reference scenario; vision scenario; low scenario; and an energy efficiency sub-scenario. Electricity consumption is forecasted to grow at an annual rate of 7.3% (Reference scenario), 9.6% (vision scenario), and 5.6% (low scenario). For power generation candidates, geothermal is ranked the best, followed by bagasse power plant, and high voltage direct current inter-connection with Ethiopia. This master plan discusses the power transmission and investment plan need to achieve the forecasted demand in 2035.

Kenya has also developed mitigation actions for the energy sector. These included: promotion of improved cook-stoves and replacing kerosene lamps with renewable lighting such as solar lanterns; promotion of energy efficient electric appliances such as light bulbs; diversification of the in the electricity sector through investment in geothermal, cogeneration, and wind; and promotion of solar technology, including solar thermal water heating and solar photovoltaic. Development of Kenya's geothermal has the largest abatement potential in the electricity generation sector at approximately 14 MtCO2e a year in 2030. Other low carbon options include the expansion of wind and hydropower-based electricity generation with an abatement potential of 2.5 MtCO2e by 2030. Off-grid electricity generation including wind turbines, solar panels or small hydro systems, can help to provide electricity to 70 per cent of Kenyans with no access to power.

6.4.3. Transport

For the transport sector, planned mitigation actions include: developing a mass rapid transit system consisting of a bus rapid transit and a light rail transit for Nairobi; improvement in heavy duty vehicle and passenger vehicle stock efficiency; and biodiesel and bio-ethanol blending.

6.4.4. Environment, water and sanitation

In the environment, water and sanitation sector, Kenya has developed the Mainstreaming Kenya's National Climate Change Action Plan into the environment (including forestry), water and sanitation sectors. The document discusses climate change impacts and vulnerabilities in the environment, water and sanitation sectors and proposes a raft adaptation and mitigation actions. Adaptation actions in the environment sector include improving coastal zone management to rehabilitate and conserve vital coastal ecosystems through the implementation of the Integrated Coastal Zone Management Plan, the National Disaster Risk Management Response Plan and National Environment Action Plan. In the forestry sector; important actions are: restoration of forests on degraded lands, which has a mitigation potential of over 30 MtCO2e a year in 2030; reforestation and reducing deforestation and forest degradation, with mitigation potentials of 6.1 and 1.6 MtCO2e, respectively (RoK 2013b).

In the mining and mineral resources sector, mitigation actions include encouraging the use of clean coal technologies with international support; making use of the natural gas that is a by-product of oil production, instead of flaring it; and allocating a percentage of royalties to a climate change fund to support reforestation and other low carbon actions. In the water sector, priority adaptation actions include: increased domestic water supply and improved sewage systems; enhanced irrigation and drainage to increase agricultural and livestock production; effective trans-boundary water resources management; and Flood mitigation schemes. In the waste sector, improved waste management systems are planned for several cities, and with proper design can contribute to mitigation. Methane produced in landfills can be captured and used for electricity generation, with a greenhouse gas abatement potential of 1.1 MtCO2e for methane capture and 0.5 MtCO2e from electricity generation from landfill gas.

6.4.5. Manufacturing

In the Manufacturing sector, Kenya has developed the document "Mainstreaming Kenya's National Climate Change Action Plan into the Infrastructure Sector" (RoK, 2013c). The report describes climate change impacts and risks in the manufacturing sector. Proposed mitigation actions include: energy efficiency improvements, which can abate 1.3 MtCO2e a year in 2030; industrial-scale cogeneration using biogas produced from agricultural residues, which is used to generate electricity and heat, with a mitigation potential of 1.6 MtCO2e a year in 2030; and more efficient kilns for charcoal production, with a mitigation potential of 1.6 MtCO2e a year in 2030.

6.4.6. Population, Urbanization and Housing

In the population, urbanization and housing sector, Kenya has developed the report "Mainstreaming Kenya's National Climate Change Action Plan into the Population, Urbanization and Housing Sector" (RoK, 2013d). The report proposes several adaptation and mitigation actions. Mitigation actions include distributed clean energy solutions for households and institutions (such as solar lanterns, improved cook-stoves and LPG cook-stoves, and energy efficient lighting and appliances). Improved cook-stoves can better the lives of individuals – particularly women and children, in rural and urban areas – by reducing time to collect fuelwood, reducing indoor air pollution, and potentially introducing cost savings to households. The mitigation potential of stepping up distributed clean energy technologies is over 10 million tons of carbon dioxide equivalent per year in 2030. Mitigation actions in the housing sector include designing and siting buildings so that they use as much as natural lighting (sunlight) and cooling as possible.

6.4.7. Health

In the health sector, Kenya has developed the report "Mainstreaming Kenya's National Climate Change Action Plan into the Health Sector" (RoK, 2013e). The report discusses climate impacts and risks in the health, and present a raft of mitigation and adaptation action. Adaptation actions proposed include: improved disease surveillance, including strengthening existing early warning, monitoring and evaluation systems for malaria epidemics; improved community-level health care and dissemination of information on changing health risks to enhance the response to climate-related diseases; and increased access to water and sanitation to improve disease vector control. Mitigation action is the use of water filters that provide access to clean water while reducing demand for firewood used to boil water, which can also slow deforestation. Unlike in the infrastructure, the abatement potentials of the mitigation actions are not quantified.

6.4.8. Relation to RCP x SSP

Calculated emissions reduction reductions in the exploration of Kenya climate mitigation goals comply with IPCC AR-4. Kenya's overall plan to abate its GHG emissions by 30% by 2030 relative to the BAU scenario of 143 MtCO2eq is largely in line with the goals of the Paris Climate Agreement. However, none of the documents described above mentions RCP and/or SSP scenarios.

6.5. Kenya's climate policy and programmes with long-term visions

Kenya has developed several long-term strategies and action plans related to addressing climate change and related fields. Kenya is a party to several international agreements on climate change: the United Nations Convention on Climate Change (UNFCCC), the Kyoto Protocol and the Paris Climate Agreement. These agreements form the basis of Kenya's policy. Indeed, Kenya has developed policy proposals, strategies and action plans to domesticate these international agreements, most of which are normative, and outline long-term vision for climate change mitigation, adaptation and resilience building in Kenya. These are discussed in turn below. It should be noted that Kenya, like many other developing countries, considers adaptation as priority, although Kenya's strategies also outline strategies for low carbon development pathway (mitigation).

6.5.1. The Climate Change Act, 2016

The Climate Change Act 2016 is the overarching legislation on climate change matters in Kenya. It is an Act of Parliament that provides for a regulatory framework for enhanced response to climate change and mechanisms and measures to achieve low carbon climate development, and for connected purposes. The Act shall be applied for the development, management, implementation and regulation of mechanisms to enhance climate change resilience and low carbon development for the sustainable development of Kenya. The Act mandates both the national and county governments to mainstream climate change responses into development planning, decision making and implementation in all sectors (GoK, 2016).

The Climate Change Act has established the National Climate Change Secretariat in the Ministry of Environment and Natural Resources. This Secretariat is the national focal point for the UNFCCC and its core mandate is coordination of climate change adaptation and mitigation actions and interventions. The Secretariat liaises and works with climate change coordination units established in different ministries, departments and agencies to ensure that climate change is mainstreamed in the different sectors of the economy. The Secretariat also works with the Ministry of Devolution and Planning to ensure the integration of climate change in the medium-term plan.

The Climate Change Act 2016 also provides for the establishment of the National Climate Change Council and Climate Change Directorate. The Council is chaired by the President while the Cabinet Secretary for Environment and Natural Resources is its secretary. The Council has representation from civil society organizations, private sector, academia and marginalized communities. The Directorate is the lead agency of the government on national climate change policies, plans and actions. Its function is to deliver operational coordination on climate change matters and reports to the Cabinet Secretary for Environment and Natural Resources. Importantly, and besides other duties, the Directorate in collaboration with other agencies at the national and county government level is required to:

i. Identify low carbon development strategies and coordinate related measurement, reporting and verification;
ii. Develop strategies and coordinate actions for building resilience to climate change and enhancing adaptive capacity;
iii. Optimize the country's opportunities to mobilize climate finance;

The Climate Change Act directs county governments to integrate and mainstream climate change actions, interventions and duties into county integrated development plans; to designate a County Executive Committee member to coordinate climate change affairs; and to submit a report on the implementation progress of climate change actions to the county assembly for review and debate, with a copy to the Climate Change Directorate for information. The Act also direct counties to develop county-specific adaptation plans to guide county-level implementation of national adaptation strategies and actions The Climate Change Directorate is supposed to liaise with county governments in management and coordination of climate change matters at the county level. However, at the county level, the Climate Change Act and its provisions are poorly known and understood by a majority of county government officers. Majority of the counties are yet to designate a County Executive Committee member to coordinate climate change matters in the respective. Thus, sensitization and capacity building of county governments on the Climate Change Act 2016 is imperative for meaningful mainstreaming of climate change adaptation actions into the medium-term plans and county integrated development plans.

Besides the Climate Change Directorate and other agencies proposed and established by the Climate Change Act 2016, several other government agencies are involved in climate change adaptation issues. The National Environmental Management Authority, a semiautonomous agency in the Ministry of Environment and Natural Resources, is the National Implementing Entity for the Adaptation Fund and the Green Climate Fund. The National Treasury is the National Designated Authority for the Green Climate Fund. The National Drought Management Authority (NDMA) is mandated "to exercise overall coordination over all matters relating to drought management in Kenya" and also oversees adaptation and resilience building in the arid and semi-arid areas. It is also the secretariat of the Common Program Framework in Ending Drought Emergencies in Kenya. The Kenya Forest Service dealt with forest management and conservation issues, including measures to reduce emissions from deforestation and forest degradation (REDD+). The Kenya Wildlife Service deals forestry and wildlife. The Kenya Water Towers Agency coordinates conservation and protection of the major water towers/ catchments.

National Climate Change Adaptation Plan (NCCAP) 2013-2017

The National Climate Change Action Plan 2013-2017 was Kenya's first plan on how to address climate change. It was developed with the aim of implementing the National Climate Change Response Strategy that was launched in 2010. The Action Plan set a normative vision; namely 'low carbon climate resilient development pathway' that Kenya aimed to achieve by 2017. The Action Plan detailed a range of adaptation and mitigation actions in the context of a low carbon climate resilient development pathway. It identified "big wins' for low carbon development in geothermal power generation; distribution of clean energy solutions; improved water resource management; restoration of forests on degraded lands; climate smart agriculture and agroforestry; and infrastructure (energy and transport). It was estimated that, together, these 'big win' sectors could provide over two-thirds of Kenya's mitigation potential.

In preparing the Action Plan, Kenya conducted a low carbon analysis that demonstrated that mitigation actions can contribute to low-carbon pathways in the six sectors: energy, transport, industry, agriculture, forestry and waste. The first step in the assessment was development of a comprehensive GHG inventory for 2000 to 2010. Emissions were then projected out to 2030 to form the reference case, with emissions increasing from 59 million tons of carbon dioxide equivalent (MtCO2e) in 2010 to 102 MtCO2e in 2030 (see Figure 3 below). This reference case formed the baseline against which abatement potential was estimated for the potential mitigation sectors. In the reference case (BAU), emissions increase up to 2030 in all sectors but forestry. Electricity emissions grow the most, and emissions increase significantly in the transport, waste and energy demand sectors. Forestry emissions decline after 2020 due to reduced clearing of forests and an increase in the size and number of trees, a result of tree-planting programs and reduced wood harvesting.

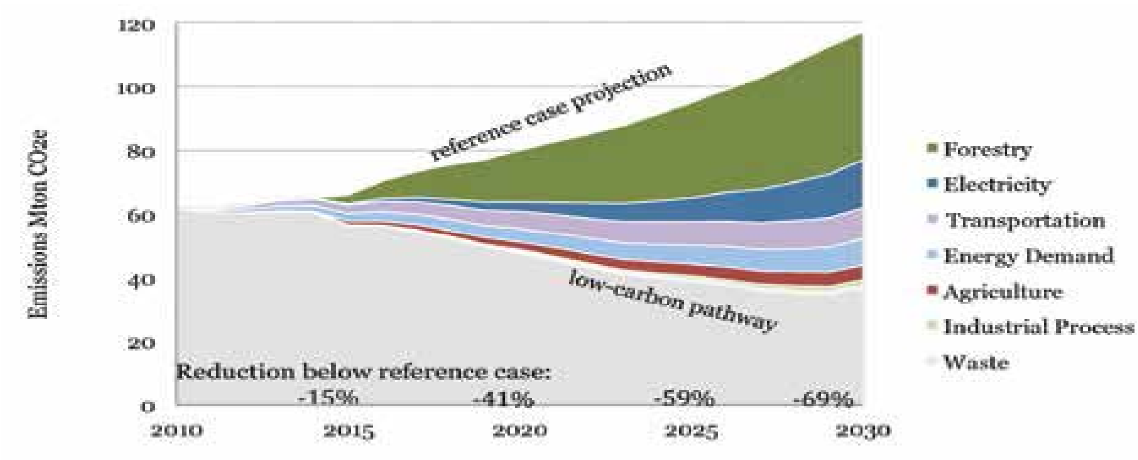


Figure 15. Composite abatement potential for all sectors (technical potential) (Source GoK CCAP Mitigation Analysis 2012)

In terms of ‘co-production’, the development of National Climate Change Action Plan was led by the National Climate Change Committee, facilitated by the National Climate Change Secretariat in the Ministry of Environment and Mineral Resources, with the support of a multi-sectoral and multi-stakeholder taskforces. Since the process involved many different societal stakeholders and sought inputs from many organizations and individuals, it can be considered ‘co-produced.’

6.5.2. National Adaptation Plan 2015-2030

A new National Adaptation Plan (NAP) has since been developed to succeed the National Climate Change Action Plan. The Adaptation Plan is based on and builds on the climate projections and scenarios presented in adaptation technical analysis report developed under the Action Plan. It analyzes the existing climate change institutional structures and proposes a comprehensive institutional framework. This proposed institutional framework has since been institutionalized in the 2016 Climate Change Act. The Adaptation Plan sets the normative vision of ‘enhanced climate resilience towards the attainment of Vision 2030 and beyond’. Drawing on the Action Plan and its adaptation technical analysis report, the Adaptation Plan presents current and future climate for Kenya. It also discusses climate hazards and risks in different sectors of the economy, and outlines adaptation actions to enhance resilience in the different sectors. The Adaptation Plan also recommends development of County Climate Change

Adaptation Plans. In the formulation of County Adaptation Plans (CAPs), the National Adaptation Plan encourages counties to identify their priority actions from those actions outlined at national level and customize them to suit their county contexts after conducting risk/vulnerability assessments. The National Adaptation Plan is anchored in the Constitution of Kenya and Vision 2030. It also aligned with the medium-term plan and medium-term expenditure framework planning processes and the 2016 Climate Change Act.

6.5.3. Kenya's Intended Nationally Determined Contribution

In line with the Cancun agreements, Kenya has also developed and submitted its Intended Nationally Determined Contribution (INDC) to the UNFCCC. In the INDC, Kenya specifies that its focus is more on adaptation. However, the INDC outlines both adaptation and mitigation measures that Kenya will undertake – with the support of the international community – to address climate change. The INDC set a normative vision, namely 'Achieve a low carbon, climate resilient development pathway', and time horizon of 2030 within which the vision is to be realized.

In terms of mitigation, Kenya seeks to abate its GHG emissions by 30% by 2030 relative to the BAU scenario of 143 MtCO2eq. This is to be realized through several strategies: Expansion in geothermal, solar and wind energy production, other renewables and clean energy options; Enhancement of Energy and resource efficiency across the different sectors; Making progress towards achieving a tree cover of at least 10% of the land area of Kenya; Development of clean energy technologies to reduce overreliance on wood fuels; Development of low carbon and efficient transportation systems; Implementation of climate smart agriculture (CSA) as outlined in the National CSA Framework; and Sustainable waste management systems. The abatement potential of each of these measures is as outlined in the sectoral plans above. The adaptation measures as though already spelled out in the NCCAP and NAP above.

There no direct linkage between the INDC and RCP x SSP. However, this can be implied. Kenya's INDC is directly linked to The Paris Climate Agreement and Decisions of COP 19 and COP 20. In terms of co-production' it can be argued that the INDC was co-produced. This is because the development of INDC built on the participatory multi-stakeholder and cross-sectoral consultative processes applied in development of National Climate Change Response Strategy and National Climate Change Action Plan at national and county levels. As noted above, the development of Action Plan involved consultations with a range of societal actors including government, civil society, development, CBOs, and research and academia.

6.5.4. The National Environment Policy, 2013

The objectives of this Policy include providing a framework for an integrated approach to planning and sustainable management of Kenya's environment and natural resources, strengthening the legal and institutional framework for good governance, effective coordination and management of the environment and natural resources and ensuring sustainable management of the environment and natural resources, such as unique terrestrial and aquatic ecosystems, for national economic growth and improved livelihoods.

6.5.5. Forest Conservation and Management Act, No. 34 of 2016 and Forest Policy 2014

The Forest Conservation and Management Act 2016 was enacted to give effect to Article 69 of the Constitution regarding forest resources and to provide for the development and sustainable management, including conservation and rational utilization of all forest resources for the socio-economic development of the forest adjacent communities. The Act acknowledges community participation in forest governance through establishment of community forest associations (CFAs). The Act also implements the Forest Policy 2014. This Policy seeks to balance the needs of the people of Kenya with opportunities for sustainable forest conservation, management and utilization. It set the target of achieving a forest cover of 10% of the land area of Kenya. The Policy (and the Act) are informed by the Constitution, National land policy, Land Act, 2012 as well as the National Climate Change Response Strategy, which underscores forestry's unique role in both climate change mitigation and adaptation.

6.5.6. Water Act No. 43 of 2016

Primarily, water is the basic ingredient for agriculture and survival of all biodiversity. The Constitution of Kenya acknowledges access to clean and safe water as a basic human right. The Water Act, 2016 provides for the regulation, management and development of water resources in line with the Constitution. The Act also gives priority to use of abstracted water for domestic purposes over irrigation. The act provides for establishment of Water Resource User Associations (WRUAs), which are community-based associations for collective management of water resources and resolution of conflicts concerning the use of water resources.

7. Conclusions and way forward

7.1. Terminology (Chapter 2)

There is broad agreement on what questions scenarios can help addressing; what types of scenarios exist; and how different scenarios could (or perhaps should) be combined. Socio-economic and climate scenarios can be integrated to model climate change impacts, thus addressing the question "what can happen?". Adaptation and/or mitigation scenarios should build on the climatic and socio-economic context provided by the RCPs and SSPs, through the use of multiple baselines with solutions depending on the context. These address the question "How can we reach a specific target?".

Despite this agreement, there is some confusion and disagreement between global and regional communities on the use of key terms to describe the characteristics of any type of scenario. Main sources of disagreement relate to whether scenarios should be classified as normative or exploratory and whether models are endogenously or exogenously used in combination with scenarios. Additionally, "projections", "pathways", and "integrated scenarios" have a slightly different meaning to regional and global scenario users and developers. Within the SENSES consortium, we had to partly agree to disagree. This is not problematic as the two communities aim for the same process, types of scenarios, and overall methodology, but use different words to explain it.

7.2. Co-production techniques (Chapter 3)

Two approaches to co-production are used in SENSES, "iterative interaction" at global level and "extended science" at regional level. Both aim at engaging in a transdisciplinary process of dialogue between scientists and a range of non-scientific stakeholders. The aim is either more at the use of existing scenarios to produce more useable climate information through a process of regular consultation, or at the development of new scenarios to create more robust and socially accountable science including a diversity of perspectives. The chapter documents over 60 co-production techniques, including an online database that provides a first overview of scenario development techniques that could guide the selection of suitable methods and/or tools.

7.3. Global scenarios (Chapter 4)

There are an enormous number of climate change scenario sets on global scale. A selection of these scenarios sets is made and sets are documented with factsheets that summarise guiding questions; results; source database location; and key publications. Scenario sets include among others climate change projections (CMIP); climate change impacts (e.g. ISIMIP); and mitigation scenarios (IAM simulation rounds).

7.4. Regional scenarios - the Netherlands (Chapter 5)

For the Dutch case study, multiple sets of existing scenarios were identified and described. These include three sets of socio-economic scenarios (national and provincial level); climate change scenarios (national); a range of sectoral scenarios and models (water, energy, agriculture) and particularly a large number of adaptation scenarios. Notably is the lack of mitigation scenarios. Socio-economic scenarios have barely been used when developing adaptation plans. Climate change scenarios are known, respected and a main source of scenario-information.

7.5. Regional scenarios – Kenya (Chapter 6)

For the Kenya case study, the most important socioeconomic scenario is the Vision 2030 and it's Big Four Agenda: food security, affordable housing, manufacturing and affordable healthcare for all. This is one single normative scenario expressing the future ambition of the country. There has been no attempt in the Kenyan context to relate to the set of SSPs. Regarding climate scenarios, all scenarios hitherto are based on the emissions scenarios of the SRES report. In the future work in SENSES in Kenya, Vision 2030 will be relate to the extended SSPs developed. Climate impacts scenarios for Kenya and beyond will be based on RCP/SSP combinations.

7.6. Next steps

In parallel to documenting existing scenarios and co-production techniques in this Deliverable, the co-production process started at global and regional level, using the material collected. At the time of writing, stakeholder workshops were organised at global level and in Kenya, and scoping interviews were conducted and analysed in the Netherlands. The co-production database was used in the selection of most suitable methods and will be improved as a result of it. The aim is to make this database online available for other users and continue to improve it.

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- Mainstreaming Kenya's National Climate Change Action Plan into the Health Sector (RoK, 2013e)

Annex 1: Factsheets of global scenarios

Climate change scenarios

The production of climate change scenarios is in general organized in individual simulation rounds, called 'studies'. These studies are mostly steered by a set of specific scientific questions. The factsheets provided in this document summarize the essential information about this study rounds. Hereby, great emphasis is applied that factsheets are written from a potential user's perspective, summarizing the most important facts for alleviated access. A factsheet briefly summarizes

- the guiding scientific questions
- the results
- the source database, where the raw data can be found
- publications
- policy briefs *[optional]*

The benefit of this formalized approach is manifold.

- The essential information of the study outcome becomes easier digestible for users. Using the same template for each scenario study alleviates mutual comparison. Further, describing each study in the same format supports orientation and comprehension in this diverse spectrum of multiple studies.
- The essential research questions and outcomes can be quickly grasped. They are summed up in a very high-level, abstract manner, no details like technical approaches or similar are allowed; only the questions to be answered and the results through the eyes of an external person, i.e. a stakeholder.
- The factsheets are stand-alone and can be used in a modular way also allowing to utilize them in different contexts outside this document.

CLIMATE CHANGE PROJECTIONS

STUDY TITLE: CMIP5

GUIDING QUESTIONS

- How does system earth develop under certain greenhouse gas concentrations? How will the system develop for the following quantitites of special interest: metereological quantities (temperature, precipitation, airpressure, wind, radiation), oceanic quantities, and landsurface quantities (evatranspiration, vegetation).

RESULTS

- See publications, too numerous. Main results are the actual data sets in this simulation round.

DATA SOURCES

CMIP5 Database

PUBLICATIONS

https://cmip-publications.llnl.gov/

IMPACT PROJECTIONS

STUDY TITLE: ISIMIP FASTTRACK

GUIDING QUESTIONS

- How good are we at telling the difference between a 1.5°C, 2°C, and a 3°C world?
- Where are the hotspots where multiple impacts coincide?
- How do impacts on one sector (e.g. changes in water availability) affect or dampen impact on other sectors (e.g. crop yields)?

RESULTS

Impact simulations cover five sectors: Water (11 participating models), Agriculture (7 participating models), Ecosystems (7 participating models), Infrastructure (1 participating model), Health (5 participating malaria models). Impact simulations are forced, i.e. by climate simulations (historical simulations + future projections until 2100) from 5 different global climate models and four different emission scenarios (RCPs) ranging from low to high Greenhouse Gas concentrations.

- Water (global): "Climate change is likely to exacerbate regional and global water scarcity considerably. In particular, the ensemble average projects that a global warming of 2 °C above present (approximately 2.7 °C above preindustrial) will confront an additional approximate 15% of the global population with a severe decrease in water resources and will increase the number of people living under absolute water scarcity (<500m3 per capita per year) by another 40% (according to some models, more than 100%). The projected population growth will lead to even more severe effects." (Schewe et al., PNAS, 2014)

- Agriculture: ISIMIP Global Gridded Crop Model (GGCM) simulations "indicate strong negative effects of climate change, especially at higher levels of warming and at low latitudes; models that include explicit nitrogen stress project more severe impacts. […] model agreement on direction of yield changes is found in many major agricultural regions at both low and high latitudes; however, reducing uncertainty in sign of response in mid-latitude regions remains a challenge. Uncertainties related to the representation of carbon dioxide, nitrogen, and high temperature effects […] show that further research is urgently needed to better understand effects of climate change on agricultural production and to devise targeted adaptation strategies." (Rosenzweig et al., PNAS, 2014)

- Biomes: "Future climate change and increasing atmospheric CO2 are expected to cause major changes in vegetation structure and function over large fractions of the global land surface. Seven global vegetation models are used to analyze possible responses to future climate simulated by a range of general circulation models run under all four representative concentration pathway scenarios of changing concentrations of greenhouse gases. All 110 simulations predict an increase in global vegetation carbon to 2100, but with substantial variation between vegetation models. For example, at 4 °C of global land surface warming (510–758 ppm of CO2), vegetation carbon increases by 52–477 Pg C (224 Pg C mean), mainly due to CO2 fertilization of photosynthesis. Simulations agree on large regional increases across much of the boreal forest, western Amazonia, central Africa, western China, and southeast Asia, with reductions across southwestern North America, central South America, southern Mediterranean areas, southwestern Africa, and southwestern Australia. Four vegetation models display discontinuities across 4 °C of warming, indicating global thresholds in the balance of positive and negative influences on productivity and biomass. Effects that counter CO2 fertilization are, among others, increased rates of evaporation or stomatal closure due to higher vapor pressure deficits. In contrast to previous global vegetation model studies, we emphasize the importance of uncertainties in projected changes in carbon residence times. We find, when all seven models are considered for one representative concentration pathway × general circulation model combination, such uncertainties explain 30% more variation in modeled vegetation carbon change than responses of net primary productivity alone, increasing to 151% for non-HYBRID4 models. A change in research priorities away from production and toward structural dynamics and demographic processes is recommended." Land use changes which are driven by demographic developments are also a major factor in determining future global vegetation and its role in the Earth system. Furthermore demographic prodesses also influence the global carbon balance. (Friend et al., PNAS, 2014)

- Health (malaria): "Malaria is an important disease that has a global distribution and significant health burden. The spatial limits of its distribution and seasonal activity are sensitive to climate factors, as well as the local capacity to control the disease. Malaria is also one of the few health outcomes that has been modeled by more than one research group and can therefore facilitate the first model intercomparison for health impacts under a future with climate change." The analysis of the ISIMIP Fast Track simulations indicate "an overall global net increase in climate suitability and a net increase in the population at risk [for malaria], but with large uncertainties. The model outputs indicate a net increase in the annual person-months at risk when comparing from RCP2.6 to RCP8.5 from the 2050s to the 2080s. The malaria outcome metrics were highly sensitive to the choice of malaria impact model, especially over the epidemic fringes of the malaria distribution."(Caminade et al., PNAS, 2014)

- Coastal infrastructure: "Without adaptation, 0.2–4.6% of global population is expected to be flooded annually in 2100 under 25–123 cm of global mean sea-level rise, with expected annual losses of 0.3–9.3% of global gross domestic product. Damages of this magnitude are very unlikely to be tolerated by society and adaptation will be widespread. The global costs of protecting the coast with dikes are significant with annual investment and maintenance costs of US$ 12–71 billion in 2100, but much smaller than the global cost of avoided damages even without accounting for indirect costs of damage to regional production supply. Flood damages by the end of this century are much more sensitive to the applied protection strategy than to variations in climate and socioeconomic scenarios as well as in physical data sources (topography and climate model). Our results emphasize the central role of long-term coastal adaptation strategies." (Hinkel et al., PNAS, 2014)

- Hotspots of climate change impacts: "Severe impacts of climate change" are determined across four categories (water discharge, crop yields, ecosystem change, length of malaria transmission season) based on a "leaving the world as we know it" indicator. This occurs when long term average conditions shift "into what is considered today moderately extreme, i.e. happening in only 10% of all years. This state occurs in all four sectors robustly at a mean global warming of 3 °C above the 1980–2010 mean, with 11% of the world population subject to severe impacts in at least two of the four impact sectors at 4 °C." (Piontek at al., PNAS, 2014).

DATA SOURCES

ISIMIP Fasttrack database

PUBLICATIONS

https://www.isimip.org/outcomes/publications

STUDY TITLE: ISIMIP2A

GUIDING QUESTIONS

- Model evaluation and representation of extreme events

- How well do impact models reproduce observed variations in impacts indicators? Are we able to reproduce extreme impact events?

RESULTS

To investigate the question different impacts models (global water models (13), regional water models (14), crop models (14), ecosystem models (8), fishery and marine ecosystem models (5), permafrost models (3)) are forced by historically observed weather fluctuations and direct human influences such as land use changes. Simulation cover the time period from 1901 to 2012.

- agriculture: “We find that [crop models forced by observed weather variations] can explain more than 50% of the variability in wheat yields in Australia, Canada, Spain, Hungary, and Romania. For maize, weather sensitivities exceed 50% in seven countries, including the United States. The explained variance exceeds 50% for rice in Japan and South Korea and for soy in Argentina. Avoiding water stress by simulating yields assuming full irrigation shows that water limitation is a major driver of the observed variations in most of these countries.” […] “Since process-based crop models not only account for weather influences on crop yields, but also provide options to represent human-management measures, they could become essential tools for differentiating these drivers, and for exploring options to reduce future yield fluctuations.” (Frieler et al., Earth’s Future, 2017)"
- water (global and regional): “Global hydrological models (GHMs) have been applied to assess global flood hazards, but their capacity to capture the timing and amplitude of peak river discharge—which is crucial in flood simulations—has traditionally not been the focus of examination.” […] “The [ISIMIP2a] runoff simulations were used as input for the global river routing model CaMa-Flood. The simulated daily discharge was compared to the discharge generated by each GHM [Global Hydrological Model] using its native river routing scheme. For each GHM both versions of simulated discharge were compared to monthly and daily discharge observations from 1701 GRDC stations as a benchmark. CaMa-Flood routing shows a general reduction of peak river discharge and a delay of about two to three weeks in its occurrence, likely induced by the buffering capacity of floodplain reservoirs. For a majority of river basins, discharge produced by CaMa-Flood resulted in a better agreement with observations. In particular, maximum daily discharge was adjusted, with a multi-model averaged reduction in bias over about 2/3 of the analysed basin area. The increase in agreement was obtained in both managed and near-natural basins. Overall, this study demonstrates the importance of routing scheme choice in peak discharge simulation, where CaMa-Flood routing accounts for floodplain storage and backwater effects that are not represented in most GHMs. Our study provides important hints that an explicit parameterisation of these processes may be essential in future impact studies.” (Fang et al., ERL, 2017)

DATA SOURCES

ISIMIP 2a database

PUBLICATIONS

https://www.isimip.org/outcomes/publications

STUDY TITLE: ISIMIP2B

GUIDING QUESTIONS

- “What are the climate impacts in a 1.5 °C world”

- "What are the climate induced effects at today's 1°C of global warming compared to the effects of historical changes in other direct human influences on Impact indicators?"

RESULTS

This round focuses on the impacts that are to be expected in a world with 1.5 °C, including up to 2°C, global warming. Climate input data are provided for two RCPs, the low emission RCP 2.6 (up to 2300) and business as usual emission scenario RCP 6.0 (up to 2100). For investigation of the pure climate effect, surrogate pre-industrial climate data has been provided in order to investigate the effects of climate change compared to the pre-industrial reference also considered in context of the UN climate negotiations. We consider three different groups of impact simulations: group 1: historical simulations accounting for observed changes in direct human influences (e.g. changes in land use patterns, water management etc.); group 2: future projections assuming fixed present day direct human influences; and group 3: future projections accounting for future projections of direct human influences (changes in population distributions, economic development (SSP2), and land use patterns etc.).

- Changes in the occurrence of extreme events (Lange et al., to be re-submitted): "The effects of climate change on different types of weather-induced disasters have largely been assessed individually. However, it is the joint impact of such events that threatens long-term economic development and leads to human migration, persistence of poverty, and social de-stabilisation. Here we use synchronized climate impact simulation ensembles to quantify historical and future changes in the extent of crop failures, river floods, tropical cyclones, heatwaves, wildfires, and droughts. Results show that climate change from pre-industrial conditions to today's 1°C global warming has almost tripled the fraction of the global population that is exposed to at least one such event per year whereas historical socioeconomic change alone would have slightly reduced this fraction. Future warming is projected to further increase global exposure approximately linearly up until 4°C. Particularly large increases are projected for low-latitude countries. Our analysis provides policy makers with a quantitative and comprehensive picture of climate change effects on the global population."

DATA SOURCES

ISIMIP 2b database

PUBLICATIONS

https://www.isimip.org/outcomes/publications

MITIGATION SCENARIOS

STUDY TITLE: CD-LINKS

GUIDING QUESTIONS

The CD-LINKS project is exploring the complex interplay between climate action and development, while simultaneously taking both global and national perspectives and thereby informing the design of complementary climate-development policies.

- How do national decarbonisation pathways that are collectively consistent with global well-below-2°C pathways look like?
- How do these low-carbon development pathways for the seven largest greenhouse gas emitters (China, the USA, the EU, India, Russia, Japan and Brazil) compare to each other and which sectoral mitigation measures are deployed?
- How much achieve currently implemented national policies and submitted NDCs on the way to limit temperature change to 1.5 and 2°C and how large is the emissions gap to cost-effective emissions pathways?
- What are implications of climate policy to achieve the 1.5 and 2°C targets for Sustainable Development Goals (SDGs)?
- How can adverse effects of climate policies on non-climate SDGs, e.g. on food security, be avoided?
- What are investment needs to limit temperature rise to 1.5 and 2°C and how do these compare to investment needs to achieve a subset of SDGs?

RESULTS

The CD-LINKS scenarios are analyzed from a set of different angles, including consistency of national action with global climate targets, investment needs and sustainable development implicaitons of climate policy consistent with the Paris Agreement. These analyses have been (and are being) published in a series of journal articles, part of which are listed below in relation to the high-level insights. In addition, a full Special Issue with national level analysis in selected G20 countries is currently in preparation.

- Roelfsema et al.: Seven G20 countries were assessed. Some seem on track to meet NDC targets with current policies, others display an ambition gap. Their NDCs are not on track with cost-efficient emission pathways which limit warming to well below 2°C. Current policies bring a reduction of 2 to 5.5 GtCO2eq. Additional policies and measures are required to fully implement the NDCs, which would reduce emissions by 7 to 17 GtCO2eq.The emissions gap in 2030 between planned national policies and a well below 2°C trajectory are 9 to 37 Gt. For a 1.5°C trajectory there is a gap of 17 to 43 Gt.
- Kriegler et al.: Although countries differ considerably in the sectoral composition of emission reductions, a robust pattern emerges, with an almost complete decarbonisation of the electricity sector by 2050 that is accompanied by accelerated electrification and a limited reduction of carbon intensity of fuel consumption in the industry, buildings and transport sectors.
- Krey et al.: Climate policies to achieve 1.5 and 2C potentially create both synergies and trade-offs with other SDGs, highlighting that integrated policy approaches are needed to ensure multiple SDGs are achieved simultaneously. In particular, dealing with undesirable distributional consequences of climate policies is key to avoid negative impacts on the poor, like ensuring food security and access to modern energy services.

- McCollum et al.: The Nationally Determined Contributions lack the pronounced reallocation of the investment portfolio needed for transforming the energy system. Charting a course toward 'well below 2 °C' instead requires that low-carbon investments overtake fossil investments globally before 2025 and then continue to grow from there. Pursuing the 1.5 °C target demands a marked up-scaling in low-carbon capital beyond that demanded by 2 °C. The investment needs for making progress on certain other SDG targets are small relative to those for energy.

DATA SOURCES

CD-LINKS Scenario Database

PUBLICATIONS

McCollum et al. (2018)

STUDY TITLE: PEP1P5

GUIDING QUESTIONS

The PEP project aims to answer crucial questions about the feasibility of 1.5°C scenarios, related to the feasibility of policies - contrasting immediate pricing only and scenarios with gradual ratcheting up of ambition. Further it assesses the implications of carbon dioxide removal (CDR) availability.

- To what extent can plausible bottom-up policy packages (sectoral policies like renewable support or efficiency targets as already observed in a number of countries) that are more ambitous than the NDCs close the emissions gap towards least-cost pathways?
- Which implementability challenges (grouped into scale, speed, disruption, price impacts and efficiency)are major hurdles for different policy scenarios?
- How do they differ between scenarios based on a range of regionally differentiated bottom-up policies and scenarios with a comprehensive and harmonized carbon price only (so called "first-best" or "cost-effective" scenarios)?
- What implications follow from the assumption of more strongly limited availability of carbon dioxide removal (CDR)?

RESULTS

The comparison across 3 different dimensions offer a rich exploration of implementability challenges.

- A global roll-out of strengthened bottom-up policies could reduce global CO2 emissions by an additional 10 GtCO2eq in 2030 compared to NDCs. It would lead to emissions pathways close to the levels of cost-effective well below 2°C and 1.5°C scenarios until 2030, thereby reducing implementation challenges post 2030.

- Comparing a gradual phase-in of a portfolio of regulatory policies with immediate cost-effective carbon pricing shows that the bottom-up policies might be less disruptive. However, they would perform worse in other dimensions. In particular, they lead to higher economic costs. Hence, such policy packages should not be viewed as alternatives to carbon pricing, but rather as complements that provide entry points to achieve the Paris climate goals.

- Assuming lower availability of CDR implies faster and more disruptive near-term decarbonization.

DATA SOURCES

SR1.5 database

PUBLICATIONS

Kriegler et al. (2018)

STUDY TITLE: ADVANCE

GUIDING QUESTIONS

The study aims to contribute the first multi-model assessment of Paris Agreement scenarios, exploring both the emission impacts of NDC until 2030 and strengthening scenarios that achieve the long-term targets of 2 or 1.5°C, with strengthening either after 2020 or 2030

- · What energy system transformations are implied by nationally determined contributions (NDCs) for 2030, and how do they differ from transformations in cost-optimal pathways reaching the Paris Agreements (PA) long-term targets of well-below 2°C and 1.5°C?

- · How much residual emissions occur in different sectors in 2°C and 1.5°C scenarios, and what are the determinants for those?

- · What implications does failure to strengthen ambition before 2030 have for individual energy sectors and for achievability of the long-term targets?

RESULTS

Aggregate NDC ambition level is not in line with long-term Paris Agreement targets. These targets require full decarbonization of energy system, for which electrification, decarbonization of power supply and increase in low-carbon fuels are required.

- Aggregate NDC ambition level is not in line with long-term Paris Agreement (PA) targets, emissions gap to cost-optimal 2°C and 1.5°C pathways in 2030 already between 9-29 Gt CO2eq.

- Higher ambition would only lead to modest increases of mitigation cost (not accounting for avoided damages and co-benefits).

- If countries fail to strengthen ambition before 2030, they lock-in more residual fossil emissions, which leads to a higher overshot of the net emissions budgets implied by the long-term targets, so that more carbon dioxide removal (CDR) is then needed to still meet the targets. On the other hand, failure to strengthen before 2030 also compromises the ability to scale-up negative emission options at tolerable costs.

DATA SOURCES

ADVANCE database

PUBLICATIONS

Zoi Vrontisi et al 2018 Environ. Res. Lett. 13 044039

STUDY TITLE: EMF33

GUIDING QUESTIONS

Objective: Assessing large-scale global bioenergy deployment for managing climate change.

- How is bioenergy used across different IAMs under harmonized variations of climate policies, availability of bioenergy technologies and constraints on biomass supply?

RESULTS

- Imposing a range of increasingly stringent carbon budgets mostly increases bioenergy use. Sector and regional bioenergy allocation varies dramatically mainly due to bioenergy technology options, final energy patterns and availability of alternative options of energy sector de-carbonization.
- Although much bioenergy is used in combination with CCS (BECCS), it is not necessarily the driver of bioenergy use.
- The flexibility to use biomass feedstocks in the energy sector makes large-scale bioenergy deployment a robust strategy in mitigation scenarios that is surprisingly insensitive with respect to reduced technology availability.
- However, the impact on achievability of stringent carbon budgets and associated carbon prices is sensitive, if the availably of e.g. BECCS is reduced.

DATA SOURCES

EMF33 Scenario Database

PUBLICATIONS

Bauer et al. (2018)

STUDY TITLE: CEMICS

GUIDING QUESTIONS

CEMICS is driven by the hypothesis that society will not take decisions on climate engineering (CE) in isolation, but in consideration of the whole portfolio of existing climate policy options. The work within that project puts CE in the context of mitigation by exploring synergies, trade-offs, and side-effects of different CDR methods. Please note: The project itself investigated the options of CE in a broader context also towards potential synergies or ethical aspects. This research however is not based on scenarios and thus not treated here.

- How much CDR is at least necessary to achieve the Paris climate targets?
- How does this minimum CDR requirement depend on short-term climate policy and medium-term emission reductions?

RESULTS

Strefler et al. 2018: There are major concerns about the sustainability of large-scale deployment of carbon dioxide removal (CDR) technologies. It is therefore an urgent question to what extent CDR will be needed to implement the long-term ambition of the Paris Agreement, and how this depends on short-term climate policy. In this paper we show that ambitious near-term mitigation significantly decreases CDR requirements to keep the Paris climate targets within reach.

- Following the NDCs until 2030 requires then both fast CO2 emission reductions until 2050 and high amounts of CDR to achieve the 2°C-target. Reducing 2030 emissions by 20% below NDC levels already alleviates the trade-off between high transitional challenges and high CDR deployment.
- In order to achieve 2°C entirely without CDR, emissions have to be roughly halved until 2030 and again every decade until 2050.
- Transitional challenges can only be kept in check if at least 5 Gt CO2/yr CDR are available in any year. At least 8 Gt CO2/yr CDR are necessary in the long term to achieve 1.5°C and more than 15 Gt CO2/yr to keep transitional challenges in bounds.

Kreidenweis et al., 2018 (data is NOT available in any database): This study assessed global and regional food price impacts of afforestation. Afforestation was incentivized by a globally uniform reward for carbon uptake in the terrestrial biosphere.

- This resulted in large-scale afforestation (2580 Mha globally) and substantial carbon sequestration (860 GtCO2) up to the end of the century.
- However, it was also associated with an increase in food prices of about 80% by 2050 and a more than fourfold increase by 2100. When afforestation was restricted to the tropics the food price response was substantially reduced, while still almost 60% cumulative carbon sequestration was achieved.

DATA SOURCES

SR1.5 database

PUBLICATIONS

Strefler et al. (2018)
Strefler et al. (2018)
Kreidenweis et al. (2016)

STUDY TITLE: LED

GUIDING QUESTIONS

Scenarios that limit global warming to 1.5 °C describe major transformations in energy supply and ever-rising energy demand. Here, we provide a contrasting perspective by developing a narrative of future change based on observable trends that results in low energy demand.

- How does a narrative of future change based on observable trends which results in low energy demand look like?
- Which quantitative changes in activity levels and energy intensity are required in the Global North and South for all major energy services consistent with the low energy demand narative?
- Is it possible to limit global warming to 1.5 °C without relying on controversial negative emissions technologies such as bioenergy with carbon capture and storage (BECCS)?
- What are sustainable development co-benefits of a low energy demand transformation?

RESULTS

- We find that global final energy demand by 2050 can be reduced to 245 EJ, around 40% lower than today's levels despite rising population, income and activity and show how changes in the quantity and type of energy services drive structural change in intermediate and upstream supply sectors (energy and land use).
- Down-sizing the global energy system dramatically improves the feasibility of low-carbon supply-side transformation by renewables and electrification. Our scenario meets 1.5°C climate and other sustainable development goals, without relying on controversial negative emission technologies.

DATA SOURCES

Low Energy Demand (LED) Database

PUBLICATIONS

Grubler et al. (2018)

STUDY TITLE: UBA SMP

GUIDING QUESTIONS

The study aims to contribute to the understanding of key sustainability impacts of mitigation pathways, and how they can be managed by policy choice in order to maximize benefits and minimize risks.

- What sustainability effects (benefits and risks) does mitigation targets of 2 and 1.5°C imply?
- How does the choice of mitigation policy paradigm impact the sustainability effects (benefits and risks) of mitigation?
- How do different measures interact?

RESULTS

The study analyses a range of crucial sustainability indicators for 2 different temperature targets achieved by 5 different policy approaches respectively.

- Mitigation leads to a number of sustainability benefits (air pollution, cooling water requirements), but under default policies also leads to severe risks (uranium use, food and energy price increases, land requirements for bioenergy, etc.). Both benefits and risks increase if ambition is raised from 2 to 1.5°C.
- A combination of additional policies (direct sector-level regulation, early mitigation action, and lifestyle changes) can alleviate air pollution, water extraction, uranium extraction, food and energy price hikes, and dependence on negative emissions technologies, thus resulting in substantially reduced sustainability risks associated with mitigating climate change.
- Importantly, we find that these targeted policies more than compensate for most increased sustainability risks of increasing climate ambition from 2°C to 1.5°C.

DATA SOURCES

SR1.5 database

PUBLICATIONS

Bertram et al. (2018)

STUDY TITLE: IMAGE 1.5

GUIDING QUESTIONS

CDR strategies face several difficulties such as reliance on underground CO2 storage and competition for land with food production and biodiversity protection. The question arises whether alternative deep mitigation pathways exist?

- How essential are bioenergy with carbon capture and storage, and other negative-emission technologies for the 1.5 degree target?

RESULTS

The study illustrates how a combination of alternative 1.5°C pathways can significantly reduce the need for CDR. They are based on the inclusion of options which are not normally considered in integrated assessment analyses, such as lifestyle change, significant reductions of greenhouse gas emissions other than CO2, swift electrification of energy demand and low population growth. While each of these alternatives will still require rapid societal changes and faces its own specific barriers, several also show important synergies with other sustainability goals.

- While this study shows that alternative options can greatly reduce the volume of CDR to achieve the 1.5°C goal, nearly all scenarios still rely on BECCS and/or reforestation (even the hypothetical combination of all alternative options still captured 400GtCO2 by reforestation). Therefore, investment in the development of CDR options remains an important strategy if the international community intends to implement the Paris target.

DATA SOURCES

SR1.5 database

PUBLICATIONS

Van Vuuren et al. (2018)

STUDY TITLE: SSP

GUIDING QUESTIONS

The SSPs are part of a scenario framework, established by the climate change research community in order to facilitate the integrated analysis of future climate impacts, vulnerabilities, adaptation, and mitigation. The framework is built around a matrix that combines climate forcing on one axis (as represented by the Representative Concentration Pathways (RCPs)) and socio-economic conditions on the other. Together, these two axes describe situations in which mitigation, adaptation and residual climate damage can be evaluated.

- In the absence of climate policy, how do scenarios based on the five different SSP narratives unfold in the future?

- Across the different narratives, how does the challenge to climate mitigation compare when trying to limit global forcing levels consistent with those of the RCPs, going as low as 2.6W/m2?

RESULTS

The SSPs are based on five narratives describing alternative socio-economic developments, including sustainable development, regional rivalry, inequality, fossil-fueled development, and middle-of-the-road development. The long-term demographic and economic projections of the SSPs depict a wide uncertainty range consistent with the scenario literature. A multi-model approach was used for the elaborati

- The baseline scenarios lead to global energy consumption of 400–1200 EJ in 2100. The associated annual CO2 emissions of the baseline scenarios range from about 25 GtCO2 to more than 120 GtCO2 per year by 2100.
- With respect to mitigation, the scenarios show that associated costs strongly depend on three factors: (1) the policy assumptions, (2) the socio-economic narrative, and (3) the stringency of the target. The carbon price for reaching the target of 2.6 W/m2 that is consistent with a temperature change limit of 2 °C, differs in the analysis thus by about a factor of three across the SSP marker scenarios. Consistent with the narratives, mitigation costs and thus the challenge for mitigation is found lower in SSP1 & SSP4 relative to SSP3 & SSP5. Perhaps most importantly, we find that not all targets are necessarily attainable from all SSPs

DATA SOURCES

SSP Database

PUBLICATIONS

Riahi et al. (2017)
Rogelj et al. (2018)
O'Neil et al. (2017)
KC et al. (2017)
Dellink et al. (2017)
Leimbach et al. (2017)
Crespo (2017)
Jiang et al. (2017)
Bauer et al. (2017)
Rao et al. (2017)
Popp et al. (2017)
van Vuuren et al. (2017)
Fricko et al. (2017)
Fujimori et al. (2017)
Calvin et al. (2017)
Kriegler et al. (2017)
van Vuuren et al. (2017)
Marangoni et al. (2017)

STUDY TITLE: EMF 27

GUIDING QUESTIONS

The EMF27 study presents a first detailed assessments of the energy system transformation requirements for low stabilization in a large ensemble of leading global integrated assessment models.

- What energy system transformations are required to achieve stabilization of concentrations at 450ppm or 550ppm CO2eq in 2100?
- How do eight different assumptions on technology availability impact such stabilization scenarios?

RESULTS

Limiting the atmospheric GHG concentration to 450 or 550 ppm CO2 equivalent by 2100 would require a decarbonization of the global energy system in the 21st century. Technology is a key element of climate mitigation.

- Robust characteristics of the energy transformation are increased energy intensity improvements and the electrification of energy end use coupled with a fast decarbonization of the electricity sector. Non-electric energy end use is hardest to decarbonize, particularly in the transport sector.
- Versatile technologies such as CCS and bioenergy are found to be most important, due in part to their combined ability to produce negative emissions.
- The importance of individual low-carbon electricity technologies is more limited due to the many alternatives in the sector.
- The scale of the energy transformation is larger for the 450 ppm than for the 550 ppm CO2e target. As a result, the achievability and the costs of the 450 ppm target are more sensitive to variations in technology availability.

DATA SOURCES

AR5 database

PUBLICATIONS

Kriegler et al. (2014)
Krey et al. (2014)
Luderer et al. (2014)

STUDY TITLE: AMPERE

GUIDING QUESTIONS

The AMPERE project aimed to improve our understanding of possible pathways toward medium- and long-term climate targets at the global and European levels. The project assessed key aspects of the mitigation challenge in a world of delayed and fragmented climate policy. WP2 of AMPERE specifically focused on "Delayed policy action and path dependency in energy systems"

- How do short-term climate policies impact the achievability of long-term climate targets?
- What is the role of different technologies and their innovation in meeting long-term climate targets?
- What impacts do fragmented policy regimes (with a coalition of front-runners and staged accession of others) have on achievability of long-term targets and global energy systems?
- What advantages and disadvantages have the frontrunners and late-comers respectively?
- How much carbon leakage is caused by fragmented policies?

RESULTS

This study explores a situation of staged accession to a global climate policy regime from the current situation of regionally fragmented and moderate climate action. The analysis is based on scenarios in which a front runner coalition – the EU or the EU and China – embarks on immediate ambitious climate action while the rest of the world makes a transition to a global climate regime between 2030 and 2050. We assume that the ensuing regime involves strong mitigation efforts but does not require late joiners to compensate for their initially higher emissions. Delaying global climate mitigation action until 2030 would require an unprecedented and more costly transformation of the global energy system in the decades that follow.

- Although staged accession can achieve significant reductions of global warming, the resulting climate outcome is unlikely to be consistent with the goal of limiting global warming to 2 degrees. The addition of China to the front runner coalition can reduce pre-2050 excess emissions by 20–30%, increasing the likelihood of staying below2 degrees.
- Given the limited remaining carbon budget in order to achieve 2°C, a weak short-term policy results in a majority of the compensation for the delayed action to occur over a twenty-year period between 2030 and 2050. The portion of global energy supplied by low-carbon options would need to quadruple in this period, meaning that almost 50% of the global energy supply infrastructure would need replacement. As a result, mitigation costs would rise between 10-40%, relative to a scenario where immediate action is taken.
- Delayed action until 2030 also increases future reliance on specific mitigation options. The longer climate action is delayed, the higher the future dependency on carbon capture and storage (combined with both fossil and biomass) becomes. On the other hand, reducing energy demand by means of increasing energy efficiency contributes towards not only the achievability of the 2°C target, but also results in mitigation cost reductions. Consistently across scenarios, new investments in unabated coal-fired power plants (i.e., without carbon capture and storage, CCS) should be avoided, if ambitious climate goals are to be achieved.
- Not accounting for potential co-benefits, the cost of front runner action is found to be lower for the EU than for China.

- Regions that delay their accession to the climate regime face a trade-off between reduced short term costs and higher transitional requirements due to larger carbon lock-ins and more rapidly increasing carbon prices during the accession period.

DATA SOURCES

AMPERE database

PUBLICATIONS

Riahi et al. (2015)
Kriegler et al. (2015)
Kriegler et al. (2015)
Bertram et al. (2015)
Johnson et al. (2015)
Eom et al. (2015)
Kriegler et al. (2014)
Kriegler et al. (2015)
Bauer et al. 2015

STUDY TITLE: LIMITS

GUIDING QUESTIONS

This study provides a novel and comprehensive model-based assessment of possible outcomes of the Durban Platform negotiations with a focus on emissions reduction requirements, the consistency with the 2°C target and global economic impacts.

- How do short-term policies (contrasting “lenient” with “stringent” bottom-up formulations) until 2020 impact the achievability of long-term stabilization at 450ppm or 500ppm CO2eq in 2100?
- What are the differences between scenarios following bottom-up policies until 2020 or 2030 before starting comprehensive coordinated action?
- How do mitigation costs for these pathways differ across regions?

RESULTS

The study yields important insights on the distribution of mitigation costs across regions.

- The challenges of implementing a long term target after a period of fragmented near-term climate policy can be significant as reflected in steep reductions of emissions intensity and transitional and long term economic impacts.

- Our results indicate that a policy with uniform carbon pricing and no transfer payments would yield an uneven distribution of policy costs, which would be lower than the global average for OECD countries, higher for developing economies and the highest, for energy exporters.

DATA SOURCES

AR5 database

PUBLICATIONS

Kriegler et al. (2013)
Tavoni et al. (2013)
Tavoni et al. (2014)
http://www.feem-project.net/limits/docs/limits_policy%20brief%20on%20policy%20analysis_en.pdf
http://www.feem-project.net/limits/docs/limits_pb.pdf

STUDY TITLE: ROSE

GUIDING QUESTIONS

- How do assumptions on fossil fuel availability and economic growth affect stabilization pathways for 450 and 550 ppm CO2eq concentrations in 2100?

- How does a continuation of fragmented low-ambition climate policies until 2030 affect the achievability of the 450 target?

- How are resource rents of fossil fuels on international markets affected by climate policy?

RESULTS

- The influence of economic growth and fossil resource assumptions on climate mitigation pathways is relatively small due to overriding requirements imposed by long-term climate targets. While baseline assumptions can have substantial effects on mitigation costs and carbon prices, we find that the effects of model differences and the stringency of the climate target are larger compared to that of baseline assumptions. We conclude that inherent uncertainties about socio-economic determinants like economic growth and fossil resource availability can be effectively dealt with in the assessment of mitigation pathways. (Kriegler et al. overview)

- We find that after a deferral of ambitious action the 450 ppm CO2e is only achievable with a radical up-scaling of efforts after target adoption. This has severe effects on transformation pathways and exacerbates the challenges of climate stabilization, in particular for a delay of cooperative action until 2030. Specifically, reaching the target with weak near-term action implies (a) faster and more aggressive transformations of energy systems in the medium term, (b) more stranded investments in fossil-based capacities, (c) higher long-term mitigation costs and carbon prices and (d) stronger transitional economic impacts, rendering the political feasibility of such pathways questionable. (Luderer et al.)

- Achieving ambitious climate targets will drastically reduce fossil fuel consumption, in particular the consumption of coal. Conventional oil and gas as well as non-conventional oil reserves are still exhausted to a large extent. We find the net present value of fossil fuel rent until 2100 at 30tril.US$ with a large share of oil and a small share of coal. This is reduced by 9 and 12tril.US$ to achieve climate stabilization at 550 and 450 ppm CO2-eq, respectively. This loss is, however, overcompensated by revenues from carbon pricing that are 21 and 32tril.US$, respectively. The overcompensation also holds under variations of energy demand and fossil fuel supply. (Bauer et al.)

DATA SOURCES

AR5 database

PUBLICATIONS

Kriegler et al. (2016)
Kriegler et al. (2016)
de Cian et al. (2013)
Calvin et al. (2013)
Bauer et al. (2013)
Cherp et al. (2013)
Chen et al. (2013)
Calvin et al. (2013)
Luderer et al. (2013)
Schäfer et al. (2013)

STUDY TITLE: UBA EMC

GUIDING QUESTIONS

The study analyses various economic mitigation challenges in a broad range of scenarios, varying the carbon tax, technology assumption and start data of ambitious policies in a set of 300 scenarios.

- How do the four crucial economic mitigation challenges - short- and long-term costs, energy price increase and total carbon value - increase with climate target stringency, i.e. lower temperature targets?
- How are the temperature-challenge trade-off curves for the four economic mitigation challenges shifted under different assumptions on technology availability and policy delay?

RESULTS

The study analysis various trade-off curves, each with temperature on the horizontal and different economic challenges on the vertical axis.

- The trade-off curves for all four analyzed economic challenges (short- and long-term costs, energy price increase and total carbon value, i.e. aggregated payments in emission pricing schemes) are highly convex, with strongly increasing costs for lower targets, practically setting a lower limit to achievable targets. If the temparature axis of the trade-off curve is using maximum temperatures (instead of 2100 temperature), this is even more pronounced.
- Both, assuming a delay of stringent policies or assuming non-availability of crucial technologies (bioenergy and or CCS) shifts the curve to higher temperatures.

DATA SOURCES

SR1.5 database

PUBLICATIONS

Luderer et al. (2013)
Luderer et al. (2013)

STUDY TITLE: GEA

GUIDING QUESTIONS

The main purpose of the GEA has been to establish a state-of-the-art assessment of the science of energy in light of the inevidable transformation that is required to address major challenges and avoiding potentially catasgtrophic future consequences for humand kind and planetary systems. The transformation pathways developed within the framework of the GEA are designed to explore technical measures, policies, and related costs and benefits for meeting the following energy objectives: - Improving energy access: Universal access to electricity and clean cooking by 2030 - Reduce air pollution and improve human health: Achieve global compliance with World Health Organization (WHO) air quality standards (PM2.5 concentration < 35 µg/m3) by 2030 - Avoid dangerous climate change: Limit global average temperature change to 2°C above preindustrial levels with a likelihood >50% - Enhance energy security: Reduce energy import dependence; increase diversity and resilience of energy supply (both by 2050)

- Which are the fundamental key-messages common to the scenario ensemble?
- Is universal access to modern energy carriers and cleaner cooking achievable by 2030 while limiting long term global warming to 2°C?

RESULTS

The pathways show that it is technically possible to achieve improved energy access , air quality, and energy security simultaneously while avoiding dangerous climate change. In fact, a number of alternative combinations of resources, technologies, and policies are found capable of attaining these objectives. From a large ensemble of possible transformations, three distinct groups of pathways (GEA-Supply, GEA-Mix, and GEA-Efficiency) have been identified and analyzed.

- Limiting climate change to to 2°C will require a technological transformation of the global energy system over the next several decades, as well as the rapid introduction of policies and fundamental political changes toward concerted and coordinated efforts to integrate global concerns into local and national policy priorities. The GES analysis demonstrates that a sustainable future requires a transforamtion from today's energy systems to those with: (i) radical improvements in energuy systems, especially in the end-use, and (ii) greater shares of reneable energies and advanced energy systems with carbon capture and storage (CCS) for both fossil fuels and biomass.
- Achieving universal access to clean cooking fuels and electricity requires that between US$36 billion and US$41 billion be spent annually over the next two decades. In addition to furthering human development and poverty alleviation goals, universal access is necessary for attaining World Health Organization guidelines for air quality in all countries by 2030. At the same time, in order to ensure a high likelihood of limiting global warming to 2°C, global CO2 emissions need to peak by about 2020 and then be reduced 30–70% by 2050 relative to 2000. Under the GEA pathways, energy security improves in the world as a whole and in the majority of regions: imports decline and supply diversity increases.

DATA SOURCES

GEA Scenario Database
IIASA ENE-MCA Policy Analysis Tool
IIASA Energy Access Tool (ENACT)

PUBLICATIONS

McCollum et al. (2011)
McCollum et al. (2013)
McCollum et al. (2012)
Rogelj et al. (2013)
Rao et al. (2013)

STUDY TITLE: EMF22

GUIDING QUESTIONS

The EMF 22 International Scenarios engaged ten of the world's leading integrated assessment models to focus on the combined implications of three factors integral to international climate negotiations, (1) the long-term climate-related target, expressed in this study in terms of the CO2-equivalent concentration associated with the GHGs regulated under the Kyoto Protocol, (2) whether or not this target can be temporarily exceeded prior to 2100 ("overshoot") allowing for greater near-term flexibility, and (3) the nature of international participation in emissions mitigation.

- What are the feasibility and implications of stabilizing greenhouse gas concentrations at 650, 550 or 450 ppm CO2eq?
- What are the implications of allowing a temporary exceedence of greenhouse gas concentrations 2100 ("overshoot") vs. implementing concentration targets as ceilings over the entire century ("not-to-exceed")?
- What are the implications of comprehensive international collaboration vs. fragmented climate policy efforts towards the climate targets?
- individual models explored the importance of economic growth and the availability of bioenergy with carbon capture and storage (BECCS)
- low vs. high technology development for achieving different climate targets

RESULTS

The challenge of mitigation increases with the stringency of the target. The more ambitious target (450 ppm CO2e, consistent with the 2°C-limit) is particularly challenging.

- The achvievabiltiy and costs of achieving climate targets depends critically on target stringency and the degree of internationl collaboration. A failure to develop a comprehensive, international approach to climate mitigation will constrain efforts to meet ambitious climate related targets. Without early, comprehensive action by major emitting regions, concentrations may exceed particularly ambitious targets such as 450 ppmv CO2-e and even 550 ppmv CO2-e.
- Regardless of the target, the global costs of achieving any long-term climate-related target will be higher without comprehensive action, and may be higher not just for the initial entrants but also for those that join along the way.
- The ability to temporarily exceed, or overshoot, long-term goals may make some of the more stringent long-term climate limitation goals more achievable and lessen the impacts of a failure to achieve comprehensive action, but these pathways come at a cost. Overshoot pathways will lead to greater climate impacts than pathways that keep concentrations below their long-term goal at all times.

DATA SOURCES

AR5 Database

PUBLICATIONS

Clarke et al. (2009)

STUDY TITLE: GGI

GUIDING QUESTIONS

The main objective of the exercise has been to explore the feasibility and costs of meeting alternative climate stabilization targets under a range of salient long-term uncertainties with a limited set of scenarios. Development pathway uncertainty, which includes alternative demographic, economic, and technological developments that lead to high (A2r), intermediary (B2), or low (B1) emissions of GHGs and hence magnitude of future climate change. Climate stabilization target uncertainty is addressed by systematic model simulations for a range of alternative climate stabilization targets imposed on the no-policy baseline scenarios. Altogether, calculations for 11 stabilization scenarios for eight comparable stabilization levels has been performed.

- How will human drivers ranging from the realm of demographics, economics, and technology to social behavior and institutions shape future emissions of greenhouse gases (GHGs)?
- Are there ways of "bending down" the curve of ever increasing radiative forcing?
- What will be the consequences of radiative forcing change on global, regional, as well as local climates both in terms of changes in magnitude (e.g., warming, precipitation) as well as in nature (most prominently variability and possibilities of extreme events)?
- What will be the impacts on natural and human systems of a changing climate?
- what are the feasibilities, costs, and benefits (in terms of avoided impacts) of response strategies?

RESULTS

The GGI scenario analysis has illustrated the importance of considering the two most fundamental uncertainties that surround future efforts to mitigate against climate change: - uncertainty of magnitude of future emission levels as described by alternative scenario baselines; - uncertainty that surrounds the ultimate mitigation target (i.e., the stabilization levels). Feasibility and costs, as well as the technological options needed to meet alternative climate stabilization goals all, depend critically on these two types of uncertainties.

- From all the variables required to frame the fundamental uncertainties involved in the climate debate, technology emerges as a particularly important area.
- An important finding from our sectorial analysis is that the energy and industry sectors will play a central role in achieving the drastic reductions in GHG emissions required for climate stabilization.
- Agriculture and forestry play a less important role in emissions reductions in absolute terms, but nonetheless are indispensable elements of a comprehensive and cost-effective mitigation portfolio. Emissions reductions from agricultural sources are comparatively important only at less stringent stabilization levels. Conversely, the forestry sector gains in importance with the stringency of the target (and thus higher marginal GHG reduction costs).
- The three top-ranked mitigation options comprise reductions through the additional deployment of biomass, nuclear, and demand-side measures, such as enhanced energy conservation and efficiency improvements.

- Large-scale CCS (beyond forest sink enhancements) portray the classic features of a 'backstop' technology. They are deployed on a massive scale only in unfavorable scenario baselines (e.g., the coal-intensive scenario A2r) or in combination with stringent stabilization targets.
- Global macroeconomic costs of climate policies would be relatively modest, especially when compared to the scenario's underlying economic growth assumptions.

DATA SOURCES

GGI Scenario Database

PUBLICATIONS

Riahi K, Nakicenovic N (eds) (2007). Greenhouse Gases - Integrated Assessment, Technological Forecasting and Social Change

STUDY TITLE: CLIMACAP-LAMP

GUIDING QUESTIONS

The Integrated Climate Modelling and Capacity Building Project in Latin America (CLIMACAP) was a European Commission funded effort focused on analyzing the effects of mitigation strategies in key Latin American Countries. The Latin American Modeling Project (LAMP) was a similar effort funded by the U.S. Environmental Protection Agency and the U.S. Agency for International Development. The projects collaborated to develop a multi-model comparison project focused on mitigation in Latin America. The study compared results of approximately 10 energy-economic and integrated assessment models, focusing on results for Latin American regions.

- What is the role of Latin American and countries in the region in meeting global mitigation goals?
- What are opportunities for energy technology deployment under climate change mitigation efforts in Latin America?
- What energy supply investment are required in Latin America to meet global mitigation goals?
- What are the impacts of a variety of climate change control policies in the Argentinian energy sector?
- What will be effects of market-based mechanisms and CO2 emission restrictions on the Brazilian energy system?
- What role plays the power sector in achieving CO2 emission reductions in Colombia?
- How can Mexico reverse current emission trends which are at odds with ambitious national GHG emission reduction targets?

- Are the commitments by Brazil and Mexico for 2020, made during the UNFCCC conferences in Copenhagen and Cancun (prior to the formulation of their NDCs) reachable?
- How will future trajectorioes of GHG emissions from AFOLU develop in Latin America, with and without climate mitigation?
- What are the macroeconomic consequences of GHG emissions mitigation in Latin America up to 2050?

RESULTS

The academic outcome of our work, includes two basic sorts of papers. One set of articles reports the efforts of teams that, through multiple models, investigated individual countries on the Latin American continent, exploring key elements and sensitivities for Argentina, Brazil, Colombia and Mexico. The second set of papers represents the work of several subgroups that explored specific issues across multiple countries and models, such as baseline scenarios, climate mitigation potential, and key characteristics and requirements of climate mitigation, including technology diffusion, investment requirements, biomass, agriculture and land-use effects, and macroeconomic impacts.

- The economic potential to reduce fossil fuel CO2 as well as non-CO2 emissions in Latin America in 2050 is lower than for the world as a whole, when measured against 2010 emissions.
- Electricity generation in Latin America increases two- to three-fold between 2010 and 2050 in the baseline.
- Energy supply investment requirements in Latin America are doubling in the baseline scenario between 2010 and 2050, while investments may triple over the same time horizon when climate policies are introduced.
- Emissions will increase over time in the baseline scenario due to a higher penetration of natural gas and coal. Climate policy scenarios with sufficiently high CO2 prices, however, indicate that such pathways can be avoided.
- The study confirms that the power sector plays a fundamental role in achieving CO2 emission reductions in Colombia, particularly through the increase of hydropower, the use of wind energy and the deployment of CCS technology.
- Decarbonization of electricity generation is needed to meet Mexico's national GHG emission reduction targets. Along with changes in transportation towards the use of more efficient vehicles, potentially in combination with the use of low-carbon fuels. Mexico has some technological flexibility in meeting deep mitigation targets, although the costs of deep mitigation may be higher than official estimates indicate.
- Brazil's commitments (made during the UNFCCC conferences in Copenhagen and Cancun) could be met through reduced deforestation, at basically no additional cost, while Mexico's pledges could cost around 4 billion US$ in terms of reduced GDP in 2020.
- Nearly 40% of GHG emissions in Latin America derive from agriculture, forestry and other land use, more than double the global fraction of AFOLU . They find significant uncertainty in future AFOLU emissions, both with and without mitigation.

DATA SOURCES

CLIMACAP-LAMP Scenario database
CLIMACAP web site.

PUBLICATIONS

van der Zwaan, B.C.C., K. Calvin, L. Clarke (Guest Editors), Climate Mitigation in Latin America: Implications for Energy and Land Use:, Energy Economics, 2016

STUDY TITLE: AIM/CGE 2.0

GUIDING QUESTIONS

The study aims to explore how to reduce mitigation cost from the social economic aspects

- Which socioeconomic factors are most essential to the mitigation costs of stringent climate goals?
- Through which channels do they affect the mitigation costs for stringent mitigation?
- What is unique about the 1.5 °C goal, as compared to the 2 °C goal?

RESULTS

This paper explores the most essential socioeconomic factors for mitigation costs under the 1.5 °C climate goal, as well as the channels that affect these factors.

- Technological improvement in low-carbon energy-supply technologies is the most important factor in reducing mitigation costs.
- Under the constraints of the 1.5 °C goal, the relative effectiveness of other socioeconomic factors, such as energy efficiency improvement, lifestyle changes and biomass-related technology promotion, becomes more important in decreasing mitigation cost in the 1.5 °C scenarios than in the 2 °C scenarios.
- Socioeconomic factors reduce the mitigation costs through different channels.

DATA SOURCES

SR1.5 database

PUBLICATIONS

Liu et al. (2018)

STUDY TITLE: AIM/CGE 2.0

GUIDING QUESTIONS

This paper aims to investigate the interaction between transport policies, mitigation potential and the cost of meeting the goal of limiting warming to below 2 °C and 1.5°C.

- Which transport policy has the most significant reduction potential?
- Can transport policies reduce mitigation potential generated by climate mitigation policies to limit global warming to 2 °C and 1.5°C.
- Is the contribution of transport policies more effective for stringent climate change targets in the 1.5°C scenario?

RESULTS

This paper is intended to detect the potential for different transport policy interventions to reduce emissions and mitigation cost for the 2°C and 1.5°C targets.

- Technological transformations such as vehicle technological innovations and energy efficiency improvements provide the most significant reduction potential.
- Low-carbon transport policies can reduce the carbon price, gross domestic product loss rate, and welfare loss rate generated by climate mitigation policies
- The degree of contribution of transport policies is more effective for stringent climate change targets.

DATA SOURCES

SR1.5 database

PUBLICATIONS

Zhang et al. (2018)

STUDY TITLE: IEA ETP

GUIDING QUESTIONS

ETP 2017 applies a combination of "backcasting" and forecasting over three scenarios from now to 2060. Backcasting lays out plausible pathways to a desired end state. It makes it easier to identify milestones that need to be reached or trends that need to change promptly in order for the end goal to be achieved.

- Can we achieve 2 dregree and beyond 2 degree targets with already commercially available technologies?

- What level of policy action and effort does becoming corbon neutral by mid centrury require?
- What sectors couild play a major role in supporting the energy system transformation?
- What's the role of hgh efficiency appliances in achieving a low carbon fuiture?
- What's the role of electrification of the transportation sector in achieving a beyond 2 degree target?

RESULTS

It shows how the energy sector could become carbon neutral by 2060 if known technology innovations were pushed to the limit. But to do so would require an unprecedented level of policy action and effort from all stakeholders.

- Looking at specific sectors, ETP 2017 finds that buildings could play a major role in supporting the energy system transformation. High-efficiency lighting, cooling and appliances could save nearly three-quarters of today's global electricity demand between now and 2030 if deployed quickly. Doing so would allow a greater electrification of the energy system that would not add burdens on the system. In the transportation system, electrification also emerges as a major low-carbon pathway.
- The report finds that regardless of the pathway chosen, policies to support energy technology innovation at all stages, from research to full deployment, will be critical to reap energy security, environmental and economic benefits of energy system transformations.
- It also suggests that the most important challenge for energy policy makers will be to move away from a siloed perspective towards one that enables systems integration.

DATA SOURCES

IAMC 1.5°C Scenario Explorer

PUBLICATIONS

IEA (2017), Energy Technology Perspectives 2017: Catalysing Energy Technology Transformations, IEA, Paris