I4CE INSTITUTE FOR CLIMATE ECONOMICS
Une initiative de la Caisse des Dépôts et de l'Agence Française de Développement

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Understanding transition scenarios

Eight steps for reading and interpreting these scenarios

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Executive Summary

The transition to a low-carbon economy implies far-reaching changes in socio-economic systems. Its scope and its exact nature will depend on the actions our societies implement in order to address climate issues, and cannot be predicted with certainty. It therefore brings **risks and opportunities for economic actors**, which they must anticipate in order to optimise their strategy in a context of uncertainty. Against this backdrop, the use of scenarios – which are **plausible representations of uncertain future states** – is very useful in order to better understand the medium- and long-term challenges of the low-carbon transition, and was in particular recommended by the TCFD (Task Force on Climate-related Financial Disclosures).

Before using scenarios, it is essential to know how to correctly interpret them. This implies first **navigating the complex ecosystem of climate-related scenarios** and identifying those that can be used to explore issues linked to the low-carbon transition: transition scenarios. It also requires fully understanding the issues relating to these scenarios.

The goals of this publication are therefore:

- Explaining the **key concepts underpinning climate-related scenarios,** presenting the **main families of scenarios** and the questions these scenarios help to answer;
- Providing **keys to reading transition scenarios** in order to **facilitate their interpretation and to avoid misunderstanding.**

Avoiding confusion: identifying transition scenarios among climate-related scenarios

Climate-related scenarios explore interactions between socio-economic systems and climate change

The use of scenarios is particularly relevant when studying a problem as complex as climate change for which sound scientific knowledge exists. Climate-related scenarios can be defined according to three major families, with each one exploring a different question concerning the interactions between socio-economic systems and the climate:

- **Transition scenarios**: What are the possible changes in socio-economic systems that could reduce anthropogenic greenhouse gas (GHG) emissions enough to limit global temperature rise to 1.5°C or 2°C?
- **Climate change scenarios**: What are the implications for the climate system of different GHG emissions trajectories, which themselves represent different socio-economic trajectories?
- **Climate impact scenarios**: What are the possible direct and indirect future impacts of climate change on socio-economic systems?

This division into three families corresponds to the vast majority of scenarios existing today and follows the structure of research by the Intergovernmental Panel on Climate Change (IPCC) Working Groups. It is clear that these different questions and the challenges arising from them are in fact closely linked and also call for integrated analysis.

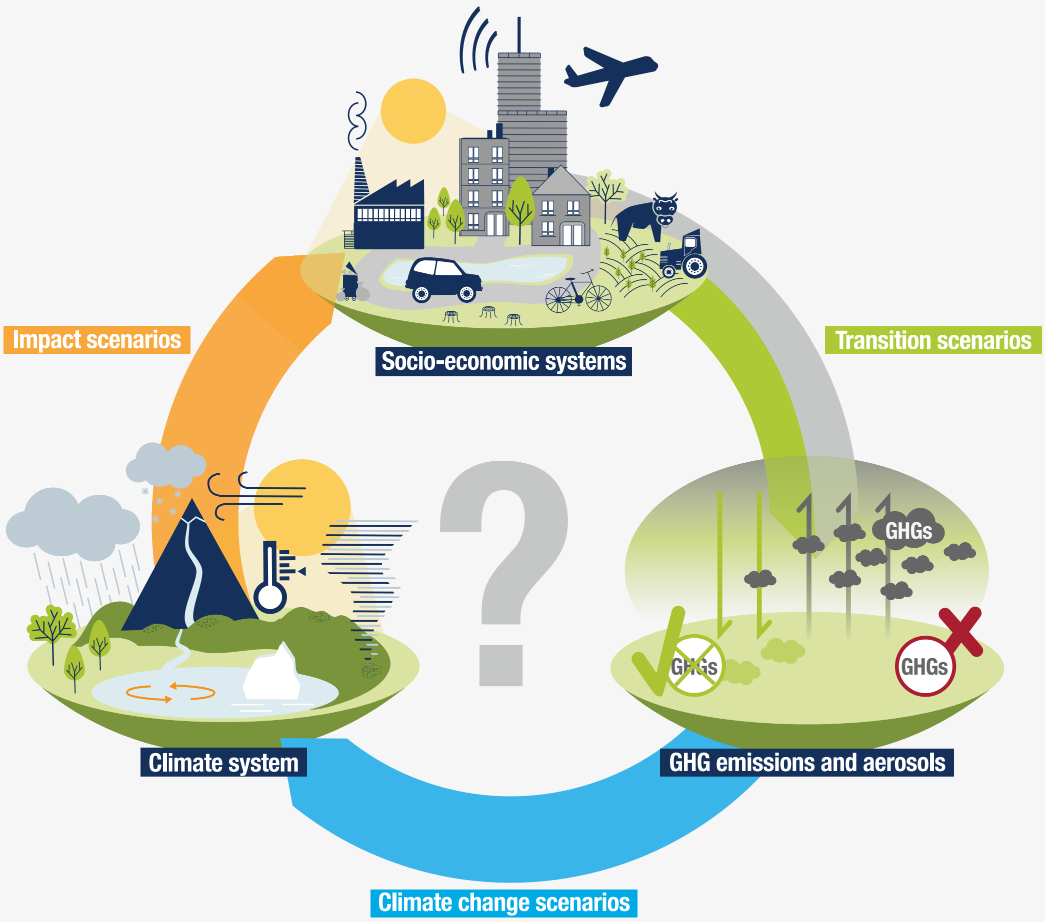
Transition scenarios

Transition scenarios explore the different possible low-carbon transitions: they describe **changes in socio-economic systems that are compatible with achieving a climate target** – which corresponds to limiting global temperature rise to 2°C or 1.5°C. Different low-carbon transitions are possible and depend on:

- The **climate target** pursued;
- Changes in the **socio-economic context** that may or may not be conducive to reducing GHG emissions;
- The **scope** and **distribution of reduction efforts over time, by sector** and **by country**;
- The **weight given to the different mitigation solutions** deployed to reduce or sequester GHG emissions;
- The role of the **different drivers of change** – political, technological and behavioural – enabling the deployment of these solutions.

Transition scenarios present different visions of the transition: these scenarios have **different purposes** and **reflect the vision of their developer**. The diversity of scenarios and of the low-carbon transitions they represent derives from the **choices made at different stages of the scenario construction process**. The use of one scenario in particular implies the adoption of its vision of the transition and of the assumptions on which it is based, some of which are not necessarily explicit. Correctly interpreting transition scenarios therefore requires **attention to the different stages of scenario construction**, in particular the input assumptions chosen and the characteristics of the model used to build the scenario.

FIGURE 1. INTERACTIONS BETWEEN THE CLIMATE AND SOCIO-ECONOMIC SYSTEMS EXPLORED BY THE THREE FAMILIES OF "CLIMATE-RELATED SCENARIOS"



Source: I4CE, 2019

Climate change scenarios

Climate change scenarios – or climate projections – explore the possible **consequences of human activities on the climate system** according to different changes in socio-economic systems. Indeed, long-term climate change is conditioned by **current and future GHG emissions**, and therefore by **uncertain changes in socio-economic systems**. In order to explore these uncertainties, climate change scenarios are built on assumptions about changes in atmospheric GHG concentrations, the RCPs, which are representative of multiple possible socio-economic trajectories. Based on an RCP chosen as an input, a climate change scenario describes **changes in the climate system and its variables such as temperatures, winds and rainfall**, for a given time horizon and geographical area.

Climate impact scenarios

Climate impact scenarios explore the **possible impacts of climate change on a given system** (for example the physical environment; an ecosystem; or a human system such as a city or a farm). The impacts of climate change will be determined by **changes in the climate**, but also by **changes in socio-economic systems**, which will determine their **degree of exposure**, their **sensitivity** and their **capacity to adapt** to climate change. A climate impact scenario is built on assumptions about: changes in the climate (through a climate change scenario), the current characteristics of socio-economic systems and their evolution and the current characteristics of physical and natural systems and their changes. More and more results of impact scenarios – which are generally sectoral – are publicly available in different forms, and can **inform strategic thinking on the impacts of climate change.**

Navigating the different transition scenarios

The diversity of transition scenarios derives from the choices made at different stages of their construction process, and especially from the input assumptions and the characteristics of the model used to build the scenario. These choices influence the way in which the results can be interpreted, and it is therefore essential to identify and understand them.

Identifying and understanding the input assumptions for the scenario

A transition scenario takes account of assumptions about changes in the socio-economic context (demographic, economic, political, etc.) that may be more or less conducive to achieving the climate target. These changes may be described in a "**baseline scenario**", which is not constrained by a climate target. The transition scenario may be developed in comparison with this baseline scenario and its results are sometimes presented as a differential in relation to it: identifying the assumptions included in the baseline scenario is therefore essential.

Transition scenarios are constrained by the achievement of a 2°C or 1.5°C climate target, which translates into a constraint on GHG emissions. Specific assumptions are thus made about the way to achieve the climate target, focusing in particular on **the international configuration of climate action**, the **mitigation solutions available**, and the **policies, measures, or behavioural changes that enable GHG emissions reductions**. It should be noted that assumptions about the availability of negative emissions technologies are particularly important: assumptions conducive to the development of these technologies can defer climate action and thereby alter the necessary rate of emissions reductions.

Identifying the main characteristics of the model

Scenarios are quantified using models that include a **representation of the economy, the energy system and land use** (or just one or two of these elements, typically concentrating on one). Models are **simplified, partial representations of reality**, and **depending on the problem they address, they function with different approaches, do not have the same scope, and do not provide the same information**. Identifying the main characteristics of the model is therefore an important step in reading a scenario. First, the characteristics of the model will influence the actual results of the scenario – in particular the analytical approach (macro-economic/techno-economic), the theoretical foundations on which they are based, and the way in which actors' foresight is represented. Second, they condition the information that will be available on the scenario – and which depends in particular on the scope and granularity of the model. According to the model used, **the same parameter cannot always be interpreted in the same way**. For example, the carbon price may represent the implementation of taxes or carbon markets, or it may represent a shadow price that reflects the emissions reduction efforts required to achieve a particular climate target.

In order to create a coherent narrative around the transition, the scenario developer describes together the results of the model and the assumptions of the scenario. This exercise gives the scenario credibility.

The eight steps to follow in order to interpret a transition scenario

A framework for reading transition scenarios was developed to provide readers with a step-by-step guide to scenarios. It summarises the eight main steps to follow in order to interpret a transition scenario according to the explanations developed in this study. Below are the different steps and some of the associated parameters and information *(which is just an outline of the framework developed in this study)*:

1. Identifying the framework in which the transition scenario was developed

Information/parameters to be identified: the organisation that produces the scenario, its purpose(s), the date and context of publication, the frequency of scenario updates, the broad lines of the transition described by the scenario.

2. Identifying the level of information available on the scenario

Information/parameters to be identified: the medium of publication, the existence of methodological annexes or tables of results, the scope (geographical, sectoral, time horizon), the granularity of results (geographical, sectoral, temporal).

3. Understanding the socio-economic context of the transition described by the scenario

Information/parameters to be identified: the existence of a baseline scenario and its key assumptions, assumptions about the socio-economic context (changes in economic growth or its determinants, population, lifestyles, technological progress, the rate of urbanisation, the rate of inequality, the degree of globalisation/international cooperation, etc.).

4. Identifying the climate target and the distribution of efforts over time

Information/parameters to be identified: the climate target set, the probability associated with it, the way in which it is taken into account in the scenario, evolution in the GHG emissions trajectory, the assumptions made/accepted about changes in GHG emissions beyond the period covered by the scenario.

5. Identifying the weight given to the different drivers of the transition and the associated assumptions

Information/parameters to be identified: the measures/regulations/policies supporting the implementation of mitigation solutions, the value and significance of the carbon price, the behavioural changes and technological progress needed for the transition.

6. Analysing the geographical and sectoral distribution of reduction efforts

Information/parameters to be identified: the GHG emissions trajectory for the scenario, changes in emissions by sector/geographical area, assumptions about changes in emissions in the sectors/geographical areas not covered by the scenario.

7. Identifying the solutions deployed to reduce GHG emissions and the associated technologies

Information/parameters to be identified: examples of parameters enabling the identification of solutions deployed and their relative weight, by major category of mitigation solutions:

- **Managing demand for energy and GHG emissions-intensive materials**: the share of emissions reductions due to energy efficiency globally and by sector; changes in primary energy consumption; changes in energy consumption in the different energy end-use sectors;
- **Decarbonising of the energy mix**: the share of the different renewable energies in the energy mix, changes in the share of electricity in final energy consumption, the share of nuclear in the electricity mix, the rate of deployment of CCUS technologies;
- **Managing emissions from the agricultural system**: changes in emissions from the agricultural sector, changes in the consumption of meat;
- **Using negative emissions**: the amount of negative emissions, the capacities of Bio-energy with Carbon Capture and Storage (BECCS) in place, the forest sinks mobilised.

8. Identifying the macro-economic consequences of the transition

Information/parameters to be identified: evolution of economic growth and the impacts of the transition on economic growth, the investments required for the changes described in the scenario, the consequences of the transition on employment, changes in electricity or energy prices for end consumers.

By way of illustration, this framework is applied to five scenarios: the Sustainable Development Scenario (SDS) by the International Energy Agency (IEA), the Advanced Energy Revolution scenario by Greenpeace, the Low Energy Demand (LED) scenario by the International Institute for Applied Systems Analysis (IIASA), the Rapid Transition scenario by British Petroleum (BP), and the REmap scenario by the International Renewable Energy Agency (IRENA).

Conclusion

The use of scenarios is particularly relevant when assessing the risks and opportunities of the transition to a low-carbon economy and building strategies that are robust against uncertainties. The use of transition scenarios requires **navigating the ecosystem of climate-related scenarios** – and in particular situating them in relation to climate change scenarios and impact scenarios. It also implies being able to correctly interpret these scenarios and thus to **identify the choices made during their development** – especially the assumptions chosen as inputs and the characteristics of the model used. This educational publication is part of a broader project on **the use of scenarios by economic actors to analyse the risks and opportunities of the transition to a low-carbon economy**. In this context, the development of a step-by-step guide to help companies conduct a scenario-based risk and opportunity analysis is underway. This guide will also include recommendations on useful information to be provided to financial actors based on scenario analysis and examples of good reporting practices.

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List of acronyms

AR5	5th Assessment Report
BECCS	Bio-energy with Carbon Capture and Storage
CCUS	Carbon Capture, Utilization and Storage
EU	European Union
GDP	Gross Domestic Product
GHG	Greenhouse Gas
IAM	Integrated Assessment Model
IEA	International Energy Agency
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
LULUCF	Land Use, Land-Use Change, and Forestry
NETs	Negative Emission Technologies
OECD	Organisation for Economic Co-operation and Development
PPP	Power Purchase Parity
RCP	Representative Concentration Pathway
SDGs	Sustainable Development Goals
SSP	Shared Socio-economic Pathway
TCFD	Task Force on Climate-related Financial Disclosures
UN	United Nations
WEO	World Energy Outlook

Introduction

At the international level, a large majority of countries have committed themselves under the Paris Agreement to maintain the increase in global temperature well below 2°C above pre-industrial levels and to continuing efforts to limit this increase to 1.5°C. Respecting this goal implies a drastic reduction in our greenhouse gas (GHG) emissions, and therefore far-reaching social, political and economic changes. The exact magnitude and nature of this transition to a low-carbon economy will depend on the actions our societies implement in order to address climate issues, and cannot be predicted with certainty. Transition to a low-carbon economy therefore brings risks and opportunities for economic actors, which they must anticipate in order to optimise their strategy in a context of uncertainty. **Against this backdrop, the use of scenarios – which are plausible representations of an uncertain future states – is very useful in order to better understand the medium- and long-term issues of the low-carbon transition.** There is growing interest in their use, in particular since it was recently recommended by the TCFD (Task Force on Climate-related Financial Disclosures[1]). The TCFD recommends more broadly that economic actors should use scenarios to assess the risks and opportunities related to the low-carbon transition but also risks related to climate change.

A recent I4CE study[2] shows that this is still not common practice, and identifies confusion in the way climate-related scenarios are understood and used. The ecosystem of climate-related scenarios has become far more complex in recent years, and this term covers objects of very different nature. Some scenarios explore possible future global changes that would put the world on track to limiting global warming to 1.5°C or 2°C, referred to in this study as "*transition scenarios*". Others describe possible future climate changes due in particular to the greenhouse gases (GHGs) emitted by human activities, called "*climate change scenarios*", and some focus on the impacts of these climate changes on humans, referred to as "*climate impact scenarios*".

Before using scenarios to analyse issues related to the transition to a low-carbon economy, it is therefore essential to, on the one hand, **navigate the ecosystem of climate related scenarios** and, on the other hand, **to be able to understand and interpret transition scenarios.**

The goal of this study is to help to understand and differentiate climate-related scenarios and to propose an in-depth analysis of transition scenarios, in order to avoid misinterpretations and to facilitate their use[3]. The first part presents the main families of climate-related scenarios (transition scenarios, climate change scenarios, and impact scenarios). It provides keys to understanding what each family represents, the questions these scenarios help to answer, the way in which they are constructed and the typical results they produce. The second part analyses in more detail transition scenarios, their components and their differences. At the end of this second part, a framework for understanding transition scenarios is proposed: it summarises the main steps to be followed in order to read and interpret transition scenarios, as well as their key parameters. This framework is applied to five publicly-available scenarios.

1 https://www.fsb-tcfd.org/
2 https://www.i4ce.org/download/very-few-companies-make-good-use-of-scenarios-to-anticipate-their-climate-constrained-future/
3 This publication is part of a project financed by Climate-KIC aimed at facilitating the use of scenarios by companies in order to anticipate climate-related risks and opportunities, in line with the TCFD recommendations.

1. Avoiding confusion: identifying transition scenarios among climate-related scenarios

1.1. Scenarios to explore interactions between socio-economic systems and climate change

BOX 1. WHAT DO WE MEAN BY SCENARIOS?

A scenario is neither a forecast nor a projection

A scenario can be defined as a plausible representation of an uncertain future, sometimes including the pathway leading to this future, based on assumptions and key parameters that are mutually consistent. A representation **of this kind is neither a forecast nor a projection, but a description of what a future state could be under certain conditions.**

A scenario is built on assumptions and sometimes a model

Scenarios explore plausible changes, **and are built on assumptions that are relevant**, probable and consistent (Godet and Durance, 2011). Scenario construction may include the use of a model that is generally quantitative, although qualitative models also exist. **A model is an abstract, simplified representation of reality, or of one component of reality, created with the goal of obtaining information not yet available using information that is available, or assumptions made**. It is composed of a set of science-based mathematical equations (physics, economics, etc.) that represent economic, physical and natural phenomena.

A scenario is a tool for exploring future uncertainties

Scenarios have been developed as decision support tools in an uncertain context. They help to identify, understand and structure uncertainties about the future – and to make choices and decisions that take better account of these uncertainties.

Numerous cause and effect relationships link the socio-economic development of our societies to climate change. The current state of knowledge, which is regularly assessed by the Intergovernmental Panel on Climate Change (IPCC)[4], enables us to explain these relationships as follows: human activities – and, more broadly, socio-economic systems[5] – emit greenhouse gases (GHGs), increasing the atmospheric concentration of these gases. This abnormally high concentration disturbs the climate system and alters the climate[6]. In turn, these changes impact socio-economic systems and modify their development conditions in a number of ways.

The use of scenarios is particularly relevant when studying a problem as complex as climate change for which sound scientific knowledge exists – knowledge upon which scenarios are built. Their use enables better identification and understanding of the uncertainties surrounding the evolution of climate change, its consequences and the way in which our societies can address it, whether in terms of mitigating anthropogenic GHG emissions or adapting to the effects of climate change.

Climate-related scenarios have thus been developed as tools to inform the decisions our societies have to make in order to address an unprecedented challenge. Three families of scenarios help to explore different questions concerning the interactions between socio-economic systems and the climate:

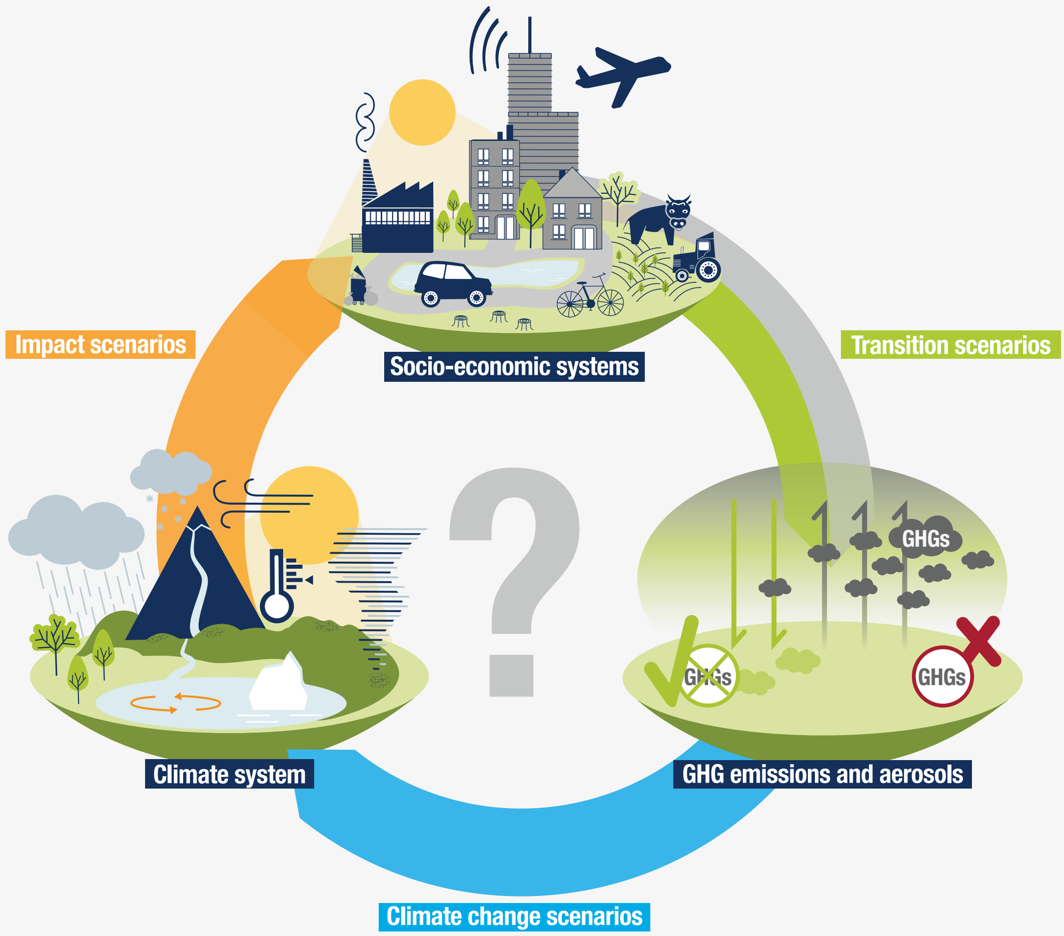
- **Transition scenarios**: What are the possible changes in socio-economic systems that could reduce anthropogenic GHG emissions enough to limit global temperature rise to 1.5°C or 2°C?
- **Climate change scenarios**: What are the implications for the climate system of different GHG emissions trajectories, which themselves represent different socio-economic trajectories?
- **Climate impact scenarios**: What are the possible direct and indirect future impacts of climate change on socio-economic systems?

4 The IPCC is a scientific body created in 1988 by the United Nations to help the global community to better understand climate change and its challenges. It is responsible for summarising and regularly assessing knowledge on climate change, its causes and its impacts. It publishes its research in the form of Assessment Reports (ARs) and special reports, such as the Special Report on Global Warming of 1.5°C published in 2018.

5 A socio-economic system is a broad concept that describes the way in which a society is organised. It encompasses a set of demographic, economic, political, institutional, social, cultural and technological characteristics.

6 Human activities mainly disturb the climate through GHG emissions to the atmosphere, but also through other processes explained in more detail in Part 1.3.

FIGURE 1. INTERACTIONS BETWEEN THE CLIMATE AND SOCIO-ECONOMIC SYSTEMS EXPLORED BY THE THREE FAMILIES OF "CLIMATE-RELATED SCENARIOS"



Source: I4CE, 2019

Due to the cause and effect relationships between socio-economic systems, GHG emissions and climate impacts, and because of the linkages between these different families of scenarios, the objectives and results of the families are sometimes confused and the scenarios misused. The aim of the following sections is to clarify what each of these families of scenarios encompasses.

⚠ Although this division into three families corresponds to the vast majority of scenarios existing today and follows the structure of research by the IPCC Working Groups, it is clear that these different questions and the challenges arising from them are closely linked. Indeed, they are beginning to be described and analysed in an integrated manner, or even within a given scenario (see **Box 2**).

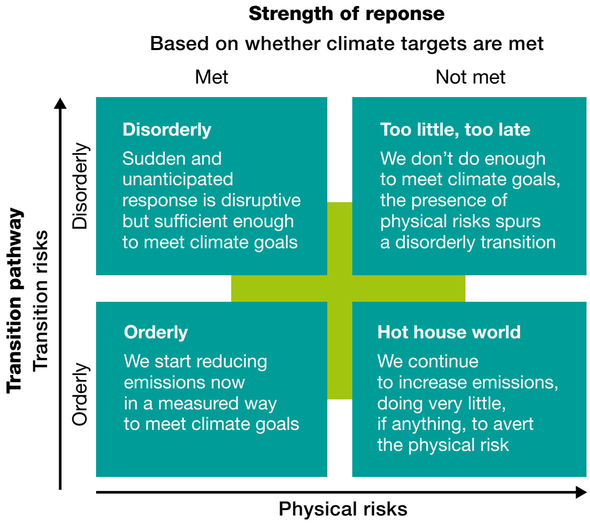
BOX 2. INTEGRATED ANALYSIS OF CLIMATE ISSUES

Economic actors will simultaneously experience the transition pathway and the impacts of climate change. These two processes influence one another, making efforts to jointly represent their evolution all the more useful. As shown in **Figure 2**, the absence of an early transition could, for example, result in strong climate impacts that would motivate a late, disorderly transition. In this case, the actors would be exposed to a specific situation: high climate risks along with high risks linked to the transition.

The implementation of a low-carbon and climate-resilient pathway – advocated by the Paris Agreement – thus implies identifying interference between actions undertaken for the low-carbon transition and those undertaken to adapt to climate change. For example, the development of hydroelectric dams contributes to the transition, but increases vulnerability to the depletion of water resources.

More broadly, the IPCC also calls for narratives of sustainable socio-economic pathways, not only describing a low-carbon socio-economic pathway that is adapted to climate change, but also, more generally, meeting the 17 Sustainable Development Goals (SDGs) adopted by the United Nations (UN) in 2015. These integrated scenarios, which are still emerging, are referred to as "climate-resilient development pathways" in the IPCC reports. Their construction calls for studying how the different actions represented can ultimately facilitate or impede the achievement of each of the Sustainable Development Goals.

FIGURE 2. EXAMPLES OF NARRATIVES INTEGRATING THE CHALLENGES OF CLIMATE CHANGE AND OF THE TRANSITION, WITH THEIR ASSOCIATED RISKS



Source : NGFS, 2019. A call for action, Climate change as a source of financial risk

1.2. Transition scenarios

1.2.1 Multiple low-carbon transitions are possible

The low-carbon transition seeks to limit global warming to 2°C and, if possible, 1.5°C

The low-carbon transition corresponds to changes in socio-economic systems so as to ensure the future GHG emissions trajectory is in line with keeping global warming below a certain threshold. This threshold was clarified by the Paris Agreement, adopted in 2015 during COP21. Ratified by 187 parties (including the European Union), it set the target of limiting the increase in global temperature to **well below 2°C** above pre-industrial levels, while **pursuing efforts to limit the increase to 1.5°C**.

To be compatible with the climate goal of 2°C or below, this reduction must be in line with achieving "**net zero emissions**" at the global level in the second half of this century. Defined in Article 4 of the Paris Agreement, this concept corresponds to the balance between anthropogenic greenhouse gas emissions and their absorption by "carbon sinks"(see **Box 5**). Also referred to as "carbon neutrality", it implies not emitting more GHGs than can be absorbed by carbon sinks[7].

As shown in **Figure 4**, achieving this target requires a shift away from our current societies, with their high-emitting activities and lifestyles (see **Box 3**), to low-carbon societies, in other words those that continue to live and to develop with zero emissions, or only very low levels.

7 For more information on the concept of "net zero emissions", see the article "Net zero emissions' objective in the Paris Agreement: Meaning and implications" (Perrier *et al.*, 2018).

BOX 3. MAIN SOURCES OF GHG EMISSIONS

Anthropogenic GHG emissions come from:

Energy use, primarily the combustion of fossil fuels (oil, coal and gas) or biomass*. This is the main source of GHG emissions, especially carbon dioxide (CO_2).

Gases emitted: CO_2, methane (CH_4) and nitrous oxide (N_2O).

Agriculture, primarily enteric fermentation in cattle, nitrogen fertilisation of soils and rice cultivation.

Gases emitted: CH_4, N_2O, CO_2.

Some industrial processes, such as the decarbonation process in the cement industry, and the use of solvents.

Gases emitted: CO_2, CH_4, N_2O, fluorinated gases (HFC, PFC, SF_6).

Waste, which emits GHGs during its decomposition or incineration.

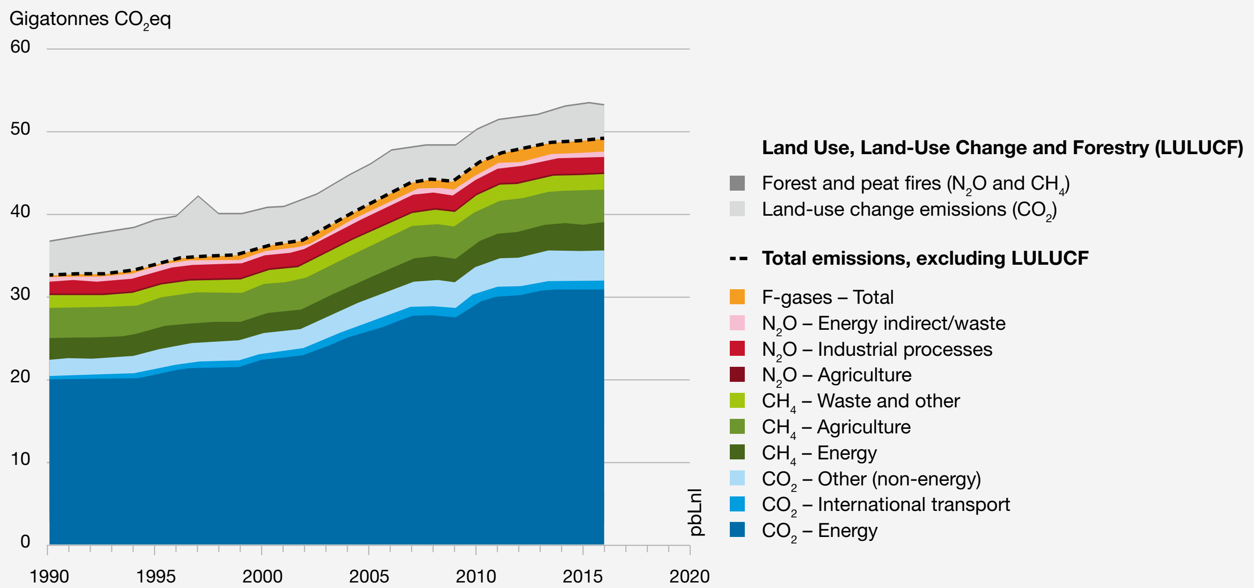
Gases emitted: N_2O, CH_4, CO_2.

Land use, land-use change and forestry (LULUCF). The emissions linked to land use and forestry may be “negative” in some areas: this means that this sector, especially forestry, absorbs more GHGs than it emits. Scientists refer to this as a carbon sink.

Gases emitted: CO_2 (the vast majority), N_2O, CH_4.

**Biomass refers to all organic matter of animal or plant origin (including wood) that can be used as a source of energy.*

FIGURE 3. GLOBAL GHG EMISSIONS BY GAS AND BY SOURCE



Source: Olivier J.G.J. et al. (2017), Trends in global CO_2 and total greenhouse gas emissions: 2017 report. PBL Netherlands Environmental Assessment Agency, The Hague

Different global changes are consistent with the same climate goal

Different global changes may be consistent with the **same climate goal**, which can be achieved through various GHG emissions reduction pathways. These different potential low-carbon transitions will depend on the following determinants:

- **Changes in the socio-economic context** (represented in blue in **Figure 4**): more or less conducive to GHG reductions, these include demographic, economic, political, technological, institutional and lifestyle changes that do not arise from the fight against global warming;
- The **scope** and **distribution** of reduction efforts over time, by sector and by country;
- The types of **mitigation solutions deployed** and their importance in the reduction or sequestration of GHG emissions: according to IPCC research, four key types of mitigation solutions can be identified (see **Figure 4**):
  - Controlling emissions from agricultural systems and soils;
  - Decarbonising the energy mix through:
    - The deployment of renewable energies;
    - The electrification of uses in the transport, industry and building sectors;
    - The deployment of nuclear power;
    - The deployment of carbon capture, utilisation and storage (CCUS) technologies (see **Box 4**);
    - The decarbonisation of non-electric fuels through the use of renewable hydrogen, biogas, etc.
  - Managing demand for energy and GHG-intensive materials;
  - Using negative emissions that absorb atmospheric CO_2 (see **Box 5**).
- The role of the different **drivers of the transition** – political, technological and behavioural – that can be used to deploy these solutions.

BOX 4. CARBON CAPTURE UTILIZATION AND STORAGE TECHNOLOGIES

Carbon capture, utilization and storage (CCUS) are technologies that enable the reduction of GHG emissions from industry and the energy sector. These technologies capture the CO_2 emitted by energy installations (for example, fossil fuel power plants) and industrial installations. The CO_2 captured is then either used for industrial purposes (for example, for oil extraction) or for the production of other goods (for example, chemicals), or stored permanently underground in deep geological formations in order to isolate it from the atmosphere.

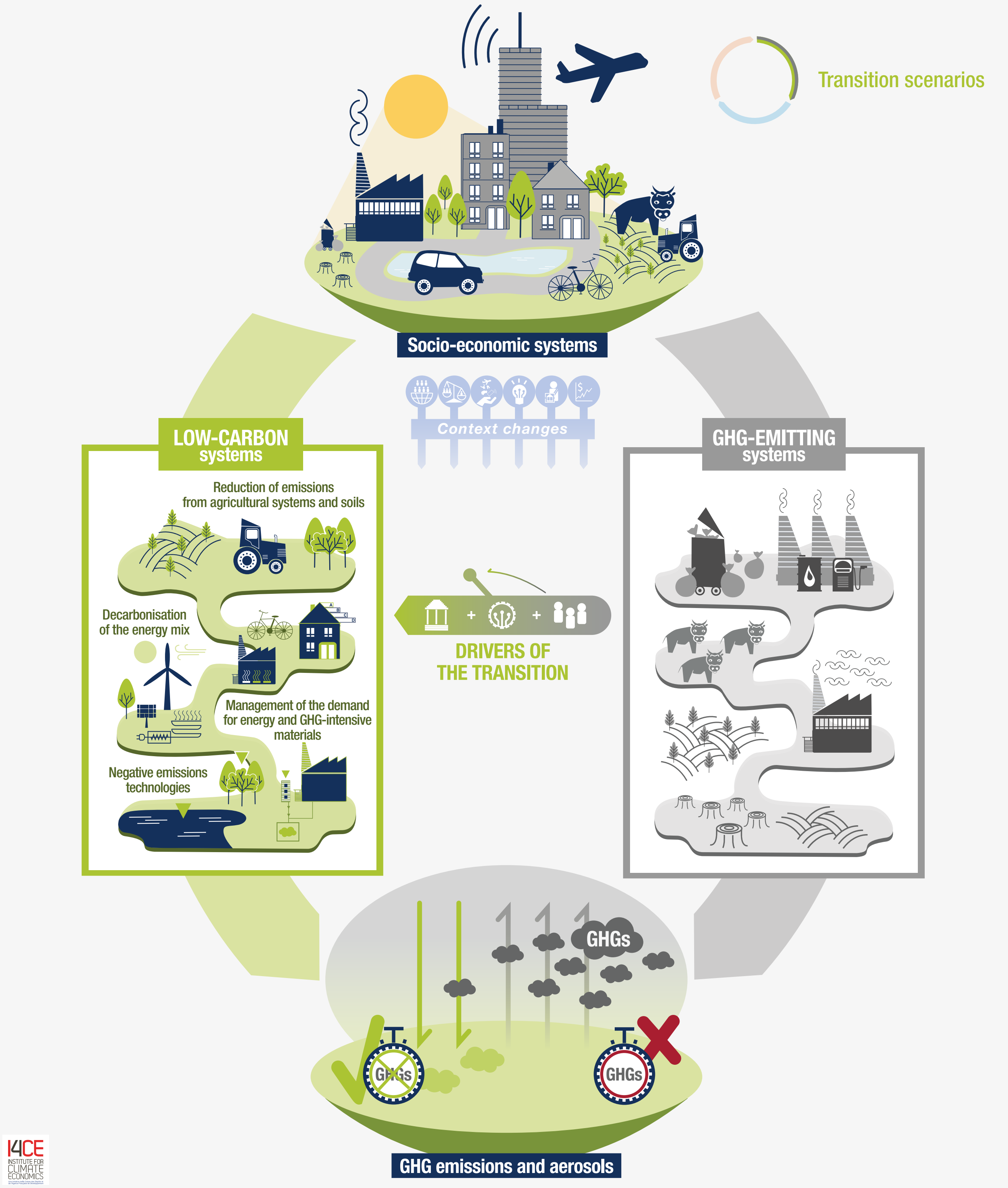
The large-scale deployment of this technology faces two major problems. First, it poses certain risks, such as the toxicity of some capture solvents, leakage during transport, and leakage or displacement of CO_2 stored underground with potential impacts on human health and the environment*****. Second, its cost is still very high. According to the IPCC, the large-scale deployment of CCUS will be difficult to achieve without establishing sufficiently stringent limits on GHG emissions, implementing measures to impose its use (for example, on new installations), or ensuring direct financial support or a sufficiently high carbon price to make this technology competitive.

In its latest report on the consequences of global warming of 1.5°C, the IPCC makes it clear that given its current rate of development and the lack of incentives for its implementation, the future deployment of CCUS remains uncertain.

* A significant scientific literature has emerged in recent years concerning the different ways of minimising the risks associated with the deployment of CCUS and ensuring the integrity of carbon sinks, described by the IPCC in Chapter 7.5.5., Working Group III, AR5.

Sources: IPCC - Clarke et al. (2014), IPCC (2018)

FIGURE 4. THE ISSUES OF THE LOW-CARBON TRANSITION REPRESENTED BY TRANSITION SCENARIOS



Source: I4CE, 2019

BOX 5. NEGATIVE EMISSIONS TECHNOLOGIES (NETS)

Negative emissions technologies (NETs) refer to a set of technologies used to remove CO_2 from the atmosphere. They can be separated into two categories:

- Technologies that help to increase natural carbon sinks, for example forestry through reforestation and afforestation, soils by increasing soil carbon sequestration, and oceans through geo-engineering technologies such as ocean iron fertilisation.
- Artificial CO_2 removal technologies, with the most commonly cited being bio-energy with carbon capture and storage (BECCS). This technology consists in producing energy from power plants using biomass, which captures CO_2 as it grows, then capturing the CO_2 emitted by the power plant and storing it in the soil.

Many transition scenarios use negative emissions in the medium and long term, especially BECCS technologies, in order to achieve their climate goals. If mitigation efforts are slower and further in the future, then transition scenarios are more likely to use these technologies to limit global warming, especially for a 1.5°C target.

The technical feasibility of the majority of these negative emissions technologies and their large-scale deployment are still highly uncertain. The IPCC thus cautions that focusing on the massive deployment of these technologies in the future implies taking a major risk concerning our capacity to limit global warming to 1.5°C. Moreover, numerous uncertainties surround the social and environmental risks linked to these technologies, especially BECCS technologies, which, if deployed on a large scale, conflict with land use for agriculture and with biodiversity conservation. They also compete with water use in a warmer, more populous world.

Sources: IPCC - Clarke et al. (2014), IPCC - Rogelj et al. (2018)

1.2.2 Transition scenarios explore the conditions for change in socio-economic systems compatible with achieving climate goal

Transition scenarios describe a pathway to a possible future in which socio-economic development, and the resulting GHG emissions, are compatible with keeping global warming below 2°C, or even 1.5°C, by the end of the century [8]. Constrained by the achievement of this climate target, they analyse the **changes needed for the transition to low-carbon societies, the mitigation solutions to be deployed and the drivers to be mobilised to enable these changes** – which correspond to the issues of the transition represented in **Figure 4**.

The construction of transition scenarios therefore takes a backcasting approach (see **Box 6**): they begin with a climate target of 2°C or below, translated by a limit on global GHG emissions corresponding to this target [9], in order to identify the changes needed to achieve this target.

BOX 6. BACKCASTING OR FORECASTING: TWO DIFFERENT SCENARIO CONSTRUCTION APPROACHES

Scenarios developed according to a **"backcasting"** approach start with a predefined end state, and go back along a possible pathway to achieve it. They identify the choices and changes to be made in order to reach this end point.

Scenarios developed according to a **"forecasting approach"** start with a present state and its prevailing trends to describe a series of events leading logically to a possible future state. They obtain a series of possible alternative futures depending on the importance given to the different input trends and assumptions in the scenario.

8 Transition scenarios, as defined in this study, do not therefore correspond to scenarios that include climate policies but whose emissions reduction efforts are insufficient to meet the climate target defined by the Paris Agreement, such as the New Policies Scenario (NPS) by the International Energy Agency (IEA).

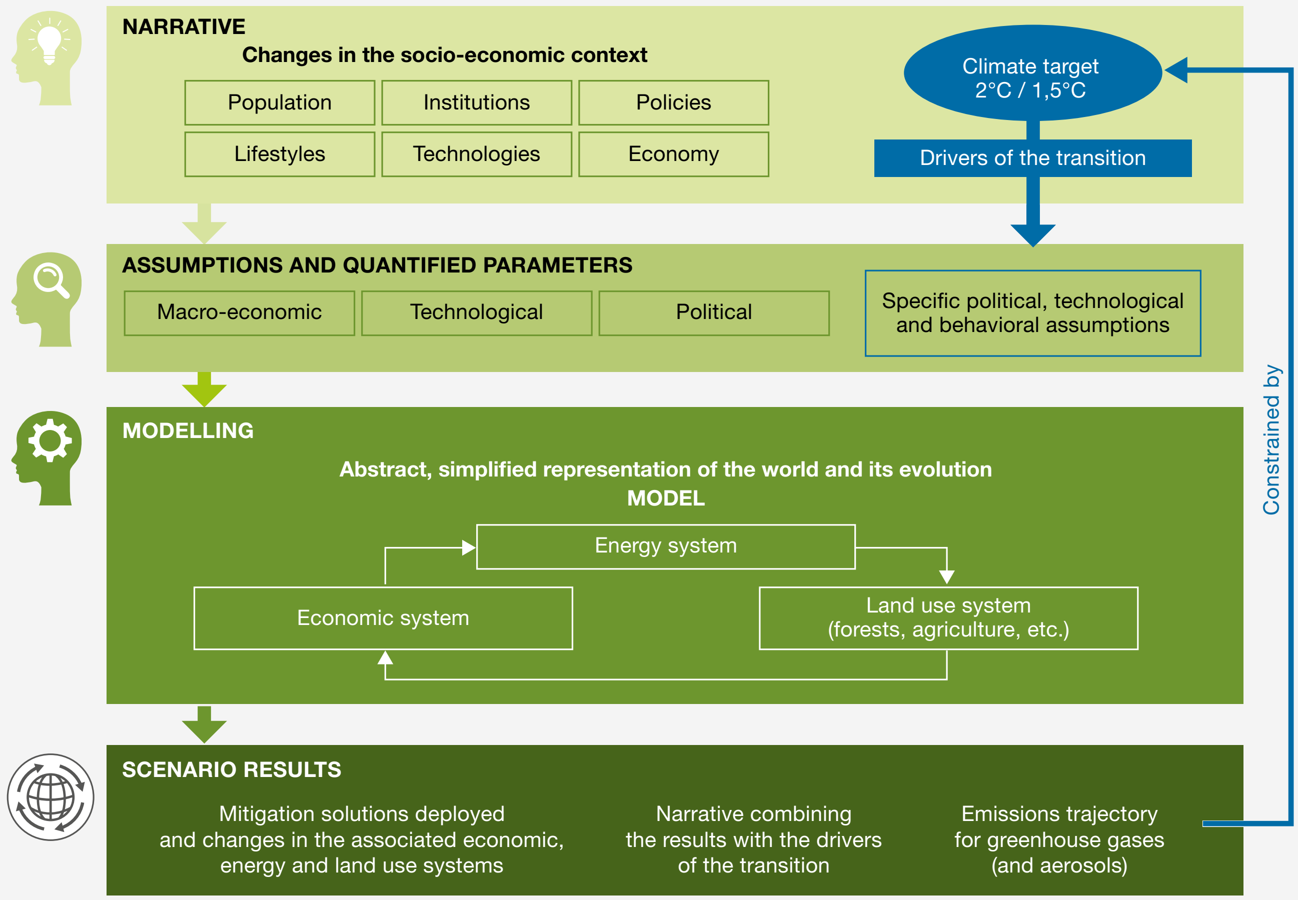
9 This implies that non-global scenarios, for example sectoral or national scenarios, must include assumptions regarding the evolution of emissions from other sectors/countries.

1.2.3 The great diversity of transition scenarios stems from the choices made during their construction

Just as multiple low-carbon transitions are possible, a multitude of transition scenarios currently exist. They translate the **vision of developers** with very different profiles: these include companies, associations/NGOs, international organisations and research institutes. **The objectives behind the construction of scenarios also differ from one scenario to another**: the purpose of some is to demonstrate the relevance of specific mitigation solutions, while others aim to identify a lower cost transition pathway, to inform the implementation of climate strategies at company or state level, or to show that meeting a climate target has a positive impact on the economy, or is compatible with other objectives.

The diversity of scenarios and of the low-carbon transitions they describe is a product of the choices made at different stages of the scenario construction process, as represented in **Figure 5**. The construction of a scenario generally begins with the development of a qualitative narrative, describing a possible future world. This narrative is then translated into assumptions and quantified parameters that serve as input values for models representing the functioning of the world, the economy and technologies. The use of models helps to describe and quantify the future changes, especially in the energy and economic systems, that are required in order to meet a given climate target. The results of a scenario thus consist of quantitative and qualitative descriptions of the changes needed for the low-carbon transition, in particular the mitigation solutions deployed. They also include the GHG emissions trajectory associated with the scenario. These results are generally put into narrative with the drivers of the transition to tell a coherent

FIGURE 5. CONSTRUCTION PROCESS AND COMPONENTS OF A TRANSITION SCENARIO



Source: I4CE, 2019

***Note:** This figure is a stylised, simplified illustration of the scenario construction process and its components. In particular, not all models include a representation of the economy, energy and land-use sectors.*

story about the transition, and to help the scenario developer to explain how the solutions and changes are implemented.

The narrative, the input assumptions and the properties of the model chosen to build the scenario configure its results. The use of a scenario therefore calls for identifying and understanding these different elements and their role in the construction of the scenario. To this end, Part 2 analyses in more detail the scenario construction process and its different components. It provides readers with the keys needed to understand transition scenarios, to differentiate them and to avoid misinterpretations. It is followed by a framework summarising the main steps to take when reading and interpreting transition scenarios, applied to five publicly-available scenarios.

1.3. Climate change scenarios

1.3.1 Human activities are disturbing the climate system

Human activities are changing climate

Many human activities emit GHGs and thereby increase their atmospheric concentration. This results in a sustained increase in the "greenhouse effect"[10], meaning that more solar energy is trapped in the climate system[11]. This energy disrupts the dynamics of the climate system and contributes in particular to warming the Earth's surface. Human activities also influence the climate by other means, for example through the emission of aerosols (fine particles) capable of modifying cloud formation and reflecting solar radiation, or changes in land cover and its capacity to reflect solar radiation (known as "albedo").

Human activities thus disturb numerous climate variables, such as air and ocean temperatures, rainfall, and wind speed and direction. These changes concern not only average climate conditions, such as rainfall at the local and global levels, in terms of total quantity of water, number of rainfall events, intensity and seasonality, but also extreme climate conditions such as heat waves, in terms of frequency, intensity, duration and geographical extent.

Natural phenomena also influence the climate

Climate change is made more complex by the fact that it does not depend solely on human activities. As illustrated in **Figure 6**, natural phenomena external to the climate system can also have a lasting impact on the climate. These typically include changes in solar luminosity, volcanism, and changes in the Earth's orbit.

Moreover, even without the influence of phenomena external to the climate system such as natural phenomena and anthropogenic GHGs, climate conditions can vary naturally due to an internal dynamic of the climate system. Scientists call this "*internal climate variability*" (represented by the two orange arrows in **Figure 6**). However, unlike the evolution of climate caused by GHG emissions, the internal variability does not affect long-term climate change.

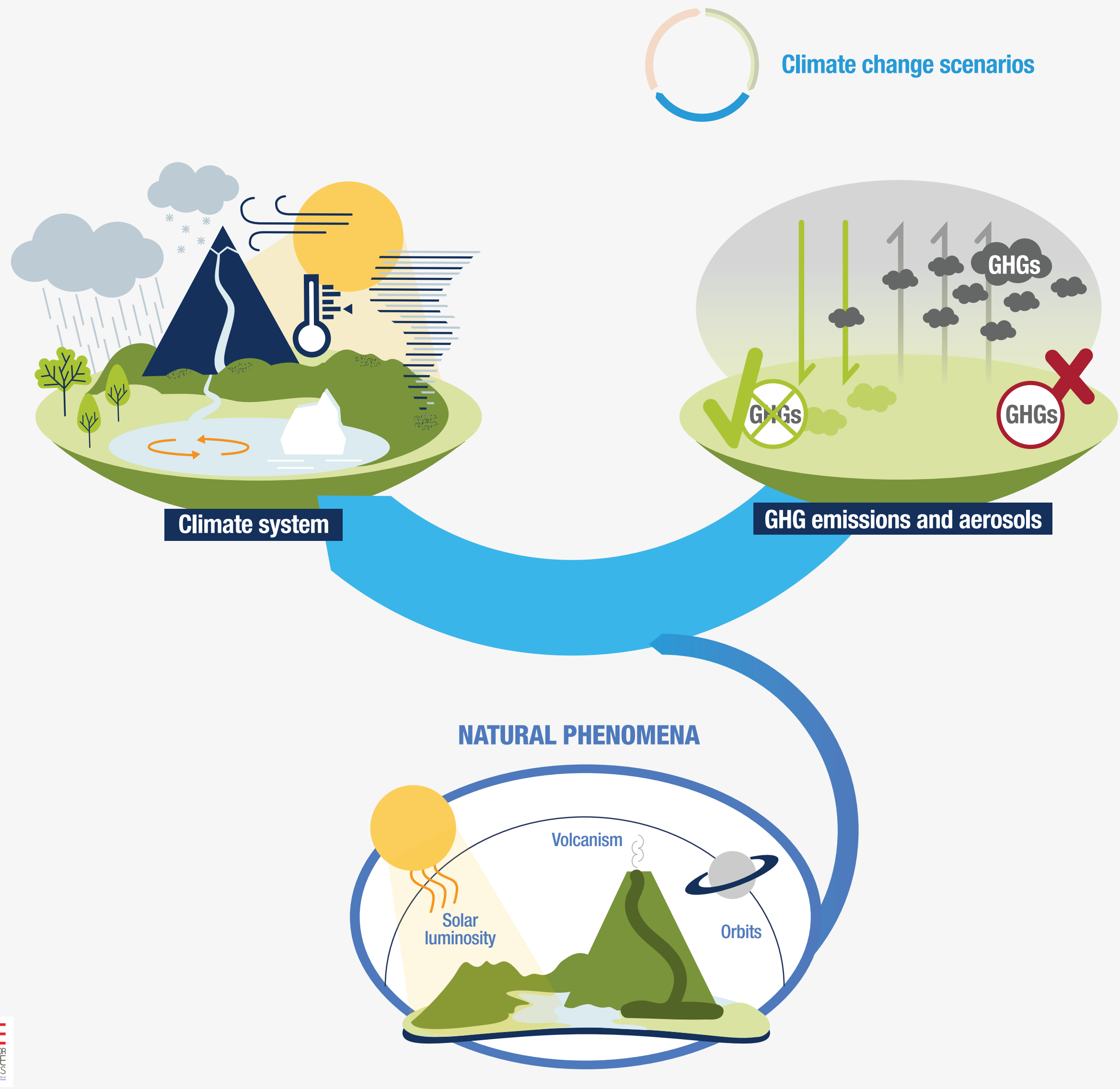
Long-term climate change is conditioned by current and future socio-economic pathways

For the next 20 to 30 years[12], the influence of humans on the climate has already been largely determined by the GHGs emitted in the last century. Over this period, climate change will also be influenced by natural dynamics specific to the climate system and over which humankind has no control.

In the longer term, climate change depends strongly on current and future anthropogenic GHG emissions. These emissions trajectories are conditioned by uncertain future socio-economic choices, resulting in uncertainties about climate change in the long term.

10 Here, the greenhouse effect refers to an effect of human origin that adds to the natural greenhouse effect, see Glossary.
11 The climate system is a complex system made up of five main interacting components: the atmosphere, the hydrosphere (oceans, lakes, rivers, etc.), the cryosphere (land ice, snow cover, etc.), the biosphere, and the lithosphere (continental surfaces).
12 Not all climatologists agree on this time horizon – it is given here simply as an indicator.

FIGURE 6. THE INFLUENCE OF NATURAL AND ANTHROPOGENIC PHENOMENA ON THE CLIMATE SYSTEM EXPLORED BY CLIMATE CHANGE SCENARIOS

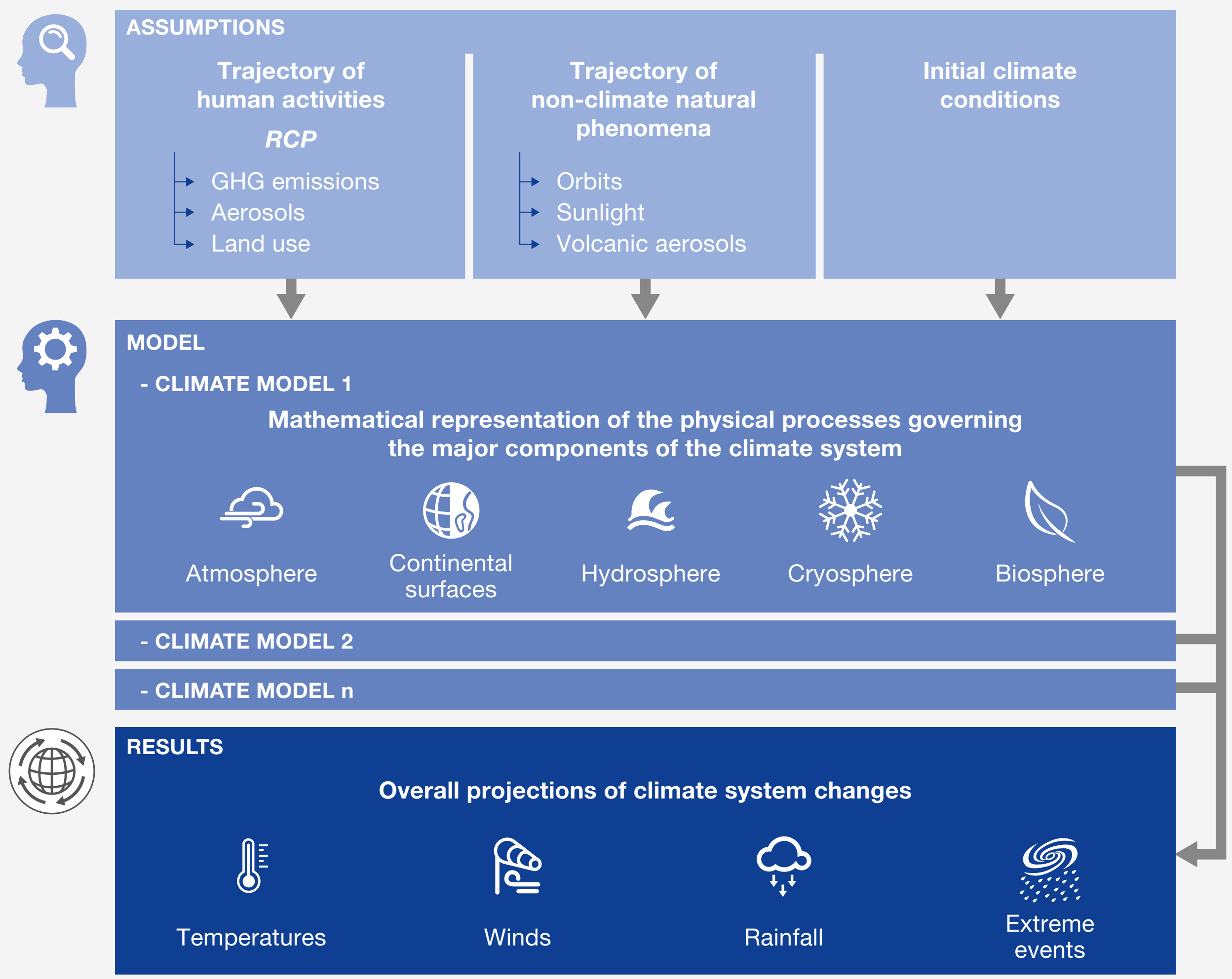


Source: I4CE, 2019

1.3.2 Climate change scenarios explore uncertainty about climate change related to human activities

In order to explore uncertainties about anthropogenic climate change, scientists produce climate change scenarios or *climate projections* according to different trajectories of human activities. Each scenario studies changes to a broad set of variables describing the climate system, for a given time horizon and geographical area.

FIGURE 7. CONSTRUCTION PROCESS AND COMPONENTS OF A CLIMATE CHANGE SCENARIO



Source : I4CE, 2019

Note: The pictograms in results represent changes to the main atmospheric components of the climate system. Climate projections can also describe other components of the climate system (oceans, glaciers, etc.).

A climate change scenario is based on quantified assumptions about the future evolution of atmospheric GHG concentrations: RCPs

Climate change scenarios are built on different trajectories of GHG and aerosol concentrations, as well as in land use, known as Representative Concentration Pathways (RCPs), which themselves represent different trajectories of human activities.

In order to organise researchers' exploration activities and to make their research comparable, the IPCC and the scientific community have established five RCPs. As explained in **Box 7**, each RCP provides a very different trajectory, and together they form a representative set of the multiple GHG concentration trajectories existing in research – which translate multiple socio-economic development trajectories.

RCPs are currently used as input data for climate models, and the IPCC aims to make them a common point of reference for the different climate change research communities (see **Box 8** for more details).

BOX 7. REPRESENTATIVE CONCENTRATION PATHWAYS (RCPS)

RCPs are **concentration trajectories of greenhouse gases, aerosols and other gases that are chemically active in the atmosphere**. They have been developed so as to be representative of the concentration and emissions trajectories in scenarios existing in the literature. They are named according to the radiative forcing they reach in 2100. Radiative forcing represents the energy trapped on the Earth's surface because of greenhouse gases: the higher its value, the more energy the earth-atmosphere system gains and the more it warms. RCPs are comprised of datasets on emissions, concentrations, radiative forcing and land use.

There were originally four RCPs, but a fifth (RCP 1.9) was recently established in the context of the IPCC Special Report on Global Warming of 1.5°C in order to explore the socio-economic development and emissions trajectories that can limit global warming to 1.5°C.

TABLE 1. REPRESENTATIVE CONCENTRATION PATHWAYS IN 2100

	Radiative forcing	GHG concentration (in CO_2eq)	Increase in global temperature	Changes in GHG concentrations*
RCP 8.5	8.5 W.m-2	1350 ppm	~ 4.3°C (3.2 – 5.4°C)	Continued, sustained increase until 2100
RCP 6	6 W.m-2	850 ppm	~ 2.8°C (2.0 – 3.7°C)	Increase then stabilisation by the end of the century
RCP 4.5	4.5 W.m-2	650 ppm	~ 2.4°C (1.7 to 3.2°C)	Slight increase then reduction by 2050 and stabilisation by the end of the century
RCP 2.6	2.6 W.m-2	450 ppm	~ 2°C (0.9 to 2.3°C)	Peak in 2020 then steady reduction
RCP 1.9	1.9 W.m-2	< 450 ppm	~ 1.5°C	Rapid, sustained reduction until the end of the century

Source: I4CE, 2019 from Guivarch et Rozenberg (2013) et Moss (2010)

* Changes vary according to the extent of use of negative emissions.

The development of the RCPs marks a methodological shift for the scientific community and the construction of climate-related scenarios (see **Box 8**). They have improved speed and coordination between the different climate change research disciplines. They have also addressed the need for more detailed data for climate models.

Climate models simulate the future climate taking into account human influence

A climate model is a numerical representation of the climate system, its components and their interactions. It draws in particular on the laws of physics. Climate models can thus be used to simulate future climate change based on the RCPs used as input assumptions.

The climate models do not all have the same characteristics (geographic scale, type of climatic phenomena represented and their level of detail, etc.). Thus, not all climate models are suited to the same uses. For example, changes in climate phenomena over large geographical areas can be studied using climate models capable of representing the globe. However, the precision of these models is not sufficient to describe specific phenomena on a regional scale, such as the circulation of the Mistral wind in the Rhône Valley in France for example. These phenomena can be studied with regional models, which use different "downscaling"methods.

In order to optimise the reliability of a climate projection, scientists generally use a number of models, which they run several times: this generates a consolidated projection known as a "multi-model" climate projection.

Climate change scenarios describe future evolution to climate variables

Climate change scenarios describe a broad set of climate variables according to a given GHG emissions and concentration trajectory. The results enable the analysis of a single climate variable in time (see example in **Box 10**) and/ or in space (using geographic maps, for example). These variables particularly concern temperatures, winds and rainfall. They can also describe other components of the climate system such as oceans and glaciers. Changes in variables can be expressed relative to a reference period – sometimes referred to as anomalies relative to a reference period – or in absolute values. These results may be available at a global scale or at a smaller scale – a country for example (see **Box 10**).

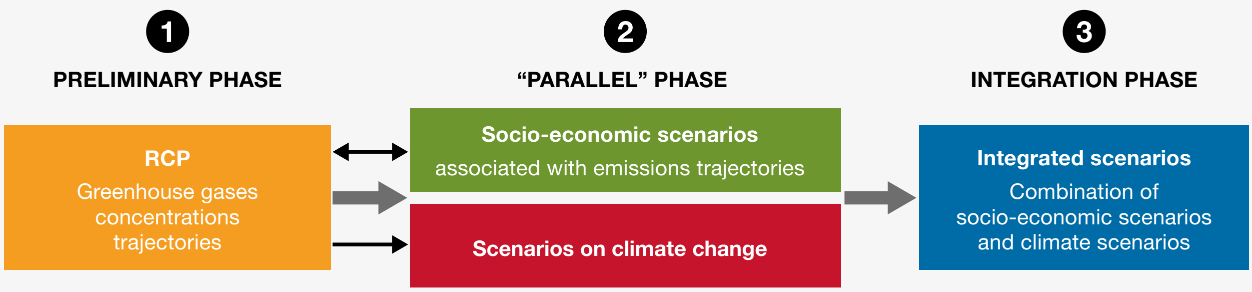
BOX 8. CHANGES IN THE CONSTRUCTION PROCESS FOR CLIMATE-RELATED SCENARIOS IN THE WORLD OF CLIMATE CHANGE RESEARCH

Scenarios for research on climate change are produced under the impetus of the IPCC. The scenario construction process prior to the RCPs (see **Box 8**) was conducted in a sequential, linear manner: socio-economic narratives were defined and then translated into GHG emissions trajectories. Next, these emissions trajectories were used as inputs for climate models to establish climate change projections. In the context of the latest IPCC Assessment Report (AR5), a new "parallel" process was established for the construction of scenarios.

This process began with the production of four RCPs, which were developed so as to be representative of the emissions trajectories in the socio-economic scenarios existing in the literature. Once developed, the RCPs enabled researchers to work "in parallel": climatologists established climate change scenarios based on climate models using the RCPs as input data, while economists developed socio-economic scenarios resulting in emissions scenarios compared to the RCPs. The final stage of this process is underway: it consists in combining the socio-economic scenarios with the climate scenarios in order to analyse the different aspects of climate change.

Each RCP is not associated with just one socio-economic scenario, but can result from a multitude of possible combinations of socio-economic, technological and political assumptions. SSPs were established to explore these combinations (see **Box 12**).

FIGURE 8. THE CONSTRUCTION PROCESS FOR CLIMATE-RELATED SCENARIOS

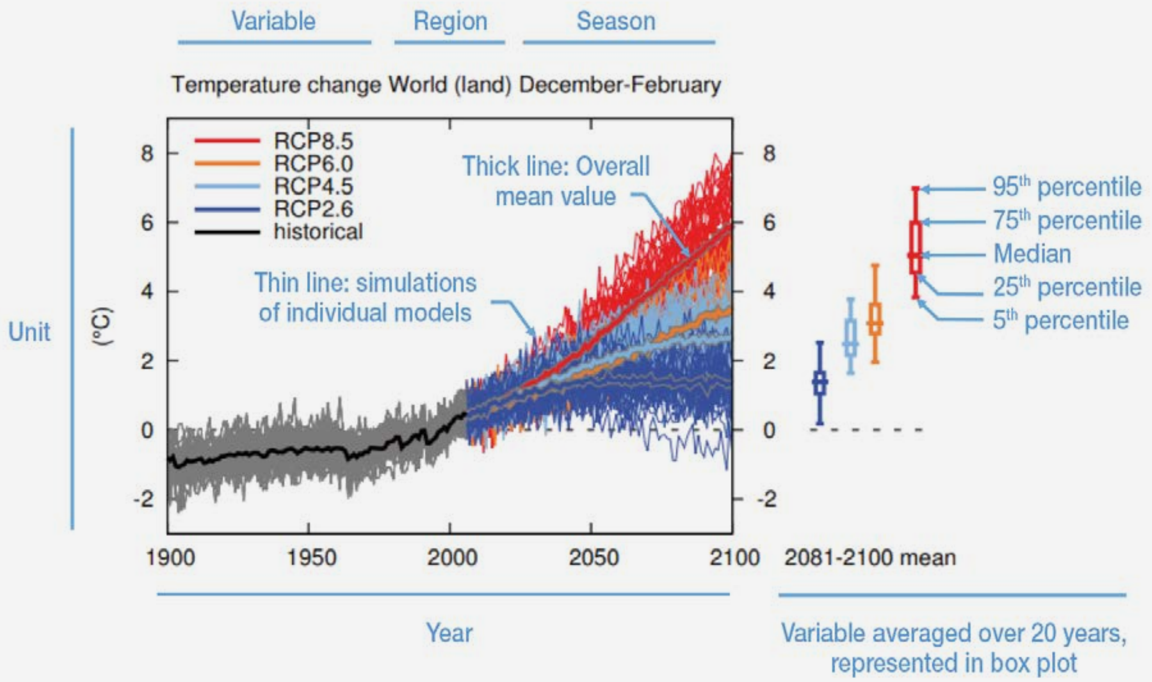


Source: I4CE, 2019, inspired by Guivarch, 2014 and Moss, 2010

BOX 9. ANALYSIS OF A CLIMATE VARIABLE FROM A CLIMATE PROJECTION IN THE 5TH IPCC ASSESSMENT REPORT

The figure below describes the time evolution of winter average surface air temperature until 2100, relative to the reference period 1986-2005. It is projected for different GHG concentration trajectories (the RCPs).

FIGURE 9. TIME EVOLUTION OF WINTER TEMPERATURE UNTIL 2100 FOLLOWING THE RCPS



Source: IPCC, 2013: Annex I: Atlas of Global and Regional Climate Projections. https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_AnnexI_FINAL-1.pdf

BOX 10. WHERE TO FIND THE RESULTS OF CLIMATE CHANGE SCENARIOS FOR FRANCE?

In France, DRIAS provides access to the results of climate change scenarios – known as “climate projections” – on its web portal.

Visitors to the site can select the characteristics of the climate projection that they wish to consult, such as the time horizon, the climate variable analysed, the input RCP, or the number of models used (several or just one). The results are generally presented in the form of mapping.

For more information: **DRIAS, futures of climate**.

1.4. Climate impact scenarios

1.4.1 The impacts of climate change will be determined by the climate itself, but also by socio-economic development choices

Major climatic changes impact human systems and their environment

As indicated in **Figure 10**, climate change radically alters meteorological conditions that can impact human systems.

Climate change can impact human systems directly. For example, an increase in the intensity and duration of heat waves impacts human health, and torrential rain can cause flooding in warehouses.

The impacts on human systems are also and above all indirect. The consequences of climate change are transmitted to the broader systems upon which humans depend. Climate change impacts natural physical systems[13]. For example, it causes sea level rise, changes to river flow regimes and drier soils. Climate change also impacts animal and plant ecosystems, leading to species migration, proliferation, reduction or even extinction. These impacts on the different systems feed into one another and cascade down, resulting in multiple impacts on human systems. For example, the increase in droughts can reduce crop yields, and the development of wetlands can lead to the proliferation of mosquitoes that carry diseases transmissible to humans.

Many impacts of climate change are already in evidence for health, infrastructure, economy, security, food and water[14]. Other impacts – referred to as "potential" – are likely to occur in the not too distant future.

The characteristics of systems and their evolution also determine impacts

Climate impacts do not depend only on changes to the climate system. They also depend on the characteristics of socio-economic systems and their changes. These include in particular their degree of exposure to climate change, their sensitivity (to what extent exposure to climate change can have negative or positive consequences) and their adaptive capacity (to what extent the system is capable of managing the effects of climate change); these three characteristics are represented by pictograms in the **Figure 10**.

A system's sensitivity and adaptive capacity determine its degree of vulnerability to climate change, which varies depending on the system. For example, an economy based on agricultural activities will have different vulnerabilities from an economy based on industrial activities: they will not be impacted in the same way by a drought, a heat wave, etc.

Societies have the capacity to modify their exposure and their vulnerability to climate impacts, as well as those of natural systems, through certain development choices. For example, intensive agriculture could result in friable, poorly aerated soils, which are more sensitive to erosion and landslides. Conversely, a city could adapt to climate change by implementing an urbanisation policy in areas with low exposure to climate impacts. It could also adapt to heat waves by reducing the vulnerability of the population, for example by providing access for all to basic services such as drinking water or energy.

13 We use the term "physical impacts of climate change" to describe impacts on the natural physical environment.
14 For more details, see Mora et al. 2018. *Broad threat to humanity from cumulative climate hazards intensified by greenhouse gas emissions*.

FIGURE 10. THE LINKAGES BETWEEN CLIMATE IMPACTS, CLIMATE AND SOCIO-ECONOMIC SYSTEMS EXPLORED BY CLIMATE IMPACT SCENARIOS

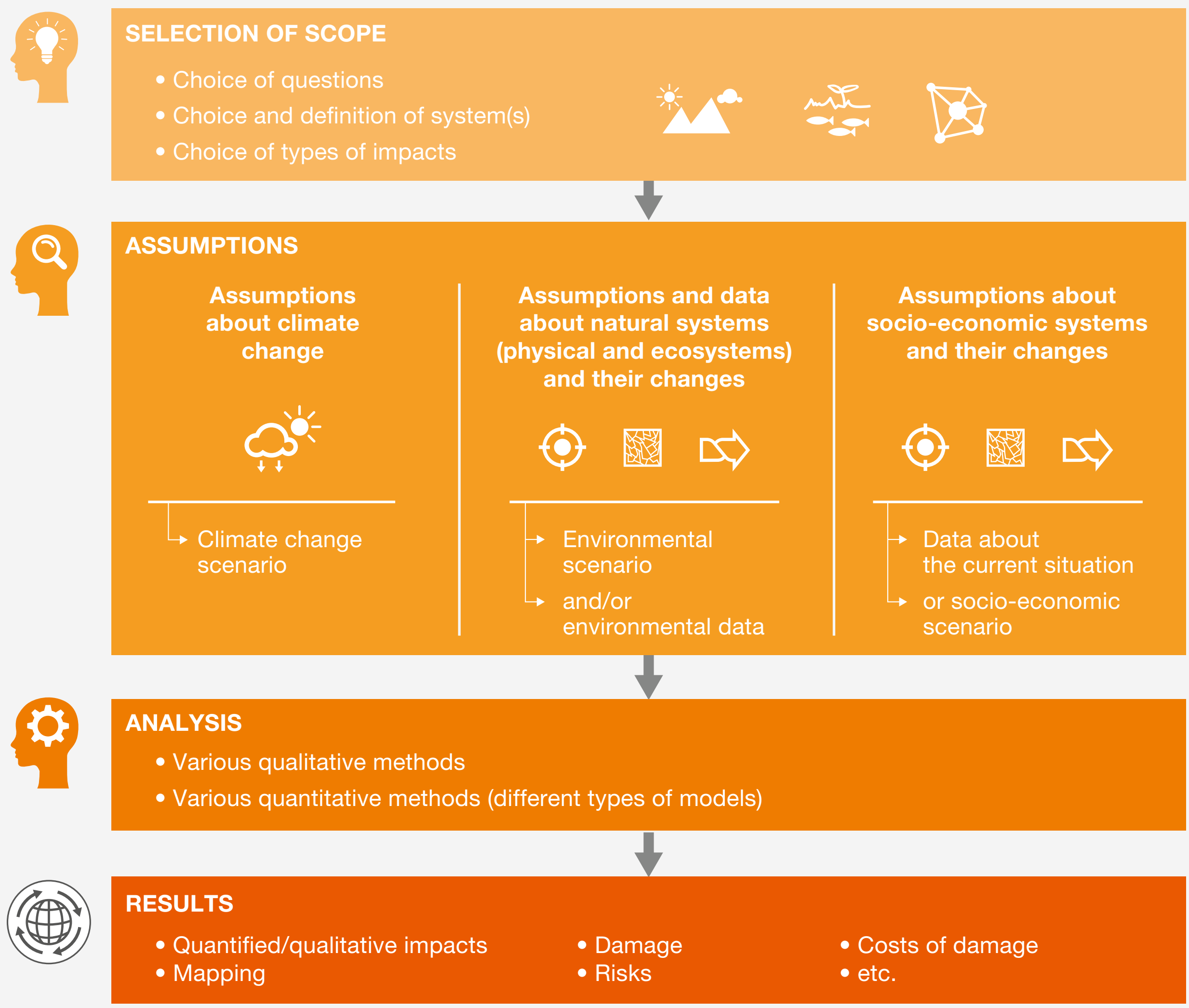
Source: I4CE, 2019

1.4.2 Climate impact scenarios study the impacts of a climate change scenario on a given system

Climate impact scenarios explore the impacts of climate change on human-related systems (the physical environment; an ecosystem; a human system such as a city, a farm, etc.). Depending on the question to be answered, the scenario may also include a representation of the dynamics specific to the systems studied, in order to integrate their capacity to modify exposures and vulnerabilities.

Impact scenarios are developed by research communities that are not yet sufficiently federated, with heterogenous methods and producing a broad range of results. There are thus numerous ways of constructing impact scenarios, and the process described below and summarised in **Figure 11** is not intended to be exhaustive.

FIGURE 11. CONSTRUCTION OF A CLIMATE IMPACT SCENARIO



Source: I4CE, 2019

1. AVOIDING CONFUSION: IDENTIFYING TRANSITION SCENARIOS AMONG CLIMATE-RELATED SCENARIOS

For a given system: numerous questions to ask and a wide range of data to mobilise

The construction of an impact scenario begins with the choice of the question to be answered –this initial question then points to the choice of the systems to be studied (*e.g.* a company, a forest, a glacier), the climate phenomena (*e.g.* heat waves), the types of impacts (*e.g.* physical damage to installations, economic losses associated with the decline in worker productivity), and the time horizon.

Impact scenarios then require three families of input assumptions and data. These concern:

1. **Climate change**: a climate impact scenario uses as input a climate change scenario, at the appropriate spatial scale and time horizon.
2. **The characteristics of current socio-economic systems or their changes**: a climate impact scenario can use as input the current characteristics of the socio-economic system – especially when considering current or very near future impacts –, or a socio-economic scenario[15] describing changes to different factors that can increase/reduce the system's exposure and vulnerability to the impact in question (inequality reduction, agricultural diversification, population change, drinking water demand, urbanisation, etc.).
3. **The physical and natural systems** that play a role in the impact scenario. For example, a climate impact scenario on agricultural yields requires data describing the water requirements of different crops, the ideal climate conditions for cultivating those crops, or assumptions about other factors that may influence yields (species evolution, land use conflicts, etc.).

Depending on the question to be answered, different impact scenarios can be built using one or more climate change scenarios, and possibly one or more change scenarios for the system considered.

Different quantitative and qualitative methods are used tobuild a climate impact scenario

According to the subject studied (physical system, ecosystem or human system; material damage, economic losses, etc.), the assumptions and data can be processed by various qualitative and quantitative methods. To study water stress on a farm, for example, a hydrological model representing a watershed can be used, as well as a soil model, a crop model, but also a model quantifying the economic impacts on the farm, its partners and its broader environment.

1.4.3 Using the results of impact scenarios as decision-making tools for resilient and adapted pathways

More and more impact scenarios on human systems and their environment – and the results of scenarios – are available online. As indicated in **Figure 11**, they take many forms. These scenarios are generally sectoral (for example, climate impact scenarios on agriculture, tourism, energy demand, etc.).

An organisation can already use these scenarios to inform strategic thinking on the impacts of climate change (for example, to increase the resilience of the organisation's strategy, or to position itself in order to seize opportunities linked to the future development of adaptation services). Initially, some sectoral scenarios can enable the organisation to become familiar with the types of climate impacts that could affect it, and to understand their determinants. To go further, the organisation can develop its own specific impact scenario, in order to refine its strategic approach to climate change. This can build on the targeted exploration of the results of impact scenarios available on numerous portals (see the examples proposed in **Box 11**).

15 In particular, SSPs (see Box 12) can be used to this end.

BOX 11. EXAMPLES OF PROJECTS AND STUDIES PROVIDING ACCESS TO DATA ON CLIMATE IMPACT SCENARIOS AND THEIR RESULTS

- **At the global level:**
  - The “Oasis Hub” web portal launched by Climate KIC and other partners in 2017 gives access to extensive data on the risks linked to climate change.
  - The different reports by the IPCC Working Group II - Impacts, Adaptation and Vulnerability.
- **At the European level:**
  - The PESETA I, II and III project aimed at assessing the physical and socio-economic impacts of climate change in Europe.
  - The ClimateAdapt platform launched by the European Commission and the European Environment Agency: it provides access to and shares extensive information on the impacts, risks and challenges of adaptation to climate change.
  - The IMPACT2C project supported by the European Commission to assess the climate impacts of global warming of 2°C for Europe.
- **At the French level:**
  - The DRIAS portal, which presents physical impact scenarios for forest fires, droughts and snowfall.
  - The Climat HD tool developed by Météo France, which provides information on future climate change but also on certain impacts.
  - The study "Climate change and insurance", published in 2015 by the the French Insurance Federation. This study, coordinated by the climatologist Jean Jouzel, indicates what models can tell us about climate impact in France by 2040. In particular, the study illustrates how the evolution of climate and the evolution of socio-economic systems together determine the impacts.

2. Navigating the different transition scenarios

As previously described, a wide variety of transition scenarios exist. This is explained in particular by the different visions and objectives of developers, the choice of certain assumptions, or the use of models with different properties.

To navigate this diversity, this section provides a more in-depth analysis of the components of a transition scenario, described above and represented again in **Figure 12**. Building on the example of existing scenarios, it identifies the different possible choices made during the construction of a scenario and their implications for the interpretation of its results, and more broadly of the scenario. A concise framework for understanding a transition scenario is proposed at the end of this section and applied to five publicly-available scenarios.

2.1. The narrative and assumptions of the scenario: a mixed picture of plausible changes towards a low-carbon world

Transition scenarios are generally built on a narrative describing a possible world change at some point in the future[16]. This qualitative story can describe the socio-economic context in which the transition takes place, the climate target, and some of the political or technological choices made to achieve it. It includes a combination of demographic, economic, political, technological and other assumptions, which are mutually consistent. **Properly identifying the narrative and the assumptions is essential**, since the use of a particular scenario implies the adoption of all of its assumptions, which are more or less explicit, and of what it disregards.

2.1.1 A transition scenario takes account of assumptions about changes in the socio-economic context

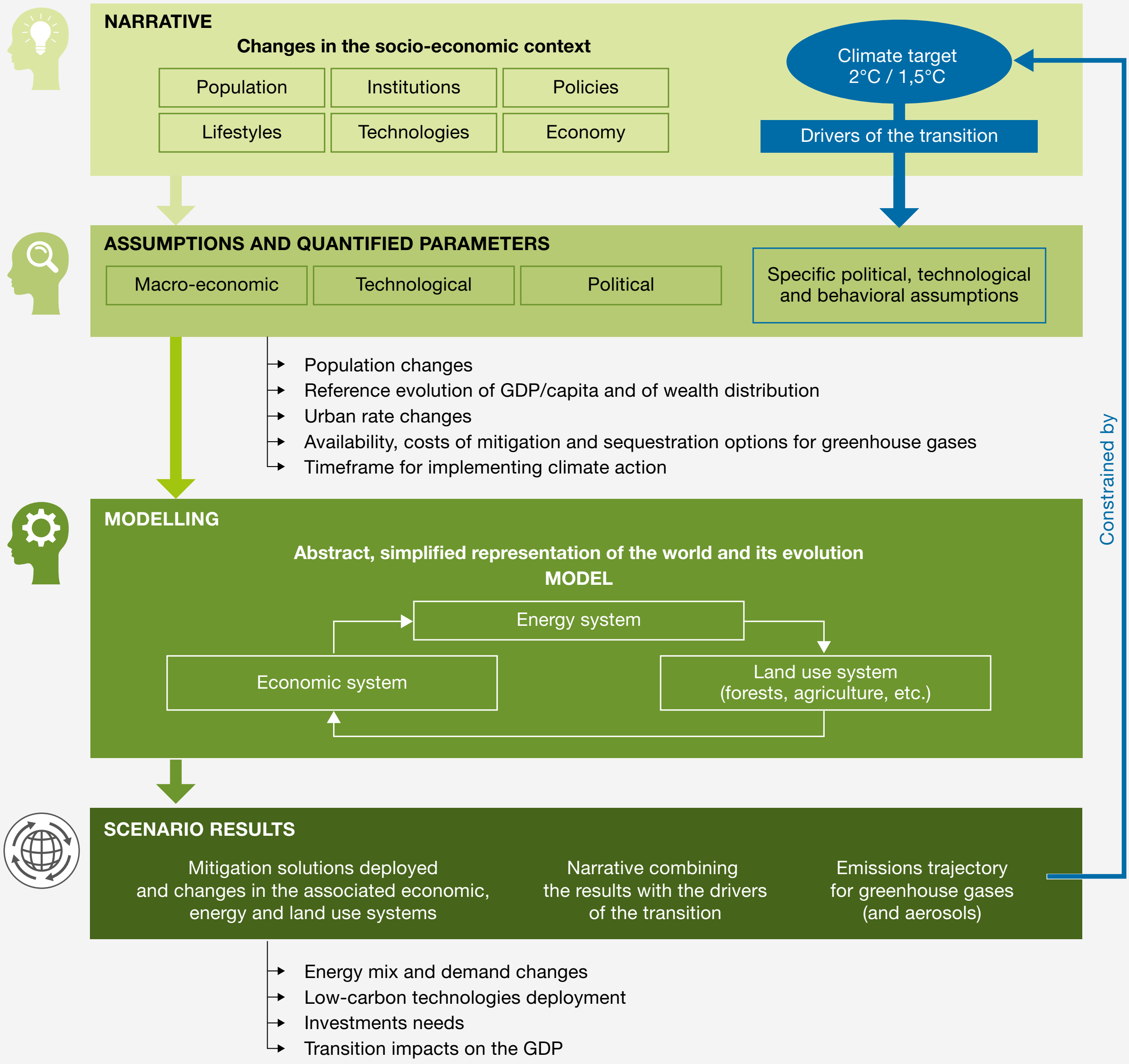
In a transition scenario, assumptions are made to describe changes in the socio-economic context in which the transition takes place (represented in blue in **Figure 5**) that will condition the extent of the effort to be made in order to achieve the climate target. These concern certain direct or indirect determinants of GHG emissions, such as demographic change, urbanisation, economic growth, growing inequalities, the rate of technological progress, the adoption of resource-intensive or, on the contrary, more sustainable lifestyles, the availability of resources and the degree of environmental protection or degradation. Some scenarios also explore geopolitical changes such as increasing globalisation, or the escalation of conflicts and nationalism.

These assumptions may be derived from projection exercises conducted specifically for the scenario or from reference projections, such as those produced by the UN for **world population change** or by the Organisation for Economic Co-operation and Development (OECD) for **economic growth**[17].

In the world of research on climate change, five socio-economic narratives, known as the Shared Socio-economic Pathways (SSPs), have been developed in order to coordinate the work of researchers (see **Box 12**) and the construction of transition scenarios.

16 The majority of time horizons for scenarios range between 2040 and 2100.
17 In some scenarios, economic growth is a result of the scenario rather than an input assumption, see 2.2.

FIGURE 12. CONSTRUCTION PROCESS AND COMPONENTS OF A TRANSITION SCENARIO



Source: I4CE, 2019

Note: This figure is a stylised, simplified illustration. In particular, the examples of the different possible input or output parameters for transition scenarios are neither exhaustive nor valid for all scenarios. Likewise, not all models include a representation of the economy, energy and land-use sectors (see 2.2).

BOX 12. SSPS – SHARED SOCIO-ECONOMIC PATHWAYS

What are the SSPs?

The SSPs are narratives of socio-economic development that explore plausible evolutions of the world in the absence of new policies and measures to limit global warming (Riahi *et al.*, 2017). They were defined by the scientific community with a view to building a common framework for reflection and facilitating the analysis of climate impacts, mitigation and adaptation options, and their costs.

How were they built?

Five narratives were developed, describing possible social, economic, political and technological changes by the end of the 21st century (**Table 2**). Each narrative was translated into quantitative data, particularly concerning economic growth, population and urbanisation (O'Neill et al, 2017). These assumptions were used as model inputs (see 2.2) in order to obtain baseline scenarios for each SSP (in other words not including any climate objective). These scenarios connect the SSPs with a trajectory of changes in energy and land use, as well as a GHG emissions trajectory. Numerous models were used for this purpose, generating alternative interpretations of the different SSPs (Riahi *et al.*, 2017). A single model was nevertheless chosen as a reference for each SSP: the corresponding scenarios were called "SSP markers", and serve as a point of comparison between the different SSPs.

The SSPs are used to produce transition scenarios

The SSPs and their assumptions are used to produce baseline scenarios, not constrained by a climate objective. They are also used to produce transition scenarios when they are constrained by a specific trajectory of changes in GHG concentrations that limits global warming – especially RCP2.6 and RCP1.9 (see **Box 7**). This combination of SSPs and GHG concentration trajectories shows that certain socio-economic changes, such as resurgent nationalism and the lack of global coordination (described in SSP3), are difficult or even impossible to reconcile with keeping global warming below 2°C.

TABLE 2. THE SSPS AND THEIR NARRATIVE

Scenario	Narrative	Challenge for mitigation	Challenge for adaptation
SSP1 Sustainability	Strong international cooperation, priority given to sustainable development, improvement in living conditions and consumer preferences for environmentally-friendly goods and services, with lower resource and energy intensity.	Low	Low
SSP2 Middle of the road	Current social, economic and technological trends continue, development and growth proceed unevenly depending on the country and region. National and international institutions work towards achieving sustainable development goals that progress slowly. The environment experiences degradation despite development that is less resource - and energy-intensive.	Medium	Medium
SSP3 Regional rivalry	Resurgent nationalism, slow economic development, persistence of inequalities and regional conflicts. Countries are guided by concerns about security and competitiveness. They focus on national or regional problems and on food and energy security issues. Low international priority is given to environmental protection, leading to strong environmental degradation in some regions.	High	High
SSP4 - Inequality	Development marked by wide disparities between and within countries. Degradation of social cohesion and multiplication of conflicts. A growing gap between an internationally connected elite, responsible for the majority of GHG emissions, and a fragmented collection of low-income, poorly educated people who are vulnerable to climate change. The energy sector diversifies between carbon-intensive and low-carbon energy sources. Environmental policies focus on local issues.	Low	High
SSP5 - Fossil fueled development	Development based on heavy use of fossil fuels and marked by high investments in health, education and new technologies. Adoption of resource- and energy-intensive lifestyles around the world. High economic growth and rapid technological progress. Local pollution problems are successfully managed and adaptation is facilitated by the reduction in poverty.	High	Low

Sources: Riahi et al. (2017), O'Neill et al. (2015), Bauer et al. (2017)

2.1.2 Context changes can be explored in a baseline scenario associated with the transition scenario

Socio-economic changes are sometimes explored in scenarios not constrained by a climate target, known as *"baseline scenarios".* Indeed, a transition scenario is generally produced in comparison with a baseline scenario, with which it shares certain contextual elements (depending on the scenario, these may be assumptions on the population growth rate, changes in economic growth, the rate of technological progress[18], etc.). Developing a transition scenario in relation to a baseline scenario **determines the level of additional efforts needed in order to achieve a climate target in a certain context that may or may not be favourable to reducing GHG emissions**. Identifying and understanding the assumptions included in the baseline scenario – if one exists – is therefore essential to fully understand the transition scenario and the differences between the two scenarios.

Baseline scenarios follow an exploratory approach also known as forecasting (see **Box 6**): they are based on current trends and changes that are more or less aligned with the world of today. They result in degrees of global warming that exceed the climate target of 1.5°C or 2°C, sometimes by several degrees. Some baseline scenarios exclude from their scope any policy whose explicit objective is reducing GHG emissions. They may, however, include policies that have the indirect effect of reducing emissions (for example health or environmental policies, etc.). Other baseline scenarios include some climate policies. For example the CPS (Current Policies Scenario) and NPS (New Policies Scenario) developed every year by the International Energy Agency in its annual publication, the *World Energy Outlook* (WEO), include the climate policies already in place (CPS) and those that the countries have committed to implementing (NPS). However, these scenarios are not compatible with keeping global warming below 2°C.

2.1.3 A transition scenario is constrained by a climate target

Transition scenarios are constrained by a climate target aimed at keeping global temperature rise to below 2°C or 1.5°C above pre-industrial levels. In practice, the inclusion of a climate target in transition scenarios translates into a limit on GHG emissions[19]. This limit may correspond to a carbon budget[20]: this is the cumulative total of emissions that the scenario must not exceed over a given period (see **Box 13**). It may also correspond to a constraint on the GHG emissions trajectory for the scenario: this trajectory must then be compatible with other emissions trajectories that meet the 1.5°C or 2°C climate target (for example, RCP2.6 or RCP1.9, see **Box 7**).

2.1.4 A transition scenario presents a certain vision of the low-carbon transition

Scenarios reflect their developer's vision of the transition, and include assumptions about how the climate target can be achieved. In particular, they translate the different drivers that make the transition possible. These assumptions concern:

- The **international configuration of climate action**, especially the scope and distribution of climate efforts over time and by country. For example, some scenarios may describe global, immediate climate action, representing the signature of a global climate agreement with the universal participation of all countries or, on the contrary, fragmented, delayed climate action.
- The **mitigation solutions available**, especially their technical feasibility, their potential, their cost and their social and political acceptability. These assumptions may vary considerably from one scenario to another, with some scenarios choosing to do without certain technologies that are still immature or present ecological sustainability challenges, such as nuclear, CCUS and BECCS technologies. The assumptions about the availability of negative emissions technologies are particularly important: assumptions conducive to the development of these technologies can defer climate action in time and thereby alter the necessary rate of emissions reductions.

18 When these parameters are input data in the scenarios. In particular, changes in economic growth and the rate of technological progress can be endogenous or exogenous parameters depending on the scenarios and the models used (see 2.2).

19 The emissions limit in transition scenarios corresponds to a certain probability of achieving the climate objective or to a possible range of temperature increases. This is mainly due to differences in the results of climate models. Indeed, depending on the climate model, the same emissions trajectory can lead to different temperature increases.

20 The carbon budget applies to CO_2 emissions only. It must therefore be accompanied by assumptions about emissions reductions for the other GHGs in order to justify compliance with a climate objective.

BOX 13. CARBON BUDGET

The notion of the carbon budget corresponds to the maximum amount of cumulative CO_2 emissions that must not be exceeded in order to keep global warming below a certain temperature. It is generally calculated from a given period – hence the reference to the "remaining carbon budget". Different emissions reduction trajectories are possible for the same carbon budget.

In the IPCC 1.5°C special report, the remaining carbon budget from January 2018 is estimated at 1170 $GtCO_2$ to keep global warming below 2°C by the end of the century. It was 3400 $GtCO_2$ from the pre-industrial period (1850-1900), meaning that we have already consumed more than 65% of this budget.

The remaining carbon budget from January 2018 to keep global warming below 1.5°C is 420 $GtCO_2$. It was 2650 $GtCO_2$ from the pre-industrial era, meaning that we have already consumed 84% of this budget. It should be noted that at the current rate of emissions – 41.2 $GtCO_2$ of global CO_2 emissions in 2017 –, the carbon budget to keep global warming below 1.5°C will be fully consumed in less than 10 years.

The concept of the carbon budget is based on a robust understanding of physical phenomena. However, there are some significant uncertainties about the estimation of a carbon budget to meet a given climate objective. These concern, for example, the climate response to emissions of CO_2 and other GHGs, or potential Earth system feedbacks such as the release of CO_2 from permafrost thaw. All of the uncertainties identified in the IPCC 1.5°C report could increase or reduce the carbon budgets described above by several hundred $GtCO_2$.

The carbon budget estimates specified here have a 66% probability of keeping warming below the objective.

Sources: IPCC (2014a) - Table 2.2; IPCC (2018); IPCC (2018b); Key figures on Climate (2019); Le Quéré et al. (2018)

- **Policies and measures specific to GHG emissions reductions**: these may be assumptions describing multisectoral policies, such as introducing carbon pricing instruments, or sectoral policies, such as banning the construction of new coal-fired power stations or removing fossil fuel subsidies, implementing more stringent regulations on energy efficiency standards for the construction of new buildings, or introducing very strict emissions and energy efficiency standards for transport.
- **Behavioural changes**: specific assumptions can be made about changes in practices or certain behaviours that facilitate the achievement of a climate target. These include, for example, changes leading to a reduction in mobility requirements or to the adoption of consumption practices in favour of low-carbon, highly energy-efficient goods and services.

Assumptions concerning changes in the socio-economic context, the climate target, and the choices made to achieve it are translated into quantified parameters, which will serve as input values for the model used to quantify the evolutions described by the scenario.

2.2. The use of models with different properties to build scenarios

The models used to quantify transition scenarios generally include **a representation of the economy, the energy system and land use** (or just one or two of these elements, typically concentrating on one)[21]. They quantify the GHG emissions resulting from socio-economic development trajectories, and explore changes in the economic, energy and land use systems that are compatible with limiting global warming.

A model is a **simplified, partial representation of the world**, designed to **address a specific problem**. Some models are created to represent the functioning of energy markets at the global level[22]. Others seek to assess the economic impacts of energy and environmental policies[23], while yet others are designed to assess the environmental impacts of human activities[24]. **According to the problems they address, models are designed and function with different approaches, do not have the same scope and do not provide the same information.**

Thus, depending on the model used, the construction of the scenario and its interpretation will not be the same**.**

21 Some models used to quantify transition scenarios also include a very simplified representation of the climate system; these are known as «integrated assessment models», or IAMs.
22 Example: the WEM developed by the IEA.
23 Example: the GEMINI-E3 model developed by the Institute of Technology in Lausanne (EPFL).
24 Example: the IMAGE model developed by Utrecht University (UU) and the Netherlands Environmental Assessment Agency (PBL).

Identifying the main characteristics of the model is therefore an important step in reading a scenario. The goal here is not to provide an exhaustive list of the different characteristics of existing models, but to draw attention to several key differences between models that will impact the information that can be obtained from a scenario, and the way in which its results can be interpreted.

2.2.1 Models can be distinguished according to two "main" types of analytical approaches

Two "main" types of models used to build transition scenarios can be distinguished according to the analytical approach adopted.

First, models built around a global, macro-economic approach to the world: these aim to represent the whole economy and interactions between sectors as well as economic agents (households, banks, governments, etc.). They are used to analyse the economic impact of climate policies. Sectors and technologies are often represented in these models in a highly aggregated form (see **Figure 13**).[25]

Second, models built around a techno-economic approach. These models are based on a general or more detailed representation of technologies (their operating costs, their emissions factors, etc.) and are often sectoral (especially for the energy system) (see **Figure 14**). Contrary to macro-economic models, economic activity is generally exogenous in these models and economic interactions between the different actors and sectors are not represented.[26]

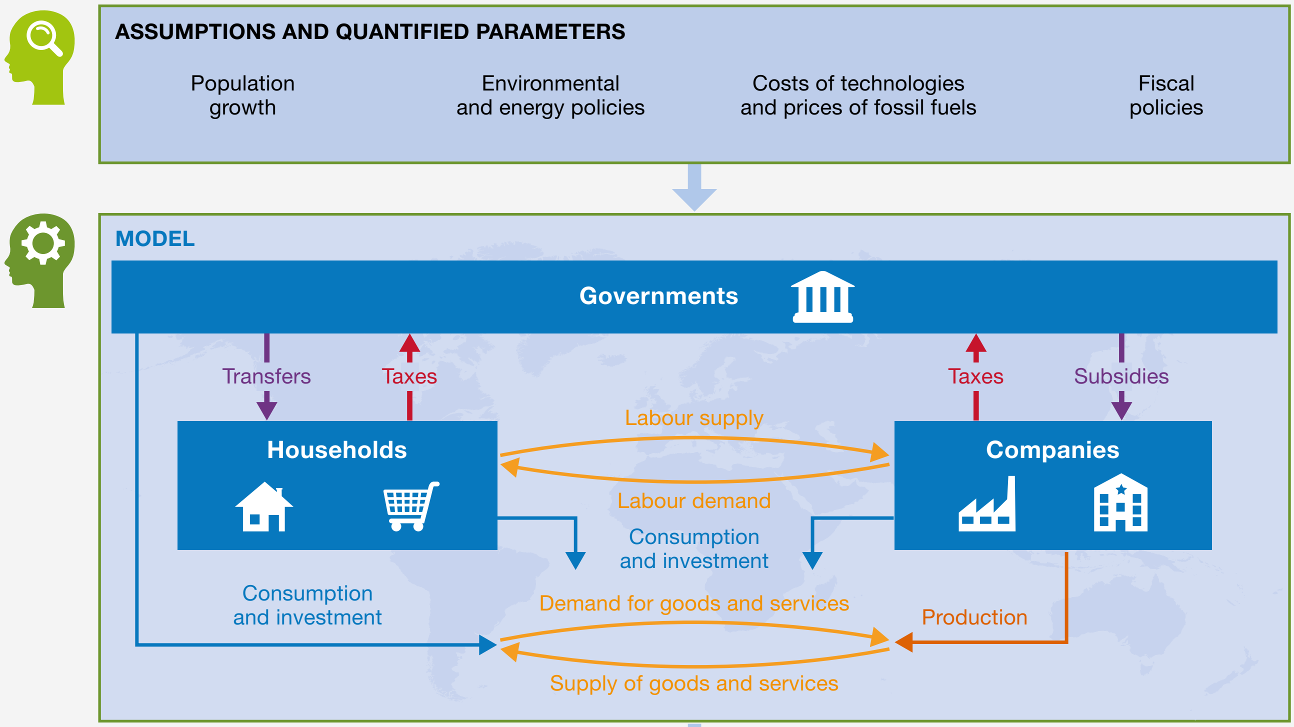
Depending on the type of model, **certain parameters will be either input assumptions or, on the contrary, outputs of the model**. For example, changes in GDP growth are generally endogenous – in other words generated through the model – in macro-economic models, which assess the economic impacts of the transition described by the scenario. Conversely, GDP changes are typically exogenous in models built around a techno-economic approach, and are set by the modeller as an input assumption for the model.

In order to expand their scope, some integrated models combine the two types of approaches described above. For example, they may include several modules: one to represent the economy as a whole and one or more additional modules to represent the energy system and its sectors of activity (housing, tertiary, transport, industry, agriculture).[27]

In addition to the combination of both approaches within the same model, some models with different sectors and approaches can be coupled, in other words used together, with the results of one model serving as inputs for others. This coupling may serve, for example, to explore both the deployment of mitigation solutions and the macro-economic impact of the low-carbon transition.[28]

25 These models are known as «top-down». Example: the GEMINI-E3 model developed by the Institute of Technology in Lausanne (EPFL).
26 These models are known as «bottom-up». Example: the POLES model developed by the European Commission Joint Research Centre (JRC), and the NégaWatt model simulating the French energy system.
27 These models are referred to as hybrid. Example: the REMIND project developed by the Potsdam Institute for Climate Impact Research (PIK), the IMACLIM-R model developed by CIRED.
28 For example, the MESSAGE-GLOBIOM model is made up of five different models: two main models representing the energy system (MESSAGE) and the land-use system (GLOBIOM), and three others representing respectively the macro-economic system, GHG emissions and the other pollutants in the climate system. It is developed by the International Institute for Applied Systems Analysis (IIASA).

FIGURE 13. SIMPLIFIED FUNCTIONING OF A MACRO-ECONOMIC MODEL



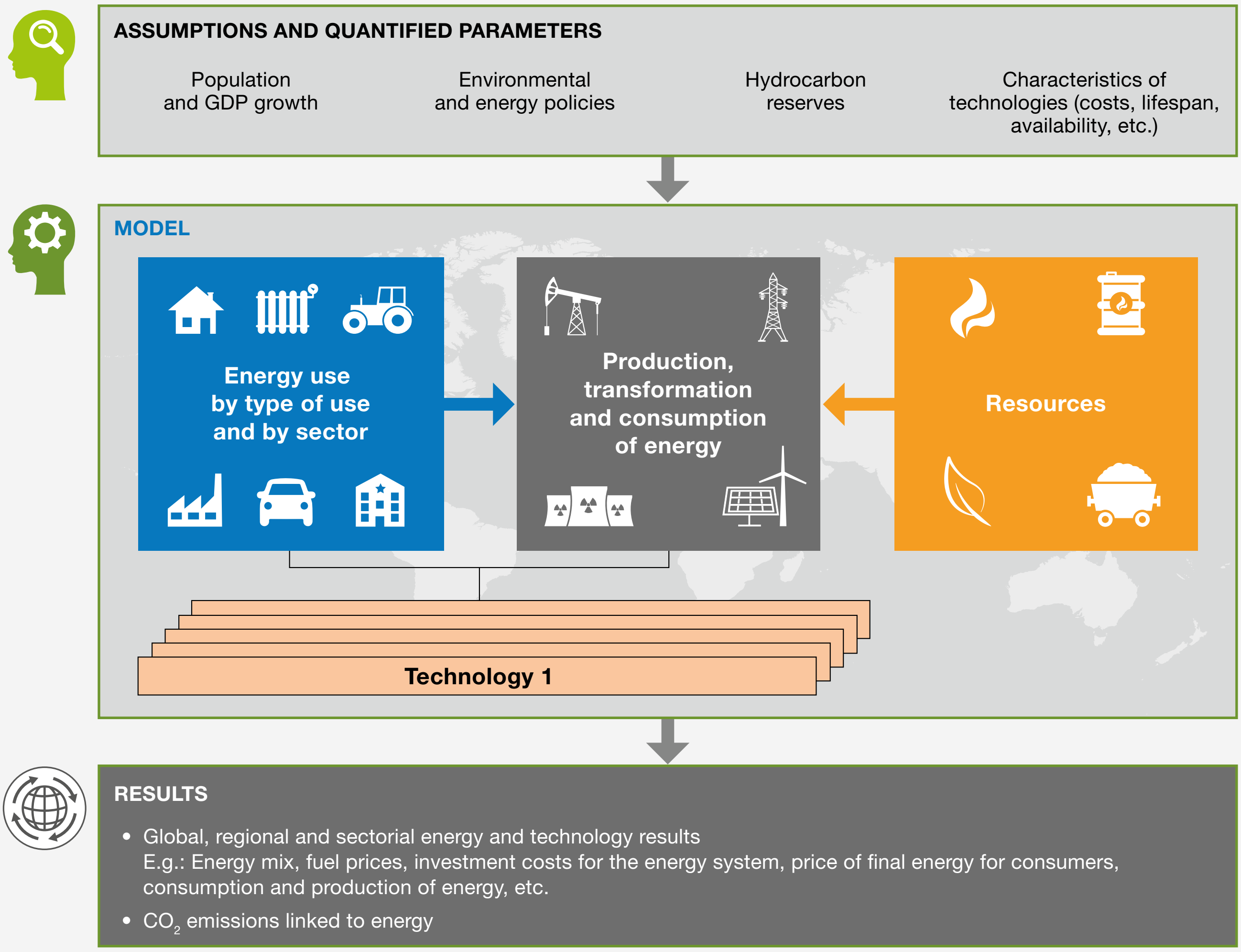
RESULTS

- **Macro-economic, global, regional and sectorial results**, e.g.: changes in GDP, changes in activity in industrial sectors, the impact of energy policies on the economy, job creation/losses due to the transition, changes in demand for energy, etc.
- Greenhouse gas emissions due to the production and consumption of goods and services

Source: I4CE, 2019 – Figure inspired by the DSGE (Dynamic stochastic general equilibrium) model developed by IBS – Institute for Structural Research.

Note: This Figure is an illustrative, simplified and therefore partial representation of a macro-economic model.

FIGURE 14. SIMPLIFIED FUNCTIONING OF A TECHNO-ECONOMIC MODEL - EXAMPLE REPRESENTING THE GLOBAL ENERGY SYSTEM



Source: I4CE, 2019 - Figure inspired by the POLES model and the WEM – World Energy Model used and developed by the IEA.

Note: This Figure is an illustrative, simplified and therefore partial representation of a techno-economic model.

2.2.2 The theoretical and operating principles, the scope and the level of detail in models influence the results of the scenario

Models are based on different theoretical foundations

Models are comprised of a set of equations, drawn from economic theory or from the technical and physical sciences to represent economic phenomena, the functioning of technologies and natural phenomena. These equations vary according to the theoretical foundations of the model, and this influences the results of the scenario. For example, models can be based on different theoretical understandings of the economy that influence the representation of the functioning of the economy and its components, such as labour market functioning and unemployment, labour productivity, and the ease of substitution between the different technologies.

A model can function so as to describe an optimal trajectory according to a given criterion

The way in which the model equations are solved and the operating principles of the model also influence the results. For example, some models will seek to describe the "best" possible evolutions of the world according to given criteria, such as minimising mitigation costs[29]

29 Example: the MESSAGE model developed by the International Institute for Applied Systems Analysis (IIASA).

or maximising well-being[30]. This type of model functions optimally. Conversely, other models simulate possible evolutions of the world without seeking to obtain optimal trajectories[31].

A model functions differently depending on the way in which actors' foresight is represented

The way in which the model functions also varies depending on the actors' foresight represented by the model. Two possibilities exist: either actors make their decisions "day-to-day", according to the information available at the time; or they are capable of anticipating future changes and thereby making the best possible decisions not only according to information available when decisions are made, but also according to future changes that they know of in advance. The way in which actors' foresight is represented influences the results. For example, in a model that simulates actors' "day-to-day" decisions, it is very likely that some technologies will still be installed in the short term, even though they will no longer be usable in the medium and long term in order to meet the climate target (*e.g.* coal-fired power stations without CCUS). On the contrary, in a model with perfect actor foresight that minimises mitigation costs over the whole period considered, technological decisions will turn at a very early stage to low-carbon technologies in order to anticipate future constraints on GHG emissions.

The scope and granularity of the model condition the information that will be available on the scenario

Models are distinguished according to their scope and their granularity – which condition the information available on the results of the scenario (see 2.3) –, especially concerning the following aspects:

- The **geographical scope** and **level of disaggregation** of the regions represented (multiregional, regional, national, local, etc.);
- The **time horizon** (2050, 2060, 2100, etc.) and the **time step**, in other words the interval between updates of changes;
- The types of **GHG emissions** and other pollutants considered in the model;
- The **sectors represented** and the level of detail with which they are represented (industry, agriculture, land use, etc.);
- The **goods/commodities** represented and the level of detail with which they are represented: energy and non-energy commodities, water, waste, etc.;
- The **technologies** and, more broadly, **the mitigation solutions** represented and the level of detail with which they are represented.

Identifying the scope of the model is important in order to correctly interpret its results. For example, a model that does not represent the land-use system cannot provide information about changes in GHG emissions from the agricultural system (excluding energy consumption)[32], or about the mitigation solutions deployed in this field. Since energy use is the main source of GHG emissions (see **Box 3**), many scenarios focus their scope on the energy system and on energy end-use sectors.

It should be noted that since most scenarios do not cover all GHGs and their sources, assumptions must be made by modellers to make it possible to compare emissions in their scenarios with trajectories resulting in a given degree of warming – especially for the sectors and GHGs not covered in the scenario. Likewise, since climate targets are expressed in degrees of warming by 2100, assumptions must sometimes be made about scenario emissions trajectories beyond their time horizon.

The representation of climate measures and policies depends on the characteristics of the model used

In models that explicitly represent technologies, energy performance standards may be represented as a constraint on the efficiency of the different technologies. Conversely, energy and climate policies may sometimes be represented by "proxies", such as a carbon price (see **Box 14**), or an energy tax to reduce energy consumption and represent energy efficiency policies.

30 Example: the REMIND model.
31 Example: the World Energy Model (WEM) developed by the IEA.
32 Example: the World Energy Model (WEM) developed by the IEA.

BOX 14. KEYS TO INTERPRETING THE CARBON PRICE IN TRANSITION SCENARIOS

The carbon price consists in applying a price to GHG emissions[a]. Two main policy instruments are used to attach an explicit price to carbon: a tax imposed on GHG emissions (carbon tax) or a market in which emissions allowances are bought and sold (emissions trading system). In addition to explicit carbon prices, other policies encouraging GHG emissions reductions (such as support policies for renewable energy or the establishment of emissions standards) implicitly put a price on GHG emissions reductions.

• The carbon price in transition scenarios

In transition scenarios, the carbon price may result from different approaches. One approach, known as **cost-benefit**, consists in assessing the socially optimal trajectory for GHG emissions – and thus the level of global warming – while minimising all costs associated with climate change, in other words the damage caused by climate change and the costs of reducing emissions. This approach is used to estimate the **social cost of carbon**, which corresponds to the present cost of damage caused by emitting one tonne of CO_2 or the corresponding amount of another GHG[b].

Another approach, known as **cost-efficiency**, consists in assessing the lowest cost mitigation pathway to achieving a given climate objective. This approach estimates the **shadow price of carbon**, corresponding to the cost of the solutions to be implemented in order to reduce GHG emissions in line with the climate objective set.

Finally, in some scenarios, the carbon price is an input, **representing the implementation of explicit carbon pricing policies** (taxes or markets).

• How should the carbon price be interpreted in scenarios?

Most transition scenarios include a carbon price, which is generally **an input** or derives from **a cost-efficiency approach with a given climate objective**. The carbon price cannot be interpreted in the same way in these two situations. In the first, the carbon price represents the establishment of carbon markets or taxes. Its value is an assumption made by the scenario developers, and does not derive from the dynamics of the model used. This is the case for the IEA SDS scenario, for example[c], in which the carbon price is accompanied by numerous other policies, such as the implementation of energy efficiency standards in industry and building.

In the second case, the carbon price represents **a shadow price reflecting the emissions reduction efforts** over time imposed by a given climate objective. In this case, the price derives from the dynamics of the model used, and does not represent the implementation of explicit carbon pricing policies. This is the approach that was used, for example, in the modelling exercises that served to establish the value of climate action in France in 2018[d]. The estimation of the shadow price is highly dependent on the scenario assumptions, but also on the characteristics of the model used (see 2.2.). For example, a model that represents a broad portfolio of mitigation solutions and is more flexible regarding the solutions to be mobilised generally results in mitigation costs – and thus a carbon price – that are lower than those from models that are less flexible regarding the solutions to be mobilised[e].

Sources: Guivarch et Rogelj (2017), France Stratégie (2019), IPCC - Rogelj et al. (2018)

a. A carbon price may cover only CO_2 emissions, or also concern other GHGs.
b. This calculation is made using models that assess the impact of climate change on socio-economic systems. This approach was used in particular for the Stern Review (Stern N. (2006), *Stern Review: The Economics of Climate Change*, United Kingdom).
c. In the 2018 version of the scenario, the CO_2 price is 63$/t$CO_2$ in 2025 and 140$ in 2040 in the developed countries, and 43$/t$CO_2$ in 2025 and 125$ in 2040 in a selection of developing countries.
d. The estimation of the value of climate action is aimed at identifying the most relevant investments and sectoral actions to achieve the objective of carbon neutrality by 2050 in France. It was estimated at 250€/tCO_2 in 2030, based on modelling exercises that mobilised techno-economic and macro-economic models.
e. To find out more, the study entitled "Carbon price variations in 2°C scenarios" by C. Guivarch compares the carbon prices generated by different models.

2.3. The results of scenarios: more or less detailed qualitative and quantitative information on the changes brought about by the transition

2.3.1 Transition scenarios provide quantitative elements about changes in socio-economic systems

Scenarios usually take the form of a written report – sometimes accompanied by tables of data or technical annexes – presenting the results of the modelling exercise. These results may include quantitative changes relating to:

- **The economy**, *e.g.* jobs created, the contraction or expansion of key sectors, impacts of the transition on GDP, investments needed to transform energy or electricity systems, or the carbon price (see **Box 14**).
- **The energy system**, *e.g.* changes in primary and final energy consumption, both globally and by sector, changes in the energy mix and the share of the different energies (fossil, renewable, nuclear) at the global level and/or by region.
- **The land-use system**, *e.g.* agricultural production and demand, land-use change (afforestation/deforestation, etc.).
- **GHG emissions trajectories** at the global level, by sector and by geographical area.
- **The mitigation solutions deployed and associated technologies**: the different types of solutions are described above, in the section on the challenges of the transition. They are also described in the framework for reading transition scenarios.

Scenarios rarely include results for each of the five areas above. In particular, depending on the type of model used, the results will not be the same. For example, a techno-economic model representing the energy system produces detailed results concerning the technologies used and changes in the energy mix (see **Figure 14**), whereas a more global economic model provides results about the impacts of the transition on employment and economic growth (see **Figure 13**). Moreover, the granularity of the scenario results is limited by that of the model (see **2.2.2**), but the results are often presented in a more aggregated manner than the information available in the model.

2.3.2 A story is created around the results and assumptions of scenarios to form a coherent narrative about the transition

The results of scenarios are also comprised of qualitative elements that tell a story about the quantified changes given directly as model outputs. This story combines both the assumptions and the results of the scenario to create a coherent narrative about the transition. It gives the scenario credibility, in particular by detailing the drivers supporting the transition (see **1.2.1**). This narrative may, for example, include information about the different policy measures implemented, the behavioural changes adopted, or even the disruptive technologies needed for the implementation of the solutions described.

3. Eight steps to interpret transition scenarios

3.1. Framework for reading transition scenarios

Based on the elements presented for transition scenarios, the following framework summarises the main steps to follow when reading and interpreting these scenarios, as well as their key parameters. It is then applied to a selection of five scenarios.

1 Identifying the context in which the transition scenario was developed

- **Issues**: The context in which the scenario was developed, the vision of its developer and its purpose guide the approach adopted for the scenario as well as the choices made during its construction – choices that largely determine the results of the scenario. Before considering the content of the scenario, it is therefore important to understand the context in which it was created, by which organisation and for which purpose. Moreover, it is important to familiarise with the vision of the transition described by the scenario (inclusion of targets other than the climate target, description of global/fragmented climate action, identification of an optimal pathway – following one or more criteria – to achieving the climate target, etc.).
- **Information/parameters to be identified**: the organisation that produces the scenario, its purpose(s), the date and context of publication, the frequency of scenario updates, the broad lines of the transition described by the scenario.

2 Identifying the level of information available on the scenario

- **Issues**: Depending on the context of their development, scenarios do not always use the same medium: although they very often take the form of written reports, these reports vary in length, detail and technicality depending on the scenario. Sometimes a summary is made public, while the detailed report is not available to all. Information on the methodology – in particular the model – and the data sources used are sometimes made public, along with tables or graphics presenting the results. The level of information available on the scenario will condition the use that can be made of it.

  ⚠ The information available on the scenario depends on the medium through which the results are presented, but also on the scope and granularity of the model used. In addition to the results made public, more disaggregated data may exist in the model.
- **Information/parameters to be identified**: the medium of publication, the existence of methodological annexes or tables of results, the scope (geographical, sectoral, time horizon), the granularity of results (geographical, sectoral, temporal).

3 Understanding the socio-economic context of the transition described by the scenario

- **Issues**: The future socio-economic context considered in the scenario – which corresponds to world changes (demographic, economic, geopolitical, institutional, etc.) exclusive of the climate target – may be more or less conducive to reducing GHGs. Understanding this context is essential in order to identify the challenges of the transition described in the scenario

  ⚠ These changes can be explored in a baseline scenario associated with the transition scenario. Since the results of the transition scenario are sometimes presented as a differential in relation to this baseline scenario, it is essential to fully understand the assumptions included in the latter.
- **Information/parameters to be identified**: the existence of a baseline scenario and its key assumptions, assumptions about the socio-economic context (changes in economic growth or its determinants, population, lifestyles, technological progress, the rate of urbanisation, the rate of inequality, the degree of globalisation/ international cooperation, etc.).

4 Identifying the climate target and the distribution of efforts over time

- **Issues**: The trajectory and results of the transition scenario are conditioned by a climate target, usually expressed as a limit on global warming by 2100. This target can be taken into account in different ways in the scenario (compliance with a carbon budget, comparison of emissions trajectories with baseline trajectories such as the RCPs, use of a climate model). The probability associated with achieving the target gives an additional indication of the ambition of the scenario. Moreover, the emissions reduction trajectory provides information about the distribution of efforts over time.

⚠ It should be noted that scenarios in which reduction efforts are further in the future generally use negative emissions technologies to meet the climate target.

⚠ For scenarios with a time horizon ending before 2100, it is important to determine whether assumptions are made/accepted about changes in GHG emissions over the period not covered by the scenario and to understand their implications in terms of the reduction efforts required, possible shifts away from the changes described by the scenario, and the use of negative emissions technologies. These assumptions about changes in emissions beyond the time horizon of the scenario determine the levels of emissions reductions required in the scenario. They are not always explicit.

- **Information/parameters to be identified**: the climate target set, the probability associated with it, the way in which it is taken into account in the scenario, changes in the GHG emissions trajectory, the assumptions made/accepted about changes in GHG emissions beyond the period covered by the scenario.

5 Identifying the weight given to the different drivers of the transition and the associated assumptions

- **Issues**: Each scenario is based on drivers of change – mainly political, technological and behavioural – that serve to implement the solutions identified at Step 7. Depending on the scenario, the weight given to the different drivers is not the same. Identifying the drivers underlying the scenario helps to understand how the transition – and the far-reaching changes it implies – are explained by the scenario developer.

⚠ The weight given to the different drivers of the transition can generally be understood through the story told around the scenario, which combines assumptions and results in order to create a coherent narrative about the transition. This story, which enables the developer to justify the results of the scenario and to explain how the different mitigation solutions are implemented, increases the credibility of the scenario[33].

⚠ The carbon price does not always represent the establishment of an explicit carbon price through a tax system or an emissions trading scheme. It sometimes represents a shadow price that reflects the emissions reduction efforts required over time to meet a specific objective.

- **Information/parameters to be identified**: the measures/regulations/policies supporting the implementation of mitigation solutions, the value and significance of the carbon price, the behavioural changes and technological progress needed for the transition.

6 Analysing the geographical and sectoral distribution of reduction efforts

- **Issues**: Many scenarios include elements on changes in emissions according to the emitting sectors: **building, transport, industry, power generation, agriculture**. The far-reaching changes implied by emissions reductions are not driven by the same sectors depending on the scenarios. The geographical distribution of emissions reductions – and therefore of mitigation efforts – also varies from one scenario to another. The distribution of efforts between sectors/countries derives from the dynamics of the model and the input assumptions of the scenario[34].

⚠ Emissions trajectories are not always comparable between scenarios: the **emitting sectors** and the **types of GHGs** taken into account vary. This is partly due to the model used to quantify the scenario.

⚠ It is important to understand the assumptions made about **changes in GHG emissions and in the sectors not represented in the scenario** (and the underlying model), which condition the emissions reduction efforts needed in the sectors covered by the scenario[35]. Likewise, in the case of a regional/national scenario, it is important to understand the assumptions made about **emissions reductions in the rest of the world**.

33 For example, an increase in the vehicle load factor in a scenario can be explained by the implementation of an ambitious carpooling policy and regulations on empty running for heavy goods vehicles.
34 This distribution may, for example, derive from the minimisation of transition costs with an optimisation model. It may also include other criteria, such as the convergence of per capita emissions.
35 This point of vigilance also applies to sectors represented in a very simplified manner, for which the assumptions are not necessarily explicit in the scenario – even if this is more difficult to detect.

- **Information/parameters to be identified**: the GHG emissions trajectory for the scenario, changes in emissions by sector/geographical area, assumptions about changes in emissions in the sectors/geographical areas not covered by the scenario (rarely indicated).

7 Identifying the solutions deployed to reduce GHG emissions and the associated technologies

- **Issues**: The weight given to the different mitigation solutions differs according to the scenario. It reflects a specific vision of the transition, which derives from the approach and the vision of the scenario developers. The mitigation solutions considered also depend on the scope of the model used and the sectors represented.

  ⚠ The representation of mitigation solutions in the scenario – and therefore the information available on these solutions – depends on the model used, its scope, its approach (techno-economic, with a more or less detailed representation of technologies, or more macro-economic) and its granularity.
- **Information/parameters to be identified**: examples of parameters enabling the identification of solutions deployed and their relative weight, by major category of mitigation solutions:
  - **Managing demand for energy and GHG emissions-intensive materials**: the share of emissions reductions due to energy efficiency globally and by sector; changes in primary energy consumption; changes in energy consumption in the different energy end-use sectors;
  - **The decarbonisation of the energy mix**: the share of the different renewable energies in the energy mix, changes in the share of electricity in final energy consumption, the share of nuclear in the electricity mix, the rate of deployment of CCUS technologies;
  - **Managing emissions from the agricultural system**: changes in emissions from the agricultural sector, changes in the consumption of meat;
  - **The use of negative emissions**: the amount of negative emissions, the BECCS capacities in place, the forest sinks mobilised.

  The qualitative story accompanying the scenario can also be useful in understanding the importance of the different mitigation solutions.

8 Identifying the macro-economic consequences of the transition

- **Issues**: Beyond the technological and political challenges, the macro-economic implications of the transition (investments, impacts on employment and growth, etc.) assessed in the scenario are important in order to better understand the economic challenges linked to the changes required for the transition.

  ⚠ Scenarios do not always provide information about the macro-economic implications of the transition; this depends in particular on the type of model used to quantify the scenario. Some parameters must therefore be interpreted differently depending on the way in which they were generated (for example, if changes in economic growth are set as an input assumption by the developer of the scenario, their value does not include the economic consequences of the transition).

  ⚠ The macro-economic impacts of the transition – when they are given in the scenario – are often presented as a differential in relation to a baseline scenario. In most cases, this scenario – and the transition scenario – do not include the impacts of climate change.
- **Information/parameters to be identified**: changes in economic growth and the impacts of the transition on economic growth, the investments required for the changes described in the scenario, the consequences of the transition on employment, changes in electricity or energy prices for end consumers.

3.2. Detailed review of a selection of transition scenarios

The previous framework is applied to a selection of five publicly-available transition scenarios, which are intended to be representative of the range of existing scenarios.

STEP 1 IDENTIFYING THE FRAMEWORK IN WHICH THE TRANSITION SCENARIO WAS DEVELOPED

	Organisation	Date of publication	Frequency of updates	Purpose(s) of the scenario and broad lines of the transition presented
IEA - SDS scenario	The International Energy Agency (IEA) is an **intergovernmental organisation created by the OECD following the first oil crisis**, with the initial goal of ensuring energy security for the OECD member countries, in **particular concerning oil supply. Its role has since expanded: it informs and advises states about energy issues**, providing extensive data and numerous analyses.	**2018**	Annual	The World Energy Outlook (WEO) is published with a view to presenting **scenarios of changes in energy markets** in the medium and long term, according to public policies that affect the energy sector. *Goal of the SDS:* • Describing changes in the energy system in line with **universal access to modern energy** services by 2030, and consistent with the **goals of the Paris Agreement** as well as with **reducing air pollution**.
Greenpeace - Advanced Energy Revolution scenario	Greenpeace is an **NGO working for the protection of the environment and biodiversity**. Since 2005, it has been producing future energy system scenarios to address the challenges of environmental sustainability.	**2015**	Five editions of the Energy Revolution report have been published since 2005.	*Goals:* • Presenting a pathway in line with ending energy-related CO_2 emissions, achieving a **100% renewable energy system and phasing out nuclear energy**. • Showing that such a future is **feasible and desirable** by describing its implications and the conditions for its achievement.
IRENA - REmap scenario	IRENA is an **intergovernmental organisation** whose goal is to inform countries about the development of renewable energy (political, economic, financial and technological implications) and to promote the widespread adoption and sustainable use of all types of renewable energy.	**2019**	Annual updates since its creation (in 2017).	*Goals:* • Presenting **a pathway to the decarbonisation of the global energy system**, largely based on the **deployment of renewable energies**. • Informing policymakers about the possible solutions for implementing the climate targets set by the Paris Agreement.
BP - Rapid Transition scenario	British Petroleum (BP) is a long-standing **oil company** of British origin	**2018**	Annual	*Goals:* • Exploring changes in the energy system **compatible with the goals of the Paris Agreement**. • Informing the **strategies of the oil company**.
Low Energy Demand (LED) scenario	The scenario was created by a group of researchers associated with the **International Institute for Applied Systems Analysis (IIASA)**. This research Institute conducts studies to analyse global challenges such as climate change. The goal of its studies is to help policymakers to implement science-based policies.	**2018**	---	*Goals:* • Presenting a transition scenario based on a **substantial reduction in final energy demand** that stands out from most scenarios proposing solutions for energy supply and production (decarbonisation of the energy mix, development of large-scale renewable projects). • Informing policymakers, showing that such a future **is not unrealistic** and what it implies.

STEP 2

IDENTIFYING THE LEVEL OF INFORMATION AVAILABLE ON THE SCENARIO

	Scenario medium	Existence of methodological annexes and/or data tables	Time horizon	Geographical and sectoral scope and GHGs considered	Granularity of results [a]		
					Time step	Geographical granularity	Sectoral granularity
IEA - SDS scenario	Scenario published in the **World Energy Outlook** (WEO), a report of several hundred pages.	A **methodological annex** describes the model; tables of assumptions and results are given at the end of the report and can be downloaded in Excel format on the IEA website.	**From 2017 to 2040**	*Geographical scope:* the world *Sectoral scope:* the energy system *GHGs:* Energy-related CO_2 emissions	Most of the results are given in 5-year time steps.	Most of the results are given for the following geographical areas: The world, North America, Central and South America, Europe, Africa, the Middle East, Eurasia and Asia Pacific. Some results are given for individual countries or groups of countries, for example the European Union (EU).	The results are given for industry, transport, building, and the production of electricity and heat.
Greenpeace - Advanced Energy Revolution scenario	Scenario published in **Energy [R]evolution: a sustainable future for all**, a detailed report of several hundred pages. NB: in the executive summary, the scenario is called “Energy Revolution”.	There are no annexes, all information is provided in the long version of the report, including the tables of results at the end of the report.	**From 2012 to 2050**	*Geographical scope:* the world *Sectoral scope:* the energy system *GHGs:* Energy-related CO_2 emissions	Most of the results are given in 10-year time steps.	Most of the results are given for the following geographical areas: the world, OECD Europe, OECD North America, Eastern Europe and Eurasia, Latin America, Africa, Middle East, China, India, and the other Asian countries.	The results are generally given for industry, transport, and the production of electricity and heat.
IRENA - REmap scenario	Scenario pu-blished in the 2019 edition of the report **Global Energy Transforma-tion: A road-map to 2050**, a report of around 50 pages.	Methodological elements and data about the scenario (downloadable in Excel format) are available on the **IRENA website**.	**From 2018 to 2050**	*Geographical scope:* the world *Sectoral scope:* the energy system *GHGs:* Energy-related CO_2 emissions	The results are given in 10-year time steps.	The results described by the scenario are for the world –results downloadable in Excel format are given by geographical area (North America, Latin America, EU28, rest of Europe, sub-Saharan Africa, Middle East and North Africa, East Asia, Southeast Asia, rest of Asia).	The results are given for industry, transport, building, and the production of electricity and urban heat.
BP - Rapid Transition scenario	Scenario published in **the Energy outlook 2019**, a report of around 70 pages including numerous figures.	Tables of data are available at the end of the report (in the Annex) and in downloadable Excel format on **the BP website**.	**From 2017 to 2040**	*Geographical scope:* the world *Sectoral scope:* the energy system *GHGs:* Energy-related CO_2 emissions	The results in the scenario are given for 2040 or as an annual percentage change between 2017 and 2040.	Most of the results are for the world, some results are given by geographical area (US, EU, other OECD countries, China, India, rest of Asia, Middle East, Russia, Brazil, other non-OECD countries).	The results concerning final energy consumption are given by sector: indus-try, building, transport.

a. The disaggregation presented here corresponds to that of the results given in the main report. It does not predict the granularity of the model used to quantify the scenario, and therefore the existence of more detailed results. For example, the IEA model used for the SDS has an annual time step and divides the world into 25 geographical areas.

STEP 2 IDENTIFYING THE LEVEL OF INFORMATION AVAILABLE ON THE SCENARIO *(CONT.)*

	Scenario medium	Existence of methodological annexes and/or data tables	Time horizon	Geographical and sectoral scope and GHGs considered	Granularity of results[a]		
					Time step	Geographical granularity	Sectoral granularity
Low Energy Demand (LED) scenario	Scenario available online in the form of an article **published in "Nature"** of around 10 pages, including a table summarising the main assumptions and results of the scenario.	The scenario is accompanied by a detailed **complementary report** and a **large database** available online (free registration).	**From 2020 to 2050** (with an exten-sion to **2100**)	*Geographical scope:* the world *Sectoral scope:* the energy system, industry, the land-use and forestry sector, waste. *GHGs:* All GHG emissions.	The time step is usually 10 years (especially for the database results).	The results are given for the world, the North and the South.	The data on energy are by sector (residential and commercial building, industry, transport and electricity production). The data on GHG emissions are by more aggregated sector (energy and industrial processes, waste, land-use and forestry sector).

a. The disaggregation presented here corresponds to that of the results given in the main report. It does not predict the granularity of the model used to quantify the scenario, and therefore the existence of more detailed results. For example, the IEA model used for the SDS has an annual time step and divides the world into 25 geographical areas.

STEP 3 UNDERSTANDING THE SOCIO-ECONOMIC CONTEXT OF THE TRANSITION DESCRIBED BY THE SCENARIO

	Baseline scenario	Economic growth (calculated from GDP in PPP) [a]	Population change	Other change(s)
IEA - SDS scenario	Yes - the **New Policies Scenario (NPS)**. This central scenario of the WEO describes changes in energy markets, taking account of the climate policies already implemented and those planned by states. **Emissions continue** to increase in this scenario.	Average annual growth rate of **3.4%** between 2017 and 2040. It is driven by China, India, Southeast Asia and Africa. It is lower in the EU (1.6%/year on average).	9.2 bn in 2040.	**Rate of urbanisation increasing** everywhere, especially in Asia Pacific and Africa. Few elements about socio-economic changes other than economic growth and population.
Greenpeace - Advanced Energy Revolution scenario	Yes - called the Reference Scenario, it is based on **the Current Policies Scenario** (CPS) presented in the WEO 2014 by IEA. This baseline scenario includes only climate and energy policies already implemented.	Average annual growth rate of **3.1%** between 2017 and 2040. Growth is driven by China, India and the other developing countries. The economic weight of the OECD decreases.	9.5 bn in 2050.	Few elements about socio-economic changes other than economic growth and population.
IRENA - REmap scenario	Yes - called the **Reference Case**. It includes the energy and climate policies implemented or planned in each country, especially the nationally determined contributions under the Paris Agreement that have been translated into national policy.	In the baseline scenario [b] : average annual growth rate of **2.4%** between 2019 and 2050. Average annual growth rate including some climate impacts on the economy: **1.8%** between 2019 and 2050.	9.7 bn in 2050.	Few elements about socio-economic changes other than economic growth and population.
BP - Rapid Transition scenario	Yes - called **the Evolving Transition (ET)**. This **central scenario** of the Energy Outlook assumes that policies, technologies and social preferences continue to evolve in a similar way as in recent years. **Emissions continue** to increase in this scenario.	Average annual growth rate of **3.2%** between 2017 and 2040.	9.2 bn in 2040.	Few elements about socio-economic changes other than economic growth and population.
Low Energy Demand (LED) scenario	No - the quantified parameters describing the socio-economic context, in particular population and economic growth, are accessible in the scenario database.	Average annual growth rate of **2.8%** between 2020 and 2050.	9.2 bn in 2050.	Five major changes: **improved quality of life, rapid urbanisation**, the development of new, **innovative energy services**, a more active role played by energy consumers, and innovation in **information and communication technologies**.

a. In all of these scenarios – except for the REmap scenario by IRENA –, GDP is an exogenous variable: it therefore includes neither the effects of the transition nor the impacts of climate change. The REmap scenario, on the other hand, gives a value for economic growth including certain climate impacts.

b. The growth rate in the REmap transition scenario is given in Step 8, which presents the macro-economic effects of the transition.

STEP 4 IDENTIFYING THE CLIMATE TARGET AND THE DISTRIBUTION OF EFFORTS OVER TIME

	Climate target set and probability associated with this target	Consideration of the climate target	Changes in the GHG trajectory (see Figure 15)	Assumptions about changes in GHG emissions beyond the period covered by the scenario
IEA - SDS scenario	**Compatibility with the Paris Agreement**.	The CO_2 emissions trajectory until 2040 is within the envelope of transition scenario trajectories from the world of research that are compatible with RCP2.6[a]. The IEA refers to the database https://tntcat.iiasa.ac.at/SspDb/	Energy-related CO_2 emissions peak in 2020 and decrease to **17.6 $GtCO_2$ in 2040**.	Maintaining the rate of emissions reductions beyond 2040 would make it possible to reach net zero emissions for energy-related CO_2 emissions by around 2070. It is noted that maintaining this reduction rate would require **major technological innovation**, in particular concerning **CCUS and negative emissions technologies**.
Greenpeace - Advanced Energy Revolution scenario	**Below 2°C.**	Achieving the climate target is justified by the emissions trajectory for the scenario, which reaches zero energy-related emissions in 2050.	Energy-related CO_2 emissions peak before 2020 – emissions are drastically reduced to **reach zero emissions in 2050.**	----
IRENA - REmap scenario	**Well below 2°C.**	Cumulative CO_2 emissions between 2015 and 2050 are below the carbon budget giving a 67% probability of limiting global warming to 2°C. Assumptions are made about changes in emissions not covered by the scenario (see Step 6).	Energy-related CO_2 emissions peak before 2020 – emissions are drastically reduced to reach **9.8 $GtCO_2$ in 2050**.	---
BP - Rapid Transition scenario	**Compatibility with the objectives of the Paris Agreement.**	The emissions trajectory for the scenario is within the envelope of trajectories of four other scenarios described as being compatible with the objectives of the Paris Agreement (the SDS by the IEA, the Sky scenario by Shell, the Renewal scenario by Equinor, and the illustrative P1 trajectory of the IPCC 1.5°C special report.	Energy-related CO_2 emissions peak before 2020, then emissions are reduced steadily to reach **18 $GtCO_2$ in 2040**.	The scenario cites changes needed to reduce remaining emissions after 2040. These include, for example, the **use of CCUS** and of **negative emissions** (BECCS), increased **electrification** in energy end-use, improvements in energy storage technologies, and the use of hydrogen and bioenergy.
Low Energy Demand (LED) scenario	**1.5°C without overshoot with a probability of more than 60%.**	A climate module (MAGICC) is used to estimate the degree of global warming. Moreover, the model used for the construction of the scenarios is constrained by a carbon **budget for 2020-2100 of 390 $GtCO_2$**.	GHG emissions peak in 2020, then emissions are drastically reduced to reach **9.4 $GtCO_2eq$** in 2050. CO_2 emissions **reach 2.7 $GtCO_2$ in 2050 and are negative from 2060.**	The scenario is extended in a stylised manner (with simplified assumptions) until 2100.

a. These scenarios explore combinations of different socio-economic narratives (the SSPs) and different radiative forcings represented by the RCPs (see **Box 12** and **Box 7**).

STEP 5 IDENTIFYING THE WEIGHT GIVEN TO THE DIFFERENT DRIVERS OF THE TRANSITION AND THE ASSOCIATED ASSUMPTIONS

	Political driver	Technological driver	Behavioural driver
IEA - SDS scenario	• **Many policies implemented in all sectors and all countries**, *e.g.* phasing out fossil fuel subsidies by 2035 for all countries, implementing stringent efficiency and emissions standards for power stations, industries, vehicles and new buildings. *Focus on the carbon price:* • The carbon price corresponds to an input assumption, and represents the **implementation of carbon pricing policies (taxes or markets)**, in addition to other measures. • For the developed countries: **from 63 $/tonne in 2025 to 140 $/tonne in 2040**; • For some emerging countries: **from 43 $/tonne in 2025** to **125 $/tonne in 2040**.	• Technological progress supported by the political driver.	• Little or no mention.
Greenpeace - Advanced Energy Revolution scenario	• **Strong international commitments** by states, with ambitious, legally binding objectives. • Implementation of **ambitious climate and energy policies** in all sectors, *e.g.* phasing out fossil fuel subsidies by 2020; • Strong political and social acceptability for renewable energies, but not for technologies with environmental and social sustainability issues: nuclear phase-out and non-use of BECCS/CCUS technologies. *Focus on the carbon price:* • Carbon pricing is recommended as a policy measure, but the price of carbon is not specified.	• Rapid technological progress supported by the political driver, especially for renewable technologies that are currently immature or not fully mature (*e.g.* hydrogen for vehicles, offshore wind, marine energy technologies) and grid technologies that enable integration of a high proportion of renewables in the electricity mix (*e.g.* smart grid or demand management technologies).	• Little or no mention.
IRENA - REmap scenario	• Implementation **of sectoral mitigation measures** (*e.g.* establishment of a minimum emissions standard for vehicles, ban on the construction of new coal-fired power stations). • Implementation of policies to establish an economic framework conducive to the rapid, large-scale deployment of renewable energies (*e.g.* price regulation policy, new tariff structures for electricity). *Focus on the carbon price:* • Implementation of carbon pricing mechanisms in industry, aviation, maritime transport and long-distance road transport: the value of carbon is not specified, however.	• Rapid technological progress supported by the political driver, helping for example to improve the digitalisation and flexibility of the power system, to increase the use of hydrogen for transport and industry, or the use of biofuels in aviation, maritime transport and long-distance road transport.	• Little or no mention.
BP - Rapid Transition scenario	• Implementation of sectoral policies and measures (*e.g.* the ban on installing new conventional coal-fired power stations at the global level from 2030, implementation of strict emissions standards for electrical appliances and new buildings). • Implementation of carbon pricing mechanisms. *Focus on the carbon price:* • The carbon price corresponds to an input assumption, and represents the implementation of carbon pricing policies (taxes or markets) in the different countries: • For the OECD countries: **from 25 $/tonne in 2025** to **200 $/tonne in 2040;** • For the non-OECD countries: **from 10 $/tonne in 2025** to **100 $/tonne in 2040.**	• Continuous technological progress in the field of renewable energy and carbon capture and storage. • Technological progress is stimulated and supported by different policies – alone, it will not be enough to sufficiently reduce emissions.	• Some marginal changes in behaviours and practices, linked in particular to the circular economy and to mobility.

STEP 5 IDENTIFYING THE WEIGHT GIVEN TO THE DIFFERENT DRIVERS OF THE TRANSITION AND THE ASSOCIATED ASSUMPTIONS *(CONT.)*

	Political driver	Technological driver	Behavioural driver
Low Energy Demand (LED) scenario	• Implementation of public policies to support and accelerate the **technological, institutional** (especially markets) **and behavioural changes** that are presented as the main drivers of the transition. *Focus on the carbon price:* • Shadow carbon price representing the cost of emissions reductions needed to achieve the climate target of: **90 $/tCO$_2$ in 2030**, increasing to **160 $/tCO$_2$ by 2050**, then to around **700 $/tCO$_2$ by 2100**.	• Rapid progress in information and communication technologies coupled with strong digitalisation. • Rapid innovation and improvement in decentralised, small-scale energy production, development of end-use technologies. • Non-development of CCUS and BECCS technologies.	• High aspirations to live in a healthy, unpolluted environment. • Consumer preferences for innovative, flexible services that are available on demand (*e.g.* shared objects and services). • Change in the role of energy consumers, who play an active part in energy production (*e.g.* development of self-consumption at household or district level).

STEP 6 ANALYSING THE GEOGRAPHICAL AND SECTORAL DISTRIBUTION OF REDUCTION EFFORTS

	Distribution between sectors (see Figure 16)	Assumptions about sectors/gases not represented	Distribution between countries/areas
IEA - SDS scenario	Emissions reductions primarily stem from the power sector, then from the transport sector. Slight reductions in other sectors.	CO_2 emissions from industrial processes and methane emissions linked to industrial processes and to energy reach 2.4 $GtCO_2eq$ in 2040. Emissions projections for the LULUCF[a] sector are taken from the OECD Baseline Scenario (2012b) – they decrease over time.	Emissions reduction efforts are greater for the developed countries (-4.5%/year on average for the OECD countries) than for the developing countries (-2%/year), with some exceptions such as China (-4.3%/year).
Greenpeace - Advanced Energy Revolution scenario	All sectors reach net zero emissions in 2050. Emissions from the power sector decrease sharply from 2020; for the other sectors, this decrease is slower until 2030, then very steady between 2030 and 2050.	---	All countries reach zero emissions in 2050, but the developed countries and Latin America have a higher reduction rate over the period 2015-2040 than the developing countries, especially the Asian countries including China and India – emissions from the latter continue to increase until 2030.
IRENA - REmap scenario	The power sector makes the greatest reduction efforts. The transport sector also makes substantial efforts.	• Assumptions for CO_2 emissions from industrial processes: 90 $GtCO_2$ of cumulative emissions between 2015 and 2050. • Assumptions for CO_2 emissions from the LULUCF[a] sector: cumulative emissions from the sector between 2015 and 2100 are close to zero (positive before 2050, zero in 2050, then negative after 2050).	North America, the European Union and East Asia make the greatest reduction efforts (around -80% between 2016 and 2040). The other countries have a slower reduction rate, in particular the rest of Asia, whose emissions decrease by around 45% between 2016 and 2040.
BP - Rapid Transition scenario	The power sector makes the greatest reduction efforts. Emissions from industry also decrease significantly, while those from transport only decrease slightly.	---	---
Low Energy Demand (LED) scenario	All sectors reach zero emissions by 2060. Negative emissions come from the LULUCF[a] sector - no use of BECCS.	Changes in all GHGs are described in the scenario database.	The countries of the South and the North reach carbon neutrality by 2060.

a. LULUCF: Land use, land-use change and forestry

STEP 7 IDENTIFYING THE SOLUTIONS DEPLOYED TO REDUCE GHG EMISSIONS AND THE ASSOCIATED TECHNOLOGIES

	Main low-carbon solutions mobilised (Mitigation solutions deployed illustrated by Figure 17, Figure 18, Figure 19, Figure 20)
IEA - SDS scenario	• Improving energy efficiency; • Developing renewable energies; • Developing nuclear, CCUS technologies; • Reducing methane emissions in oil and gas production (upstream).
Greenpeace - Advanced Energy Revolution scenario	• Improving energy efficiency; • Developing renewable energies, especially solar and wind; • Electrifying all sectors; • Decarbonising non-electric fuels through the use of hydrogen and biofuels for transport; • Decarbonising heat production, especially through the deployment of geothermal, the use of biomass and solar thermal collectors; • Choosing the non-use of CCUS and nuclear phase-out.
IRENA - REmap scenario	• Electrifying heat production and the transport sector; • Deploying renewable energies for electricity generation and for direct/end uses (solar, thermal, geothermal, biomass); • Improving energy efficiency (relatively less important than the first two solutions); • CCUS deployment not mentioned.
BP - Rapid Transition scenario	• Decarbonising the energy mix through the development of renewable energies, electrification and the deployment of CCUS technologies; • Energy efficiency gains, which do not offset the increase in demand for energy services: energy demand thus continues to increase until 2040.
Low Energy Demand (LED) scenario	• A drastic reduction in demand for energy through energy efficiency improvements in energy end use and the development of innovative energy services; • Electrifying energy uses; • Decarbonising and decentralising energy production through the development of renewable, variable and flexible energies; • Choosing the non-use of CCUS.

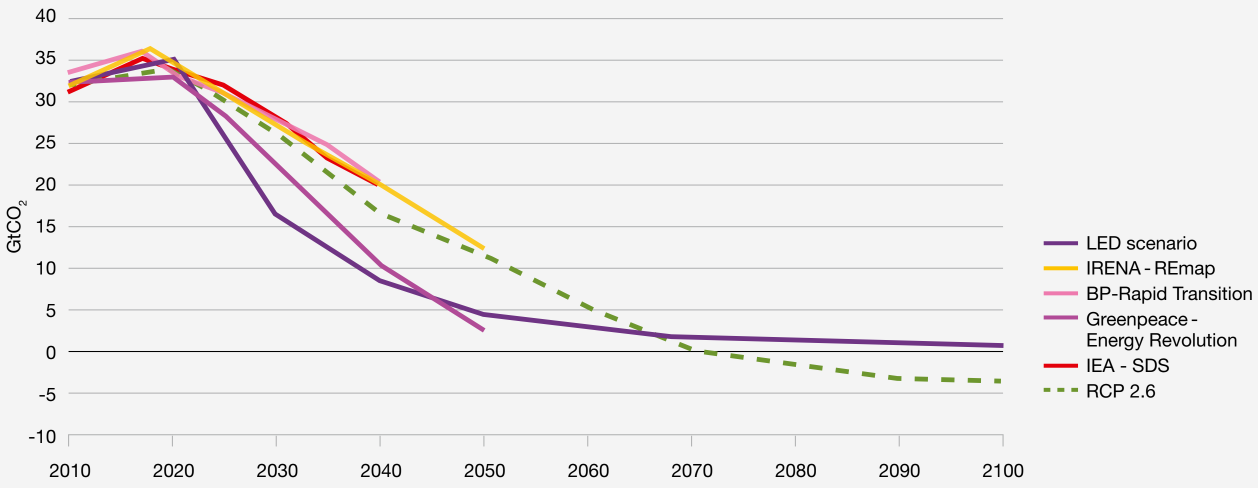
STEP 8

IDENTIFYING THE MACRO-ECONOMIC CONSEQUENCES OF THE TRANSITION

	Necessary investments	Impacts of the transition on GDP	Impacts of the transition on employment	Energy and electricity prices for end consumers	Fossil fuel prices
IEA – SDS scenario	**67,713 billion $** of cumulative investments in the energy system (energy supply and use) between 2018 and 2040 – 60,042 billion $ for the New Policies Scenario.	---	---	Electricity prices for end consumers are given for some regions. E.g. the electricity price increases from 85 $/MWh in 2017 to 120 $ MWh in 2040 in China, from around 130 to 165 $/MWh in the United States and from around 230 to 260 $/MWh in the EU.	Fossil fuel prices are endogenous to the scenario. Oil price: 74 $/barrel in 2025 and 64 $/barrel in 2040. Gas and coal prices vary according to the region. E.g. gas price in the EU: 7.7 $/MBtu in 2040; coal price in the EU: 66 $/tonne in 2040.
Greenpeace – Advanced Energy Revolution scenario	Over the period 2012-2050: **64,600 billion $** of cumulative investments in the power system (1,656 billion $/year on av.) **+16,730 billion $** of cumulative investments for heat production (429 billion $/year on av.).	---	**Positive impact on employment in the energy sector:** the scenario results in more jobs in the energy sector for each period in relation to the baseline scenario. For example, in 2030, there are 48 million jobs in the energy sector for the Advanced Revolution Scenario, compared to 28 million in the baseline scenario.	Prices for end consumers are not given, but electricity generation costs are given for the different parts of the world. For example, in the EU, the electricity generation cost increases until 2030 to reach almost 10 cts$/kWH, then decreases to around 8 cts$/kWh in 2050.	Fossil fuel prices are input assumptions. Oil price: 103.5 $/barrel in 2025 and 100 $/barrel in 2040. Gas and coal prices vary according to the region. E.g. gas price in Europe: 9.7 $/GJ in 2040; coal price for OECD countries: 3.3 $/GJ in 2040.
IRENA – REmap scenario	**110,000 billion $** of cumulative investments in the energy system for the period 2016-2050. In comparison, the cumulative investment requirements for the baseline scenario for the same period are 95,000 billion $.	Positive impact on GDP: the annual growth rate between 2019 and 2050 is 2.4% in the baseline scenario and **2.5%** in the REmap scenario (respectively 1.8% and **2%** when taking account of certain climate impacts).	• **Positive impact of the transition on employment in the energy sector:** new jobs linked to the transition far exceed jobs lost in the fossil fuel sector5. • Relatively insignificant impact of the transition on employment at the global economic level.	---	Fossil fuel prices are not given – it is simply noted that they are "taken from national studies or recognised sources (such as the IEA)".
BP – Rapid Transition scenario	---	---	---	---	---
Low Energy Demand (LED) scenario	Investments in energy supply are estimated at slightly more than **1,000 billion $ per year** between 2020 and 2050. (1,170 billion in 2020 and 1,053 billion in 2050).	---	---	---	---

a. Several IRENA studies assess the impacts of the transition on employment in the energy sector, including the study entitled *Perspectives for the energy transition: Investment needs for a low-carbon energy system*, IRENA and IEA, 2017

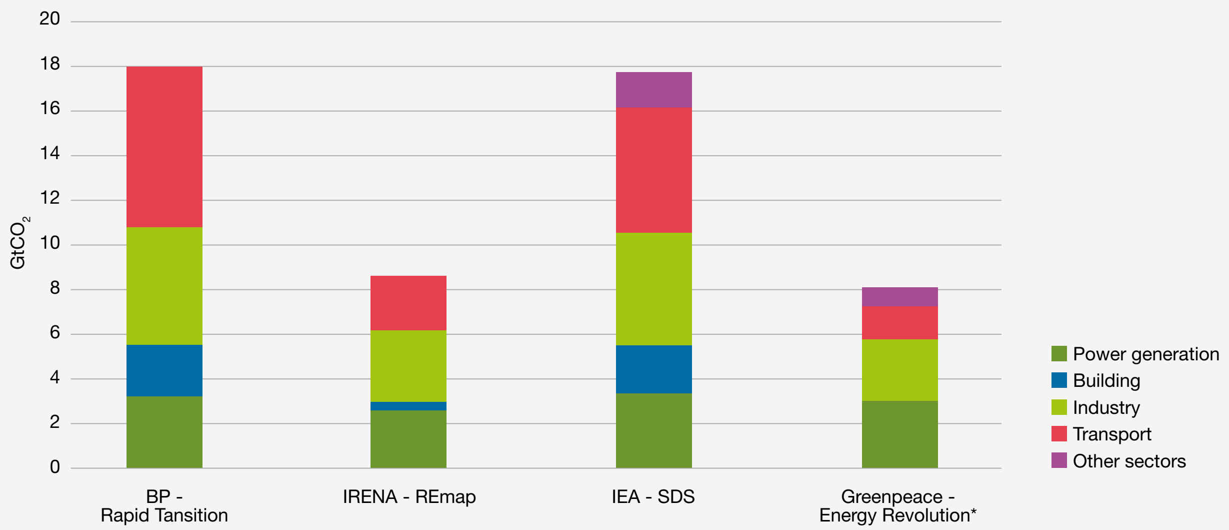
FIGURE 15. EMISSIONS TRAJECTORIES FOR CO_2 LINKED TO ENERGY AND INDUSTRIAL PROCESSES* ACCORDING TO DIFFERENT TRANSITION SCENARIOS



Source: I4CE, 2019.

* The scope of emissions in some of the scenarios selected does not include CO_2 emissions linked to industrial processes. To enable the visual comparison of emissions trajectories between the different scenarios, a yearly amount of 2.6 $GtCO_2$ was added to the emissions in scenarios that do not include industrial processes – SDS by IEA, Rapid Transition by BP, REmap by IRENA and Advanced Energy Revolution by Greenpeace. The amount of 2.6 $GtCO_2$ corresponds to current CO_2 emissions linked to industrial processes (Fischedick, 2014), and is compatible with information on these emissions taken from the SDS scenario by IEA (by visual reading) and REmap by IRENA (which gives the amount of cumulative emissions linked to industrial processes until 2050).

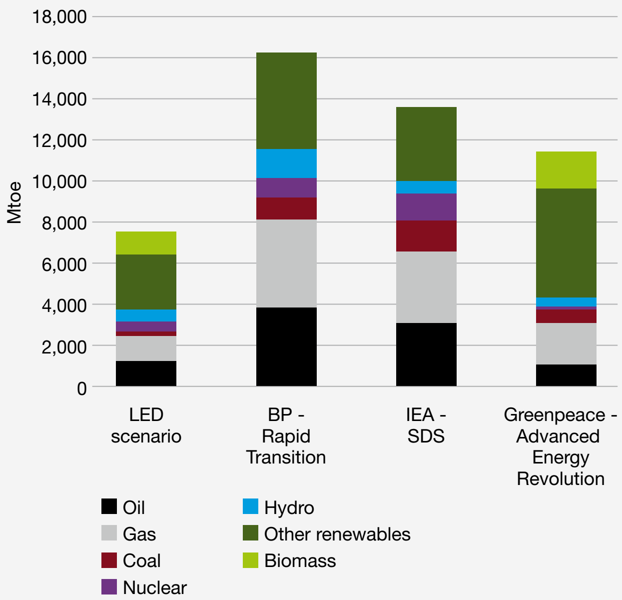
FIGURE 16. ENERGY-RELATED CO_2 EMISSIONS BY SECTOR IN 2040 ACCORDING TO DIFFERENT TRANSITION SCENARIOS



Source: I4CE, 2019.

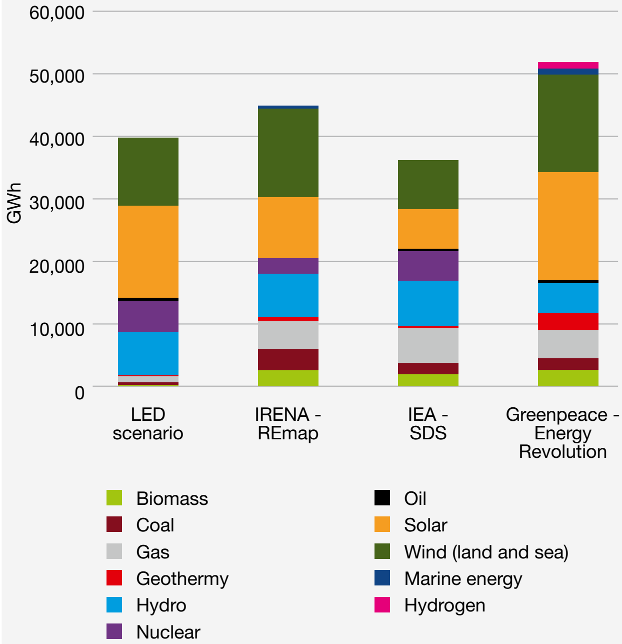
** Emissions from the "Building" sector in the Greenpeace Advanced Energy Revolution scenario are not nil in 2040; they are counted in "Other sectors".*

FIGURE 17. PRIMARY ENERGY CONSUMPTION BY SOURCE IN 2040 ACCORDING TO DIFFERENT TRANSITION SCENARIOS



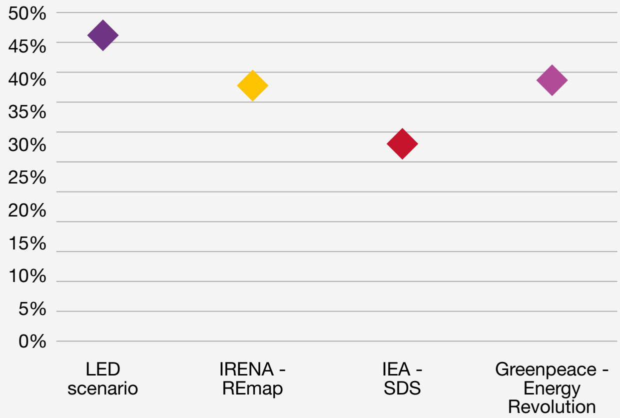
Source: I4CE, 2019.

FIGURE 18. ELECTRICITY GENERATION BY SOURCE IN 2040 ACCORDING TO DIFFERENT TRANSITION SCENARIOS



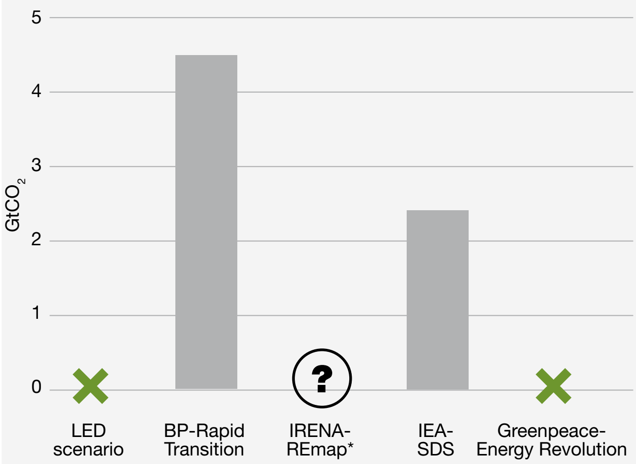
Source: I4CE, 2019.

FIGURE 19. SHARE OF ELECTRICITY IN FINAL ENERGY CONSUMPTION IN 2040 ACCORDING TO DIFFERENT TRANSITION SCENARIOS



Source: I4CE, 2019.

FIGURE 20. AMOUNT OF CO_2 CAPTURED BY CCUS IN 2040 ACCORDING TO DIFFERENT TRANSITION SCENARIOS



Source: I4CE, 2019.

* For the REmap scenario by IRENA, the amount of CCUS is not indicated. However, it is noted that CCUS technologies have been considered at the global level for three of the main emitting industries: steel, cement and chemicals/petrochemicals – but not for electricity production.

Conclusion

The transition to a low-carbon economy brings risks and opportunities for economic actors, which they must anticipate in order to optimise their strategy in a context of uncertainty. Against this backdrop, **the use of scenarios – which are plausible representations of uncertain future states – is very useful in order to better understand the medium- and long-term challenges of the low-carbon transition**. Before using scenarios, it is essential to know how to correctly interpret them. This implies first navigating the complex ecosystem of climate-related scenarios and identifying those that can be used to explore issues linked to the low-carbon transition: transition scenarios. It also requires fully understanding the challenges of these scenarios.

A wide variety of transition scenarios exist, which all explore different visions of the transition and address different goals. The choices made at each stage of the construction process – input assumptions, the use of a model – condition the results of scenarios, and are not always explicit. To understand the challenges of a scenario, it is therefore essential to decipher these different elements. A framework for reading transition scenarios has been developed, and proposes eight stages for correctly interpreting them. By way of illustration, it is applied to five scenarios: the SDS scenario by the IEA, the Advanced Energy Revolution scenario by Greenpeace, the LED scenario by IIASA, the Rapid Transition scenario by BP and the REmap scenario by IRENA.

This publication is part of a broader project on the use of climate-related scenarios by economic actors to analyse the risks and opportunities of the transition to a low-carbon economy. In this context, the development of a step-by-step guide to help companies conduct a scenario-based risk and opportunity analysis is underway. This guide will also include recommendations on useful information to be provided to financial actors based on scenario analysis and examples of good reporting practices.

Glossary and useful links

Useful links for further understanding of climate-related scenarios

- **Climate change scenario Primer, Senses Project:** https://www.climatescenarios.org/primer/

  This interactive tool helps to understand what climate change scenarios are and how they are connected to socioeconomics, energy & land use, emissions, climate and climate impacts. They explain the basic terminology by using interactive visualizations.

More information about RCPs and SSPs:

- **RCP database:** https://tntcat.iiasa.ac.at/RcpDb/

  This public database provides a set of quantitative data describing the RCPs and changes in emissions and concentrations of the different greenhouse gases associated with them.

- **SSP database:** https://tntcat.iiasa.ac.at/SspDb/

  This public database provides the data underlying the different SSPs (population, economic growth, rate of urbanisation). It also provides the results of scenarios based on the SSPs, concerning changes in the energy system (energy demand, energy production by source, etc.), changes in the land-use system, the GHG emissions trajectory, changes in climate indicators (radiative forcing, temperature increase), and economic indicators. Each SSP is associated with several scenarios, baseline scenarios – not constrained by a climate target – and transition scenarios, which are constrained by radiative forcing targets corresponding to the different RCPs. These scenarios were quantified using several integrated assessment models, thereby providing several interpretations of the SSPs. For each SSP, the interpretation of one model in particular was selected as the "SSP marker".

More information about the models used to build transition scenarios:

- **Database on integrated assessment models**: https://www.iamcdocumentation.eu/index.php/IAMC_wiki

  Developed by the Integrated Assessment Modelling Consortium, this database presents and describes the characteristics of numerous integrated models used to build transition scenarios – some of which are mentioned in this publication.

- **Reference cards of models used to build transition scenarios and assessed in the IPCC 1.5°C special report:** https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_Chapter2_SM_Low_Res.pdf

  In the framework of the special report on the impacts of global warming of 1.5°C, the IPCC has combined the reference cards of the models used to build the transition scenarios analysed in the report.

- **Online article "How integrated assessment model are used to study climate change?" by Carbon Brief:** https://www.carbonbrief.org/qa-how-integrated-assessment-models-are-used-to-study-climate-change

More information about the concepts linked to climate change scenarios and climate impacts:

- **Site produced by Réseau Action Climat (RAC) – "Le climat change":** http://leclimatchange.fr/

  This site provides an educational analysis of the IPCC 5th Assessment Report and its main conclusions (in French only).

- **Site produced by IPSL with the support of INSU (CNRS) – "Le climat en questions":** http://www.climat-en-questions.fr/

  This educational site (in French) proposes answers to the most common questions about the climate and climate change, provided by expert scientists from several recognised institutions. It groups questions according to broad subject areas (climate functions, observation, current and future changes, etc.). To facilitate the understanding of sometimes complex phenomena, two reading levels are proposed: basic and advanced.

- **Météo France website – "Comprendre: tout savoir sur la météo, le climat et Météo-France":** http://www.meteofrance.fr/climat-passe-et-futur

  The Météo-France website provides insights about the weather, the climate and climate change, including many examples about the climate in France (in French only).

- **Web portal "DRIAS, les futurs du climat":** http://www.drias-climat.fr/

  The French DRIAS web portal (providing access to regionalised French climate scenarios for impact and adaptation of our societies and environments) proposes an interactive introduction to climate change and climate impact scenarios at the French level. In the Discover section, users can select the characteristics of the scenario they wish to consult (geographical coverage, climate variable or impact of interest, input assumptions, models). In the Data and Products section, users can order data series free of charge.

- **Website summarising "Traceable evidence of the impacts of climate change on humanity":** http://impact.gocarbonneutral.org/

  Associated with the article by Mora et al. published in 2018 in the journal Nature Climate Change, this database lists *the climate impacts observed for 10 major categories of climate hazards across six key aspects of human life, and the studies associated with them. It highlights the diversity of climate impacts facing humankind today.*

- **Online article "How do climate models work" by Carbon Brief:** https://www.carbonbrief.org/qa-how-do-climate-models-work

Glossary

General

Integrated Assessment Model (IAMs): Models that include not only an integrated representation of human systems, but also of important physical processes associated with climate change, such as the carbon cycle, and sometimes representations of impacts from climate change.

IPCC: IPCC is a scientific body created in 1988 by the United Nations to help the global community to better understand climate change and its challenges. It is responsible for summarising and regularly assessing knowledge on climate change, its causes and its impacts. It publishes its research in the form of Assessment Reports (ARs) and special reports, such as the Special Report on Global Warming of 1.5°C published in 2018.

Model: Structured imitations of a system's attributes and mechanisms to mimic appearance or functioning of systems, for example, the climate, the economy of a country, or a crop.

Risk: The potential for adverse consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur.

Scenario: plausible representation of an uncertain future, sometimes including the pathway leading to this future, based on assumptions and key parameters that are mutually consistent.

Socio-economic system: A socio-economic system is a broad concept that describes the way in which a society is organised. It encompasses a set of demographic, economic, political, institutional, social, cultural and technological characteristics.

Transition

Integrated Models: Integrated models explore the interactions between multiple sectors of the economy or components of particular systems, such as the energy system. In the context of transformation pathways, they refer to models that, at a minimum, include full and disaggregated representations of the energy system and its linkage to the overall economy that will allow for consideration of interactions among different elements of that system. Integrated models may also include representations of the full economy, land use and land use change, and the climate system.

The five transition scenarios reviewed in this report

- ***Advanced Energy Revolution* scenario by Greenpeace (2015) - or "Energy Revolution":** https://www.greenpeace.org/canada/fr/publications/1575/revolution-energetique-2015/

  The Greenpeace transition scenario presents a trajectory aimed at ending energy-related CO_2 emissions by 2050, achieving a 100% renewable mix and phasing out nuclear power.

- **Low Energy Demand (LED) scenario by A. Grublers et al. (2018):**
  - ***Scenario:*** http://pure.iiasa.ac.at/id/eprint/15301/
  - ***Associated database:*** https://db1.ene.iiasa.ac.at/LEDDB/

  Developed by researchers from the International Institute for Applied Systems Analysis (IIASA), this scenario proposes a transition in line with a climate target of 1.5°C. It is based on a sharp reduction in energy demand through the development of innovative energy services for end users and the development of small-scale, decarbonised and decentralised energy production systems.

- **Rapid Transition (RT) scenario by British Petroleum (BP) (2018):** https://www.bp.com/en/global/corporate/energy-economics/energy-outlook.html

  Developed in the context of the Energy Outlook published yearly by the oil company BP, the Rapid Transition scenario describes the changes needed in the energy system to meet the objectives of the Paris Agreement.

- **REmap scenario by IRENA (2019):** https://www.irena.org/publications/2019/Apr/Global-energy-transformation-The-REmap-transition-pathway

  The transition scenario by IRENA presents a trajectory for the decarbonisation of the energy system largely based on the deployment of renewable energies and on energy efficiency to limit global warming to well below 2°C. It has been updated since 2017 with complementary analyses, such as the assessment of the socio-economic impacts of the transition.

- ***Sustainable Development* (SDS) scenario by IEA (2018):** https://www.iea.org/weo2018/scenarios/

  The transition scenario by IEA presents a trajectory of change in the energy system aimed at meeting the following three objectives: ensuring compatibility with the Paris Agreement, guaranteeing access to modern energy *services and reducing the impacts of air pollution on health. It is presented in the IEA's flagship publication, the World Energy Outlook, which provides a yearly analysis of changes and possible developments in energy markets.*

Climate change and impacts

Adaptation: The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects.

Aerosol: A suspension of airborne solid or liquid particles that reside in the atmosphere for at least several hours. Aerosols may be of either natural or anthropogenic origin.

Adaptive capacity: the ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences. The adaptive capacity may increase or decrease over time. This may arise with changes in available resources to conditions in the system of interest, or with cumulative effects of more frequent critical events. A catastrophic event may also reduce permanently the coping range of the system if the system is not able to recover its functionality over time (i.e. limited resilience).

Climate: Climate describes the average weather conditions over large geographies and long period of time, typically 20 to 30 years. It is a statistical distribution of the weather patterns that can be experienced. **Climate change**: a change in the state of the climate that can be identified (*e.g.*, by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use.

Climate Impacts (Consequences, Outcomes): Effects on natural and human systems of extreme weather and climate events and of climate change.

Climate model: A numerical representation of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes, and accounting for some of its known properties.

Climate projection – or climate change scenario: A climate projection is the simulated response of the climate system to a scenario of future emission or concentration of greenhouse gases and aerosols, generally derived using climate models.

Climate system: The climate system is the highly complex system consisting of five major components: the atmosphere, the hydrosphere, the cryosphere, the lithosphere and the biosphere, and the interactions between them.

Exposure: Presence of the system of interest in a place and setting that could be adversely affected.

Extreme event: An extreme weather event is an event that is rare at a particular place and time of year. When a pattern of extreme weather persists for some time, such as a season, it may be classed as an extreme climate event, especially if it yields an average or total that is itself extreme (*e.g.*, drought or heavy rainfall over a season).

Greenhouse effect: Two-thirds of the energy from the sun is absorbed by the atmosphere, the land and the ocean (the remaining third is directly reflected back to space by clouds, aerosols, the atmosphere and the earth's surface). Atmosphere and terrestrial surface in turn emit infrared radiation (net heat energy) that clouds and greenhouse gases absorb and return largely to Earth's surface. The heat is thus trapped, which causes the rise of the temperature on Earth's surface. This phenomenon is called the greenhouse effect.

Physical impacts of climate change: In IPCC's vocabulary, these are the impacts of climate change on geophysical systems, including floods, droughts, and sea level rise. These are a subset of climate impacts.

Radiative forcing: Radiative forcing is the change in the net, downward minus upward, radiative flux at the top of atmosphere due to a change in an external driver of climate change, such as, for example, a change in the concentration of carbon dioxide or the output of the Sun.

Resilience: Capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation.

Sensibility: Degree to which a system of interest is affected, either adversely or beneficially, by a change.

Vulnerability: Propensity or predisposition of the system to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

Weather: Weather describes the conditions of the atmosphere over hourly or daily measurements such as temperature, rainfall, cloudiness, sunshine, and wind speeds.

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