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Support to the development of ambitious climate change scenarios in Europe

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Support to the development of ambitious climate change scenarios in Europe

Final report

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Abstract: Support to the development of ambitious climate change scenarios in Europe

A long-term vision for climate protection is essential for triggering the actions and policies needed to bring about economy-wide decarbonisation. The scientific basis for long-term climate planning comes in the form of so-called climate protection scenarios. These studies model emission pathways and potential mitigation options with a time horizon of mid-century and, like national strategies, differ substantially country to country in their scope, content and ambition, i.e., the magnitude of foreseen emission reductions. This document summarises the findings of a assessment of European climate protection scenarios initiated by the German Environment Agency (UBA) project: "Supporting the development of ambitious climate change scenarios in Europe." The principle finding from a descriptive evaluation and exemplary comparative analysis is that scenario development varies substantially by EU Member State—with countries emphasising different mitigation options and pathways based on *inter alia* national context. Considering the importance of long-term scenario development in the strategy development process, a process for alignment and a more unified basis for scenario development in Europe could improve modelling and thus long-term climate planning overall – and facilitate also effective regional and EU level approaches as complement to national strategies.

Kurzbeschreibung: Unterstützung für die Entwicklung ambitionierter Klimaschutzszenarien in Europa

Eine langfristige Vision für den Klimaschutz ist entscheidend, um die Maßnahmen und Politiken auszulösen, die für eine wirtschaftsweite Dekarbonisierung erforderlich sind. Die wissenschaftliche Grundlage für solche langfristige Klimaplanung bilden so genannte Klimaschutzszenarien. Diese Studien modellieren Emissionspfade und potenzielle Minderungsoptionen mit einem Zeithorizont von Mitte des Jahrhunderts und unterscheiden sich ebenso wie nationale Strategien von Land zu Land in ihrem Umfang, ihrem Inhalt und ihren Zielen, d.h. dem Umfang der vorgesehenen Emissionsreduktionen. In diesem Dokument werden die Ergebnisse einer im Rahmen eines Forschungsprojekts des Umweltbundesamtes (UBA) initiierten Bewertung europäischer Klimaschutzszenarien zusammengefasst. Die grundlegende Erkenntnis aus einer deskriptiven Bewertung und einer exemplarischen vergleichenden Analyse ist, dass die Entwicklung von Szenarien in den einzelnen EU-Mitgliedstaaten sehr unterschiedlich ist - wobei die Länder unterschiedliche Minderungsoptionen und -pfade hervorheben, die unter anderem auf dem nationalen Kontext basieren. Aufgrund der Bedeutung der langfristigen Szenarien im Strategieentwicklungsprozess erscheint für die Zukunft ein Prozess sinnvoll, der zu einer Annäherung der Annahmen und Ansätze führt, der höhere Vergleichbarkeit schafft und damit es auch ermöglicht, über nationale Lösungsansätze hinaus effiziente regionale und EU-weite Strategien zu identifizieren.

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BECCS	Bioenergy carbon capture and storage
CCS	Carbon capture and storage
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
CH_4	Methane
EU ETS	European Union emissions trading system
EU	European Union
ECF	European Climate Foundation
F-gases	Fluorinated greenhouse gases
GDP	Gross domestic product
GHG	Greenhouse gas
IDDRI	Institute for Sustainable Development and International Relations
IRENA	International Renewable Energy Agency
kgoe	Kilogram of oil equivalent
LULUCF	Land use, land-use change, and forestry
N_2O	Nitrous oxide (laughing gas)
PPP	Power purchasing parity
PtG	Power-to-gas (any power-based gaseous fuels)
PtL	Power-to-liquid (any power-based liquid fuels)
RES	Renewable energy source
SD	Standard deviation
tCO_2e	Tonnes of carbon dioxide equivalent
TE	Trading economics
UBA	Umweltbundesamt (German Federal Environment Agency)
UNFCCC	United Nations Framework Convention on Climate Change
WISE	Warsaw Institute for Economic Studies

Summary

A long-term vision for climate protection is essential for triggering the actions and policies needed to bring about economy-wide decarbonisation. The lead up and adoption of the Paris Agreement in 2015 served as a clear impulse for such long-term climate planning, requesting countries to submit "long-term low greenhouse gas emission development strategies" aimed at 2050. This has now been made an obligation under EU law, i.e., with the European Regulation on the Governance of the Energy Union and Climate Action. As of early 2019, around half of the EU Member States have delivered so-called national long-term climate strategies, and many governments around the world, including the remaining EU countries, have followed suite or are in various stages of developing their own. There is also a draft strategy for the EU as a whole under consideration. These strategies serve two clear purposes: to outline greenhouse gas (GHG) emission reductions (i.e. emission pathways and targets) for the middle of the century and offer a roadmap (i.e. a technology and policy scenario) by which to meet these targets.

The scientific basis for long-term climate planning comes in the form of so-called climate protection scenarios. In most cases, these studies model emission pathways and potential mitigation options with a time horizon of mid-century and like national strategies differ substantially in scope, content and ambition, i.e., the magnitude of foreseen emission reductions. Given the importance of climate protection scenarios and modelling as the foundation for ambitious and actionable long-term climate policy in the EU, the German Environment Agency (UBA) instigated a project to support the development and enhancement of these studies. This document synthesises work completed under the UBA-funded project "Supporting the development of ambitious climate change scenarios in Europe." The bulk of the project work involved mapping and assessing the current state of long-term climate protection scenarios in European countries, focusing in on a representative sample of six studies from France, Germany, UK, Sweden, Poland and Italy. The German and French studies were further evaluated using a criteria catalogue based on four guiding questions pertaining to the level of mitigation foreseen, how mitigation is achieved, contextual circumstances and methodological strength.

Three key takeaways from the descriptive and quantitative evaluations are as follows.

- The studies analysed fall into three groups with regard to 2050 emission reductions: (1) over 90% (UK and DE at least 93 to 94%). (2) 80-90% (IT, F and Swedish scenarios achieve emission reductions of 80 to 85%. (3) Below 80% (PL, 57%).
- Technological considerations vary from study to study, especially concerning biomass, CCS, nuclear power as does the importance of behavioural change (incl. the role of dietary shifts). These differences emphasise the numerous pathways that are used to achieve emissions reductions depending on national circumstances.
- The exemplary application of the criteria catalogue for the German and French scenarios offers an initial normative comparison and identifies differences, for example regarding comprehensiveness. It can be used to analyse individual strategies and compare them.

While it is no surprise that EU Member States are at various stages of national strategy development, moving forward it is crucial that all countries recognize the importance of long-term scenario development in the strategy development process. Ambitious and robust scenarios beget more ambitious and actionable climate protection strategies, which then translate into actual emission reductions. A process for alignment and a more unified basis for

scenario development in Europe could improve modelling and thus long-term climate planning overall – and facilitate also effective regional and EU level approaches as complement to national strategies.

Zusammenfassung

Eine langfristige Vision für den Klimaschutz ist entscheidend, um die Maßnahmen und Politiken auszulösen, die für eine wirtschaftsweite Dekarbonisierung erforderlich sind. Die Vorbereitung und Verabschiedung des Pariser Abkommens im Jahr 2015 diente als deutlicher Impuls für eine solche langfristige Klimaplanung und forderte die Vertragsstaaten auf, "langfristige Entwicklungsstrategien für niedrige Treibhausgasemissionen" vorzulegen, für das Jahr 2050. Dies wurde nun auf EU-Ebene durch die Verordnung zur Governance der Energieunion, für alle EU-Staaten verpflichend gemacht. Bis Anfang 2019 haben rund die Hälfte der EU-Mitgliedstaaten so genannte nationale langfristige Klimastrategien umgesetzt, und in vielen Teilen der Welt, einschließlich der übrigen EU-Länder, entwickeln ebenso ihre eigenen Strategien. Parallel dazu wird in 2019 auch der Entwurf für eine 2050 Strategie für die EU als Ganzes diskutiert, vorgelegt von der Europäischen Kommission. Diese Strategien dienen zwei klaren Zielen: der Darstellung der Emissionsminderungen von Treibhausgasen (d.h. Emissionswege und -ziele) für die Mitte des Jahrhunderts und der Erstellung eines Fahrplans (d.h. eines Szenarios für die entsprechenden Technologiefade und Politiken), mit dem diese Ziele erreicht werden sollen.

Die wissenschaftliche Grundlage für eine langfristige Klimaplanung bilden so genannte Klimaschutzszenarien. In den meisten Fällen modellieren diese Studien Emissionspfade und potenzielle Minderungsoptionen mit einem Zeithorizont bis zur Mitte des Jahrhunderts, und wie die nationale Klimaschutzstrategien, unterscheiden sie sich erheblich in Umfang, Inhalt und Ambition (d.h. in der Größenordnung der vorgesehenen Emissionsreduktionen). Angesichts der Bedeutung von Klimaschutzszenarien und -modellen als Grundlage für eine ambitionierte und umsetzbare langfristige Klimapolitik in der EU hat das Umweltbundesamt (UBA) ein Projekt zur Unterstützung der Entwicklung und Weiterentwicklung dieser Studien initiiert. Dieses Dokument fasst die im Rahmen des vom UBA geförderten Projekts "Unterstützung bei der Entwicklung ehrgeiziger Klimaszenarien in Europa" durchgeführten Arbeiten zusammen. Der Großteil der Projektarbeit umfasste die Kartierung und Bewertung des aktuellen Stands langfristiger Klimaschutzszenarien in europäischen Ländern, wobei der Schwerpunkt auf einer repräsentativen Stichprobe von sechs Studien aus Frankreich, Deutschland, Großbritannien, Schweden, Polen und Italien lag. Die deutschen und französischen Studien wurden anhand eines Kriterienkatalogs weiter bewertet, der auf vier Leitfragen basiert ist: der Grad der vorgesehenen Minderung, die Art der Minderung, die Kontextbedingungen und die methodische Stärke.

Die wichtigsten Ergebnisse der deskriptiven und quantitativen Auswertungen sind wie folgt.

- Die analysierten Studien unterteilen sich in drei Gruppen im Hinblick auf die Emissionsreduktionen im Jahr 2050: (1) über 90% (UK und DE mindestens 93 bis 94%). (2) 80-90% (IT-, F- und schwedische Szenarien erzielen Emissionsreduktionen von 80 bis 85%. (3) Unter 80% (PL, 57%).

- Die technologischen Aspekte variieren von Studie zu Studie, insbesondere in Bezug auf Biomasse, CCS, Kernkraft und die Bedeutung von Verhaltensänderungen (einschließlich der Rolle von Ernährungsumstellungen). Diese Unterschiede unterstreichen die zahlreichen Wege, die je nach den entsprechenden nationalen Gegebenheiten und Vorlieben zur Erreichung von Emissionsminderungen genutzt werden.

- Die exemplarische Anwendung des Kriterienkatalogs für das deutsche und französische Szenario bietet einen ersten normativen Vergleich und identifiziert Unterschiede, zum

Beispiel in Bezug auf die Vollständigkeit. Mit ihm können einzelne Strategien analysiert und verglichen werden.

Es ist zwar nicht verwunderlich, dass sich die EU-Mitgliedstaaten in verschiedenen Phasen der nationalen Strategieentwicklung befinden, aber es ist entscheidend, dass alle Länder die Bedeutung der langfristigen Szenarioentwicklung im Strategieentwicklungsprozess erkennen. Ambitionierte und robuste Szenarien bieten ehrgeizigere und handlungsfähige Klimaschutzstrategien, die sich dann in tatsächlichen Emissionsreduktionen niederschlagen. Für die Zukunft scheint daher ein Prozess sinnvoll, der zu einer Annäherung der Annahmen und Ansätze führt, der höhere Vergleichbarkeit schafft und damit es auch ermöglicht, über nationale Lösungsansätze hinaus effiziente regionale und EU-weite Strategien zu identifizieren.

1 Context: national climate policy planning for 2050

1.1 Organising the transformation – Implementing the Paris Agreement

Formulating a long-term vision for climate protection is essential for triggering decarbonisation on an economy-wide scale. As of late 2018, almost half of the EU Member States have delivered so-called national long-term climate strategies, and many governments around the world, including the remaining EU countries, have followed suite or are in various stages of developing their own.[1] At the national level, these strategies serve two clear purposes: to outline GHG emission reduction targets (i.e. emission pathways) for mid-century and offer a roadmap (i.e. a climate protection scenario) by which to meet these targets.

Adopted at the end of 2015, the Paris Agreement served as a strong impulse for long-term climate planning. Most prominently, the agreement calls on the international community to produce so-called "long-term low greenhouse gas emission development strategies" (Article 4.19) and the accompanying decision specifies the year 2020. The EU's commitment to the forward-looking dimension of the PA is reflected in Article 15 of the Regulation on the Governance of the Energy Union and Climate Action (EU(2018)1999), which requires Member States to develop long-term climate protection strategies by the first month of 2020. These strategies must have a time horizon of 30 years or more and should contribute to the EU-wide aim of achieving net-zero emissions "as early as possible," all the while pursuing net-negative emissions. The majority of existing national strategies, especially those formulated prior to the PA, are aligned with the 2009 European Council 2050 climate goal of 80-95% emissions cuts below 1990 levels.[2]

Since the adoption of this Regulation, a new conversation has been opened with the European Commission's proposal for a new vision of a greenhouse gas neutral Europe by 2050 (also mandated by the Governance Regulation's Article 15).[3] This is based on detailed analysis and scenario building – identifying a variety of options, and not one single path forward.[4]

The importance of long-term climate planning cannot be understated. Ambitious national climate strategies serve as a signal for decision-makers, markets and investors on both the speed and trajectory of long-term decarbonisation. They can be further substantiated and supported through dedicated *governance* frameworks that define procedures and institutions to monitor progress and help ensure that strategies are being implemented.[5] Furthermore, advantages arise from the *process* of producing a long-term climate strategy. The drafting process itself can facilitate dialogue and consensus-building between stakeholder groups, galvanising private-sector support for ambitious climate action that may not otherwise exist. Moreover, strategy development provides ample opportunities for public consultation, which raises awareness, enhances transparency and accountability and may lead to an upwards revision of the underlying emission reduction goals.[6]

[1] Iwaszuk, E.; Duwe, M. (2018): 2050 climate strategies in EU countries: State of play.

[2] European Council (2009): Presidency conclusions, 15265/1/09 REV 1 CONCL 3.

[3] European Commission (2018) Clean Planet for all. A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy" COM(2018) 773

[4] See UBA (2018) Fact Sheet: EU 2050 strategic vision "A Clean Planet for All". Brief Summary of the European Commission proposal. Available from: https://www.umweltbundesamt.de/publikationen/fact-sheet-eu-2050-strategic-vision-a-clean-planet

[5] Duwe, M.; et al. (2017): "Paris compatible" governance: Long-term policy frameworks to drive transformational change.

[6] Rüdinger, A.; et al. (2018): Towards Paris: Compatible climate governance frameworks – An overview of findings from recent research into 2050 climate laws and strategies.

As a rule, national strategies are based on robust modelling and climate protection scenarios or studies, which take a comprehensive look at current and future emissions from multiple economic sectors. These scenarios should ideally take into account the national plans of neighbouring countries, other multilateral considerations, such as EU-level developments, as well as the domestic socio-economic implications of different climate policy pathways. Climate protection scenarios thus form the foundation upon which a country formulates its long-term strategy for climate action.

1.2 Project work and methodology

Initiated by the German Federal Environmental Agency (UBA) in 2015 (before the adoption of the Paris Agreement and the adoption of the Governance Regulation), this project was tasked with supporting the development of ambitious climate protection scenarios in the EU by analysing the current state of national scenario development and fostering a wide-reaching network for Member State engagement on long-term climate action. The objectives of the project work were:

- to gain a broader understanding of the current state of European climate scenarios and modelling studies;
- facilitate future bi- and multilateral networking and engagement on the topic;
- lay the groundwork for an EU-wide discussion on ambitious long-term climate protection for 2050
- and promote a forward-looking vision aimed at the complete decarbonisation of the European economy among Member States.

Project tasks were sub-divided into different streams of work. First, a survey was conducted of existing climate protection studies or scenarios in Europe; these were compiled into a list from which six representative and more ambitious country studies were chosen for further analysis. Next, a qualitative, comparative analysis of the six country studies was conducted and the results were published in a report. The subsequent task involved establishing a set of criteria for a more systematic evaluation of the studies, including a normative assessment of scenario *quality*. The initial stages of the project included a technical workshop on modelling for climate scenario development, which engaged the authors of the country studies as well as other stakeholders. Throughout the course of the project, the project partners provided additional ad hoc support to the UBA on matters pertaining to long-term climate policy development.

2 National long-term climate policy scenarios in Europe

2.1 Mapping and assessment

Currently, a diverse array of national long-term climate policy scenarios exists in Europe. These differ greatly in ambition, methodology and scope in large part due to varying national contexts, political circumstances and starting points (e.g. extant energy mixes). As a first step, six studies were identified from a longer list of European decarbonisation scenarios using a stepwise scoring system that probed for numerous conditions, including sufficient scenario detail, sectoral coverage (at least electricity, heat and transport) and level of ambition as well as the age of the study (no older than five years). In terms of ambition, climate scenarios were scored based on the degree to which they met pre-determined GHG, energy consumption and renewable energy targets.[7] The final set of six studies was also chosen to cover the span of sub-regions within Europe, and studies that described a political process were given preference.

As a next step, a descriptive analysis of the six countries studies was conducted that examined the following five design elements in detail:

- General information on the study itself (i.e. title, authorship)
- Scope of the study (i.e. geographical, GHG gas and sectoral coverage)
- Objectives and main results (i.e. study type, main objectives, both robust and uncertain outcomes, lessons learned and main challenges)
- Modelling information and input parameters (i.e. technology options, structural transitions, multilateral dimensions and EU integration, long-term challenges, data sources for the primary input parameters as well as modelling timeframe and methodologies)
- Framework parameters and key outcomes (i.e. main assumptions about population, GDP, oil prices and CO_2 prices; outcomes by sector and key total outcomes)

Information was drawn primarily from the studies themselves but was also collected from the study authors either by telephone or in many cases in person at a workshop organized in the context of the project (see section 2.2 below). The analysis allows for an initial comparison and assessment of the six studies (see Table 1); key findings are summarised below.

Scope: In regard to scope, while all studies provide ambitious decarbonisation scenarios, there is a significant amount of variability in coverage. Four studies cover nearly all GHG emissions reported under the UNFCCC—Öko-Institut (Germany), négaWatt (France), WISE (Poland) and the Centre for Alternative Technology (UK).[8] While the French case utilizes the results of a separate report to integrate agricultural and waste emissions, the studies from Swedish and Italian research organisations cover exclusively CO_2 or energy-related emissions.

[7] These included annual per-capita emissions of 2t CO_2e by 2050, 90% reduction in GHG emissions by 2050 compared to 1990, 90% reduction in annual energy-related CO_2 emissions by 2050 compared to 1990, 40% reduction in final energy consumption by 2050 compared to 2010 and 100% renewable energy by 2050.

[8] UNFCCC/Kyoto Protocol accounting and reporting recognises six GHGs (the "Kyoto Gases"): carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6), and nitrogen triflouride (NF_3)

Modelling and transparency: All six studies are based partially on bottom-up or energy system models. However, methodological details are not provided in all cases and the studies differ considerably in the amount of information they provide. In some cases, supplemental information was obtained directly from the authors.

Technological considerations: The studies account for technological developments in different ways. For instance, the Polish example is the only study that considers nuclear a mitigation option; all others rule or phase out the use of nuclear power. Depending on regional resources and potentials, technology choices also differ for renewable energy. While the German and Swedish scenarios limit the use of biomass due to sustainability concerns, the remaining four studies make substantial use of bioenergy. Notably, none of the studies embrace CO_2 removal technologies (CCS) to a large extent—while the French, Swedish and UK scenarios exclude it entirely, CCS for coal-fired power plants plays a role in the Italian and Polish studies. The German study only allows CCS in industry to achieve reductions in process emissions. The reduction in final energy consumption is generally comparable (falling between 33-57%) in all normative type studies. However, in the case of the Polish study, *2050.pl*, which uses an exploratory approach, final energy consumption is reduced by only 3%.

Structural/behavioural change: For the most part, studies assume little or no changes to future industry structures. The French study, however, is unique among the six because it accounts for process innovations as well as developments in consumptions patterns. More specifically, the French scenario first considers sufficiency options before applying efficiency measures and other mitigation options. Only the German (Öko-Institut) and UK (Centre for Alternative Technology) scenarios foresee a role for behavioural change—predominantly dietary changes—to reach complete decarbonisation.

Time horizon: Aside from the UK study (which reaches almost complete decarbonisation of the economy by 2030), all studies have the target year 2050.

Multilateral considerations: Most countries concentrate on domestic emissions only, and with the notable exception of the Polish study by WISE, which foresees significant increases in imported electricity by 2050, no study relies on energy imports to reach reduction targets. Accordingly, no synergies with cross-border activities are accounted for.

Pathways and policy considerations: Only the German and Polish studies model specific policies and the consequences of specific mitigation pathways.

Emission reductions: The six studies fall readily into three groups with regard to emission reductions: (1) The UK and German cases achieve total GHG reductions (excluding LULUCF) of 93 to 94% between 2010 and 2050 (UK: 2030). In the British scenario, including LULUCF even results in zero carbon emissions. (2) The Italian, French and Swedish scenarios achieve 2050 emission reductions of 80 to 85% compared to 2010. Although these reductions are lower than those for the Öko-Institut and Centre for Alternative Technology projections, they still fall within the range of the EU long-term target of 80 to 95% by 2050. (3) At 57% reductions between 2010 and 2050, the study from WISE (Poland) does not meet the target range.

Table 1: Overview of country studies analysed

Country/ Study	Sectors / Gases	Annual per capital emissions 2050	GHG emissions 2010-2050	Energy-related CO_2 emissions 2010-2050	Final energy consumption 2010-2050	Share of RES 2050
France Association/Institut négaWatt, *Scenario négaWatt 2011 – 2050*, 2013	All sectors except LULUCF / CO2, partly CH4, N2O	1.2	- 84%	- 93%	- 57%	99%
Germany Öko Institute, Fraunhofer ISI, *Climate protection scenario 2050 – Second round*, 2015	All sectors and gases	0.8	- 95%	-96%	-51%	96%
Italy SDSN/IDDRI, *Pathways to deep decarbonisation in Italy. IT 2015 Report*, 2015	Energy / CO_2	1.1	n/a	- 83%	-43%	93%
Poland WISE/Institute for Sustainable Development, *2050.pl – The journey to the low-emission future*, 2013	All sectors except LULUCF / all gases	4.9	- 63%*	- 53%	- 3%	41%
Sweden IVL Swedish Environmental Research Institute, *Energy Scenario for Sweden 2050*, 2011	Energy / CO_2	0.7	n/a	- 85%	- 33%	99%
UK Centre for Alternative Technology, *Zero carbon Britain – Rethinking the future*, 2014	All sectors and gases	0.0**	- 100%**	- 99%**	- 57%**	100%**

* The study contains statements on how to achieve a reduction of 80%, but no scenario with sufficient details.

** Already by 2030

Sectoral considerations: Emissions are reduced significantly across all scenarios in the energy and building sectors; any variation between scenarios is more or less in line with the overall level of ambition. From a technological perspective, emission cuts are more difficult in the transport sector—this is reflected in the scenarios by a significant variation in emission reductions. Transport emissions fall by nearly 100% in the German and UK scenarios, but reductions are less in the Polish (53%), Italian (73%) and French (91%) cases. As a result, the transport sector still accounts for a substantial share of emissions in these countries in 2050. For industry, as for energy, the overall ambition level of the scenario determines the degree of emission reductions. Emission cuts in this sector are sizable in the German, UK and French scenarios but lower in the other countries. LULUCF is accounted for in the German and UK studies only, in both cases acting as a sink to offset emissions. Finally, in the German, French and UK projections, agriculture and waste account for a significant share of remaining emissions in 2050. Even though the German and UK studies assume significant changes in eating habits, the emissions from agriculture remain a key challenge in 2050.

The findings summarised above can be found in a report published in 2017.[9]

2.2 Key challenges for national 2050 modelling

Modelling long-term emissions pathways and climate scenarios is no easy task. Such studies pose a challenge not only because of the many uncertainties that accompany modelling the future but also the high number of interactions and contingencies that must be accounted for when considering economy-wide developments. The uncertainties and complexities of long-term climate modelling must then be synthesised into a clear narrative and communicated to policy makers and stakeholders in a transparent manner.

In general, questions remain regarding who will pick up the cost of low-carbon transitions—this is conspicuously absent from many studies, even those models that take into account both microeconomic (households, firms) and macroeconomic dimensions. The complete elimination of emissions in certain sectors—e.g. transport and power—is acutely difficult to model because assumptions must be made about the development of technology costs.[10] While the industry sector is specifically challenging due to the sheer number of actors, agriculture, unlike other sectors, involves emissions that simply cannot be reduced with current technologies. Studies are also limited in their treatment of carbon neutrality, especially when it comes to the role of carbon budgeting as well as the advantages and problems with considering negative emissions from BECCS. The sustainability concerns of biomass and carbon capturing technologies will need to be more adequately addressed in future models.

National context can pose additional problems. For instance, political values and situations, which themselves develop over time and election cycles, influence the speed and direction of decarbonisation but are themselves nearly impossible to model. Additionally, many scenarios suffer from the so-called "island approach," i.e., they ignore interactions with neighbouring countries and thus may not reflect the most cost-efficient approach given that, for example, peak demand capacity needs are only met with national resources and important technological solutions are excluded.

Finally, as the use of models becomes more and more frequent in climate policy the need for transparency and accountability rises. Open source models and data sources facilitates ease-of-access and may help increase stakeholder buy-in. However, regardless of the type of model, it is crucial that technical studies are applied responsibly—as easier access may increase the use by non-experts and consequently the chances that policy is based on flawed analysis.

It is important to note that, due to these and other challenges, national long-term climate protection scenarios should not be seen as all-encompassing forecasts of the future but used

[9] Duscha, V.; Wachsmuth, J.; Donat, L. (2017): Analysis of selected climate protection scenarios for European countries.
[10] Haug, I.; Duscha, V. (2018): Topics of interest in context of modelling for 2050 long-term strategies in the EU and its MS.

instead as one factor in decision making. These scenarios can aid national governments in long-term climate strategy development but out of necessity are based on numerous assumptions, which must be revisited and updated in the future. Thus, a number of questions still remain regarding how open models should be and the optimal level of transparency.

On 13 April 2016, within the context of the project Ecologic Institute and Fraunhofer ISI convened a technical workshop on national 2050 climate modelling. Twenty-five European experts gathered in Berlin to discuss the ambitious long-term climate protection scenarios currently being developed or already employed by countries in the European Union. The event served as a forum for dialogue and experience exchange to address the questions such as:

- What are the major challenges in developing long-term scenarios?
- To what extent do underlying assumptions vary across the scenarios?
- How can structural change be handled and modelled?

Five country studies were presented by the authors, namely those from France, Italy, Poland, Sweden and the UK (see full list of presentations in Appendix A). The workshop employed small group discussions to further unpack several topics of particular interest. Following an initial discussion round on varying assumptions and categories for further comparison, participants split up to discuss four more targeted challenges in long-term climate planning: mitigation options, structural change, ambition and lock-in and multilateral dimensions.

Mitigation options: Climate protection scenarios can set one and the same emission reduction target but vary considerably in the way they project to achieve these targets. Different scenarios draw on different mitigation options and exclude others. Such choices have an impact on economic, environmental and social costs achieved in/calculated for such scenarios. Which options to include and to exclude can be a challenge for modelling. This decision can be a political one (i.e. based on the perception of national political reality) or be based on what the authors consider a "realistic" projection of technological development as well as the environmental, economic and social risks one is willing to take. The group discussion revealed that experts decide on technologies taking into account issues of sustainability, public acceptance, current political priorities and feasibility. The discussion also stressed that questions regarding the availability of resources under changing dietary and other consumption habits require further investigation.

Structural changes: The three sectors in which structural changes are most likely to play an important role, were seen to be industry (including changes in the business models), transport and agriculture. Also changes in society, such as income inequality, were considered important. Further, it is necessary to distinguish between structural change as an assumption and as a result due to feedback loops. The energy system reflects the society and society builds its energy system. Thus, changes in one will affect the other and vice versa. The negaWatt scenario for example determines structural change endogenously, while many other scenarios rather keep the existing structure (e.g. the German study).

Level of ambition and lock-ins: From the point of view of modellers, the most important lock-ins to address are related to the retrofit of buildings, the infrastructure for transport as well as the role of CHP plants. With regard to different levels of ambition in varying timeframes, the following issues were raised:

- the lack of grid infrastructure tends to restrict the realizability of scenarios in the long term

- models based on cost optimization (the majority) see extremely high costs as they approach complete decarbonization;
- models are flexible with regard to the timeframe to reach a certain target, however, socio-economic developments like demographics and lifestyle changes are not, and for the latter, it is not the actual size of changes that pose a problem but the timeframe.

Multilateral dimensions: In the discussion, experts highlighted challenges of scenarios that do take into account the multilateral dimension: the sustainability of mitigation options; a loss of control; and environmental effectiveness.

3 Comparing 2050 scenarios: A criteria catalogue

Following the descriptive analysis, a set of criteria was developed for the systematic evaluation of national long-term climate protection scenarios. The catalogue is both descriptive and normative, insofar as it facilitates a comparative evaluation of the six scenarios as well as an assessment of individual scenario *quality* when appropriate. Most but not all criteria lend themselves to this 'nested' descriptive-normative evaluative framework. The descriptive evaluation of a criterion highlights divergences and convergences as well as possible learning points but does not evaluate quality, i.e., attach positive or negative weight to aspects of the study. However, in many cases, a descriptive criterion is also viewed through a normative lens, allowing for a subjective scoring of scenarios based either on a best practice ideal or determined relative to the other scenarios. (See Appendix B for a comprehensive description of the criteria catalogue, including the scales and scoring methodologies used.)[11]

The evaluative criteria were organised and developed around four key guiding questions:

1. How much mitigation is foreseen?
2. How will mitigation be achieved?
3. What are the contextual circumstances?
4. Is the scenario based on appropriate and robust methodology?

In other words, *what* does the scenario entail, *how* is it achieved, are broader considerations included and is the scenario methodologically valid? Furthermore, criteria were identified based on (1) numerous discussions among project partners, including the workshop proceedings from April 2016 and (2) data provided in the analysis of the six reports published in 2017 (both summarised above).[12] The final catalogue was composed of twenty-one criteria, grouped into eight overarching dimensions—ambition, scope, mitigation options, sustainability, national context, multilateral dimensions, appropriateness and robustness (see Figure 1). In some cases, criteria were further divided into sub-criteria to allow for a more nuanced evaluation, and a scale and scoring system (if appropriate) was developed for each criterion. A traffic light system with degrees *poor*, *okay* and *good* was used to score most normative criteria.

As a next step, the criteria catalogue was applied to the French and German studies for exemplary purposes. While both scenarios seem quite ambitious at first sight, they differ from each other to some extent in each of the assessed dimensions—most prominently in overall ambition, use of CCS and BECCS, sectoral emissions, multilateral dimensions as well as scenario design and methodology. Looking at the net GHG reduction targets and/or the per capita GHG targets reveals that the German scenario (with 95% reduction in 2050 compared to 2008/2010 levels) is more ambitious than the French (with 84% reduction in 2050 compared to 2010 levels). However, despite these differences both countries received an *okay* on their overall emissions reduction targets. The story was a bit difference for per capita emissions; here Germany scored a *good* with a target of 0.8 tCO2e p.c. and France only received an *okay* at 1.21 tCO2e p.c.

Concerning sustainability, the German study considers land use change, while the French study does not. Both studies include biofuels and biomass, but only the German considers BECCS as

[11] For a similar approach to comparative policy evaluation, upon which the work in this study built on, see Duwe, M; Evans, N.; Donat, L. and Schock, M. (2016). Submission of a Final Tool Concept for the Assessment of Low-Carbon Development Strategies. Maximiser, WWF EPO.

[12] Duscha, V.; Wachsmuth, J.; Donat, L. (2017): Analysis of selected climate protection scenarios for European countries.

well. While the French scenario excludes CCS completely, the German scenario does so only for electricity generation but allows its use in industry.

Data was sourced from a variety of places for the criteria on national context, including the World Bank, Eurostat and various national databases. Sectoral emissions and gross value-added shares of agriculture, transport and industry, in particular, provide some indication of the economic structure of each country. The data highlight significant differences between France and Germany. In terms of emissions, transport and agriculture are more important in France than in Germany. The opposite is true for the industrial sector, which accounts for a larger share in Germany compared to France for both emissions and gross value added.

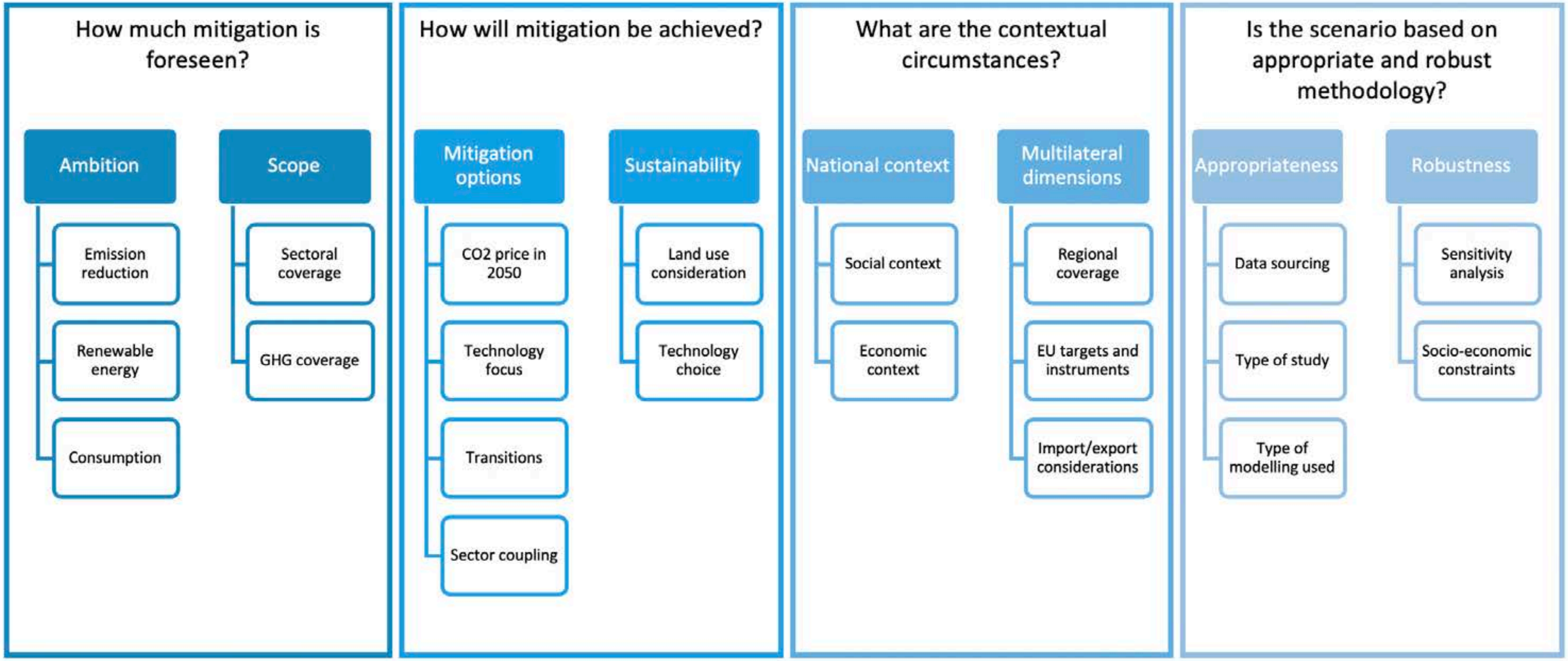
In regard to multilateral dimensions, only the import/export criterion is valuated. Since the German strategy includes both imports and exports for multiple sectors, it received a *good* valuation. The French strategy does not include much detail in this regard, leading to a *poor* valuation. Neither study considers EU targets and instruments. The German study covers only the national scale, while the French case also considers the local scale.

In terms of study type and modelling, both the German and the French scenario are normative scenarios that derive pathways to a given target. The German scenario is mostly normative preserving in the sense that it assumes that consumption patterns and industry structure do not change unless absolutely necessary to achieve the target. Contrary to that, the French scenario is normative transforming in the sense that the analysis of each sector starts with detailed sufficiency considerations that imply changes of today's consumption patterns and industry structure. With regard to the robustness dimension, the German scenario covers socio-economic constraints quantitatively in all the bottom-up sector models, but it shows quantitative results from sensitivity analyses only for a few key parameters focussing on the macroeconomic impacts. Hence, a score of *good* is attributed to the indicator on socio-economic constraint, and an *okay* is attributed to the indicator on sensitivity analyses. The French scenario is similar in its coverage of sensitivities, as it uses two different models to show the robustness of the macroeconomic impacts but contains only qualitative arguments otherwise. Different from the German scenario, socio-economic constraints are taken into account only for certain aspects such as the French fleet of nuclear power plants, but not in an integrated manner. Therefore, the French scenario obtains an *okay* for both robustness sub-criteria.

This cursory overview of the evaluation shows how the criteria catalogue goes a step beyond the initial descriptive analysis by scoring and comparing scenario *quality*. The same technique can be applied to multiple scenarios simultaneously and using a simple scoring method, dimensions such as robustness, scope and ambition among others can be viewed side-by-side.

On 1 October 2018, Ecologic Institute hosted a workshop in cooperation with Fraunhofer ISI and the Öko-Institut at the European Climate Foundation (ECF) in Brussels with the title "Insights from a comparative analysis of long-term climate policy scenarios". The purpose of the workshop was to present the criteria catalogue and to elicit feedback from select stakeholder groups about the comparative analysis. Over the course of the event, approximately forty participants—representing a diverse set of stakeholders varying from civil society to industry stakeholders as well as the political spectrum in Brussels—discussed the current state of the negotiations and drafting of the EU ETS, how to achieve the deep decarbonisation and how scenarios can be incorporated into the EU long-term strategy. It became clear that several areas require greater attention, such as R&D, finance and co-benefits, as well as out of the box solutions, i.e., nature-based solutions, sector decoupling and circular economy.

Figure 1: Guiding questions and structure of the criteria catalogue for the evaluation of climate protection scenarios



Source: Duwe, Matthias, et al (2021): Criteria for the evaluation of climate protection scenarios. Umweltbundesamt Climate Change Series 57/2021. 37p. https://www.umweltbundesamt.de/publikationen/criteria-for-the-evaluation-of-climate-protection

4 Outlook: From scenarios to strategies

A key function of climate protection scenarios is to form the scientific basis of long-term climate strategy (LTS) development. Insights from analysis into long-term strategies in Europe indicates that almost all existing national LTSs in the EU (at the time of writing) are based on climate protection scenarios akin to the six analysed here.[13] In other words, LTSs translate climate policy modelling and emissions pathways into tangible governmental action, and in doing so can provide a clear trajectory for policy planning while further transposing international obligations into national law.

All EU Member States have the legal obligation under the EU's Governance Regulation to submit a national LTS by the 1st of January 2020, which underlines the importance of adequate national climate protection scenarios. Around half of the Member States already have already adopted such strategies as of late 2018– and a conversation is underway on the formulation of an EU 2050 strategy also (to be submitted to the UNFCCC in 2020). There is thus a growing body of documentation and experience – which can serve as guidance for policy-making but also help improve both scenarios and strategy development.

Dialogue and ongoing learning are key elements in long-term climate planning, for two key reasons. Firstly, as future projections and long-term plans are by definition exercises that suffer from great uncertainty, scenarios and building strategies for the long-term are not one-off processes but must become constant exercises. New information needs to be built in on a regular basis, updating and refining strategies, to create more effective and efficient policy. Secondly, while there is growing experience, there are significant differences in the current approaches, which can lead to rather different outcomes and policy recommendations. Sharing and updating are needed to improve mutual understanding and create a common basis (about technology options and expected costs, for example). This would foster scenarios and strategies across Europe that are "compatible" with one another.

The results of the descriptive and evaluative analyses undertaken highlight similarities but, more importantly, substantial differences between the climate protection scenarios for the six EU Member States. This is not a surprising finding. EU Member States are at various stages of national strategy development—and even the completed strategies differ considerably. While it is not a hard and fast rule, more ambitious scenarios are generally associated with more ambitious strategies. For instance, the Öko-Institut's "Climate Protection Scenario 2050" is among the highest in terms of overall emissions reduction ambition (80-95% compared to 1990 levels) and this is reflected in Germany's national 2050 targets. There are similar parallels for both France and the UK, which have set national emission reduction targets for 2050 of 75% and 80%, respectively.

A further insight from the conversation with stakeholders is that ambitious protection scenarios must be communicated properly to stakeholders and policy makers in order to function as input for the development of national climate strategies. Ideally, the results of scenario building are synthesised into a narrative—which then paints a clear picture of the direction and speed of decarbonisation for each individual country. In other words, the shift from *scenarios* to climate governance in the form of national *strategies* is crucial.

Further dialogue on the lessons from current experience in Europe is clearly needed. The objectives of and the work undertaken for the UBA project "Supporting ambitious climate change protection scenarios in Europe" served as an impulse for the "Climate Recon 2050"

[13] Iwaszuk, E.; Duwe, M. (2018): 2050 climate strategies in EU countries: State of play

initiative, which has created a platform for policymakers and stakeholders from selected EU Member States to exchange best practices and lessons learned regarding past scenarios and ongoing strategy formulation or revision, respectively. [14]

Analysis undertaken under the Climate Recon 2050 platform paints a similar picture of similarities and differenced for the strategies themselves. Some are adopted as official resolutions by parliament or a cabinet or attached to existing legislation, while others take the form of a ministerial or governmental report with little binding strength. National strategies often contain milestones and a monitoring/review mechanism to ensure that action is distributed over time. For instance, France and Portugal are currently[15] in the process of updating their national strategies to reflect new ambition driven by the PA.

The draft EU 2050 strategy presented by the European Commission in late November 2018 [16] adds to the wealth of information and thinking out there to inform long-term policy-making and is likely to be studied also by Member States drafting their national strategies during 2019. It has already opened a window for a political discussion on a new long-term goal for the EU as a whole, of achieving net-zero emissions by 2050. This would have implications for national scenarios and strategies also. The door is now wide open for a broader dialogue on long-term scenarios and how they can best be used to inform long-term strategies and policy-making in the EU.

[14] Project specifics available under https://climatedialogue.eu

[15] as of January 2019

[16] European Commission (2018) Clean Planet for all. A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy" COM(2018) 773.

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A Appendix: Workshop proceedings – Ambitious climate protection scenarios in Europe

Wednesday, 13 April 2016, 09:30-16:30

Ecologic Institute, Berlin, Pfalzburger Straße 43/44, 10717 Berlin

Introduction

On 13 April 2016, 25 European experts gathered in Berlin to discuss ambitious long-term climate protection scenarios that have been developed for selected Member States of the European Union. The workshop provided a forum for dialogue and exchanging experience to address the following questions:

- What are the major challenges in developing long-term scenarios?
- To what extent do underlying assumptions vary across the scenarios?
- How can structural change be handled and modelled?

The workshop is part of a research project, commissioned by the German Environment Agency, that analyses 2050 climate protection scenarios across EU Member States and aims to trigger a debate on the transformation towards a sustainable, low-carbon economy in the European Union.

Decarbonisation studies for selected EU Member States

Five experts presented ambitious low-carbon scenarios for different EU Member States.

- Yves Marignac, “Scenario NegaWatt” (France)
- Maria Rosa Virdis, “Pathways to Deep Decarbonisation” (Italy)
- Maciej Bukowski, “2050.pl - the journey to the low-emission future” (Poland)
- Matthias Gustavsson, “Energy Roadmap 2050 for Sweden” (Sweden)
- Paul Allen, “Zero Carbon Britain - Rethinking the Future” (United Kingdom)

Outcomes of the discussion

The workshop employed small group discussions to get at several topics of particular interest. Following an initial round on varying assumptions and categories for further comparison, participants split up to discuss four more targeted topics: mitigation options, structural change, ambition and lock-in, multilateral dimension.

General discussion of topics

A number of modelling teams have developed scenarios for different countries aiming at very low emission levels by 2050 (in the range of 80 to 95%). However, for most countries—if at all—only one or two such low-carbon scenario exist, making it difficult to compare different low-carbon scenarios for one country. Moreover, a complete elimination of emissions in sectors (such as, e.g., emissions from agriculture but also a complete decarbonisation of the power sector which can become extremely costly) is difficult to model from a technological as well as a cost perspective.

Major factors that characterize national low-carbon scenarios are:

- characteristics of the country in question: geographical situation, current industrial structure and energy system
- political values: What are the aims besides decarbonisation? What is acceptable? Sufficiency? How are the results used in the political context?
- modelling: tools used, depth of systemic analysis

Assumptions and variables that characterize scenarios are:

- sustainability criteria: e.g. for the use of CCS and biomass
- transition: to what extent is the necessary societal transformation covered?
- modelling of power sector: multilateral dimension addressed?
- assumptions on sufficiency: level of mobility, dietary aspects, ...
- Political and societal circumstances/ political will
- The key-storyline of the transition/scenario
- Context of the study
- Modelling methodology
- Finding hidden things (e.g. imports/exports, availability of biomass/resources in general)
- Quality of life/lifestyle

Categories/criteria identified so far:

- Scope of the study (sectors/ gases included in the study; LULUCF)
- Achievements/ targets (per capita emissions; reduction of GHG emissions; reduction of final energy consumption; share of RES in electricity mix)
- Modelling specifics (models applied; modelling timeframe – pathway of target year?)
- Technology options (mitigation options included/excluded; Share of RES/ RES-E; Modelling of carbon dioxide removal technologies; key assumptions in transport sector)
- Structural changes (industry; agriculture; energy infrastructure & markets; behavioural changes consumption/ nutrition)
- Multilateral dimension (regional coverage; modelling of EU 2020 targets/ ETS; role of effort sharing/ domestic efforts) Long-term challenges (considerations beyond 2050; changes between medium and high ambition)

- Input data (Energy price assumptions; growth assumptions; input parameters; data sources)

Additional remarks:

- In the modelling process, it is important to reflect in which way the neighbouring countries are changing
- Modelling of a group of countries only available for power sector, although this would be interesting in general, lack of multilateral studies

Mitigation options

Climate protection scenarios can set one and the same emission reduction target but vary considerably in the way they project to achieve these targets. Different scenarios draw on different mitigation options and exclude others. Such choices have an impact on economic, environmental and social costs achieved in/calculated for such scenarios.

Which options to include and to exclude can be a political decision (or based on the perception of national political reality) or be based on what the modellers consider a "realistic" projection of technological development, or which environmental, economic and social risks one is willing to take. The discussion revealed that modellers decide on the technologies taking into account issues of sustainability, public acceptance, current political priorities and feasibility. While none of the scenarios presented during the workshop saw nuclear power as an energy source in 2050, the scenarios show very different approaches to the use of carbon capture and storage (CCS). Some excluded CCS completely; others included CCS but for industrial processes only, others also for energy production.

The experts also highlighted the importance of lifestyle change as a mitigation option. This concerned mainly meat consumption, energy use in housing and transport. They also stressed that such changes might bring about new questions on the availability of resources, which would require further investigation.

Structural changes

In some sectors, decarbonisation can be achieved by replacing one technology with another that—in certain characteristics—is still very similar to the existing technology. An example is power generation by renewable energies instead of power generation from fossil fuels. In other sectors, however, this is not possible as technologies for reducing emissions do not exist (yet) or are extremely costly. Examples are emissions from agriculture in the food industry or process emissions in the cement or iron and steel production. In these cases, behavioural or structural changes can help to reach the desired reductions.

The three sectors in which structural changes are most likely to play an important role, were seen to be industry (including changes in the business models), transport and agriculture. Also changes in society, such as income inequality, were considered important. Further, it is necessary to distinguish between structural change as an assumption and as a result due to feedback loops. The energy system reflects the society and society builds its energy system. Thus, changes in one will affect the other and vice versa. The negaWatt scenario for example determines structural change endogenously, while many other scenarios rather keep the existing structure (UBA Treibhausgasneutrales Deutschland).

Participants agreed that (for several reasons) scenarios should not be seen as forecasts of the future, but that they can be used as a one element on which to base decision making. However, structural change is an important factor and including it in the scenarios (and being explicit about it) should be one focus in future scenario development. Also, timeframe and depth of changes can vary between sectors. Scenarios with a rather radical change of the system were seen as useful and informative in addition to other, more conservative [mainstream] scenarios. Yet, they need to be developed in a systematic way to enabling users/decision makers to learn from them. Also, even radical change will not or unlikely occur from one day to the next, but it will take time to transform the system.

Levels of ambition and lock-ins

The EU as a whole aims at reducing GHG emissions by 80-95% until 2050. In the national scenarios there are, however, different levels of ambition (possibly reflective of the EU practice of internally sharing reduction efforts between countries). However, pathways to achieve a 95% reduction can significantly differ from pathways with a lower level of reduction, in particular because the more ambitious pathways may require additional infrastructure and/or structural and behavioural changes. Furthermore, less ambitious pathways will require additional reductions after 2050 to support a stabilization of the global climate. Thus, it is important to identify extendable pathways as well as possible lock-ins that prevent the realization of additional emission reductions.

The discussion about the long-term considerations and implications of different levels of ambition showed that there are in particular concerns with regard to identifying and addressing lock-ins. Other aspects in the discussion were the availability of no-regret measures and modelling issues related to time scales and optimization.

From the point of view of modellers, the most important lock-ins to address are related to the retrofit of buildings, the infrastructure for transport as well as the role of CHP plants:

- Retrofit of buildings: Lock-ins may result both from retrofits of the building envelope and of heating systems. They can be addressed in the construction of scenarios by modelling the building stock in detail, in particular allowing to distinguish between the impact of deep retrofits of parts of the building stock and shallow retrofits of the whole building stock.
- Transport: The infrastructure of transport is partly long-lasting and strongly influenced by the systemic choices of how to decarbonise the transport sector. It is there- fore important to address these systemic consequences for infrastructure systematically.
- CHP plants are a very efficient option from today's point of view. In ambitious scenarios, however, they face a reduction of full-load hours. This not only reduces their efficiency from a technical point of view but may also destroy their business models.

In the discussion, several no-regret measures that appear to be compatible with different levels of ambition were named, partly with some caveats though:

- As the lifetimes of electric appliances are relatively short, the continuous adoption of efficient appliances does not result in any kind of lock-in.
- Decarbonisation pathways will benefit from sufficiency considerations independent of their level of ambition. However, assuming that consumption patterns adapt according to

sufficiency considerations may avoid additional mitigation options that will be necessary if consumption patterns do not change.

- The reinforcement of the electric grids is a prerequisite for any kind of 100% RES supply with electricity. Still, this has to be done in a way that ensures that all kinds of generation technologies can be integrated. This entails that the grid also has to include smart systems, storages and likely also some kind of power-to-gas technologies.

With regard to the modelling of different levels of ambition in varying time frames, the following issues were raised in the discussion:

- Models are flexible with regard to the time frame to reach a certain target, however, socio-economic developments like demographics and lifestyle changes are not. For the latter, it is not the actual size of changes that pose a problem but indeed the time frame.
- A lot of models are based on cost optimization. A cost-optimized 80% scenario may result in extremely high costs, when the level of ambitions is increased to 95%. More- over, the time frame for increasing ambition e.g. from 80 to 95% is important.
- Restrictions of the grid infrastructure (electricity, district heating and fuels) are affecting the realizability of scenarios a lot, but mainly show up only implicitly in long-term scenarios. The focus on shorter time scales in the planning of electricity grids may result in missing long-term developments. For instance, ambitious scenarios show a decrease of electricity demand until 2030 and a strong increase afterwards.

Multilateral dimension – EU policy context

Most national scenarios take—by definition—a perspective that strongly focuses on developments within the national territory and aim to solve the challenge of decarbonisation within its boundaries. The discussion revealed that many decarbonisation scenarios follow an "island approach", i.e. they ignore any interactions with neighbouring countries. However, this might not reflect the most cost-efficient approach given that, for example, peak demand capacity needs are only met with national resources. It might also exclude important technology options.

Even a scenario based on an island approach will include assumptions about developments outside of the country in question – including technology availability and cost developments, availability of certain resources to be imported, etc. The external inputs and outputs thus can play an important role in the outcomes of the scenarios.

For long-term decarbonisation, the interaction with other countries has also important potential synergy effects in terms of the possibility to look beyond national resources (e.g. importing renewable electricity or other clean energy sources and using underground carbon storage, e.g. US-Canadian Weyburn project). For EU Member States, this then includes the question as to what extent such intra-EU trade and the related infrastructure has been taken into account, and if not, what implications this has had for mitigation options chosen.

In the discussion, experts highlighted challenges of scenarios that do take into account the multilateral dimension: the sustainability of mitigation options; a loss of control; and environmental effectiveness.

Table A1: Ambitious climate protection scenarios in Europe workshop – Agenda

Time	Description
09:30 – 10:00	Arrival and registration
10:00 – 10:15	Welcome address, Dr. Guido Knoche, German Environment Agency Short round of introduction
10:15 – 10:30	Presentation of the project and status quo of the research Matthias Duwe, Ecologic Institute
10:30 – 11:15	Decarbonisation studies for selected EU Member States - PART I Yves Marignac, “Scenario NegaWatt” (France) (confirmed) Maria Rosa Virdis, “Pathways to Deep Decarbonisation” (Italy) (con- firmed)
11:15 – 11:30	Coffee Break
11:30 – 12:30	Decarbonisation studies for selected EU Member States - PART II Maciej Bukowski, “2050.pl - the journey to the low-emission future” (Poland) (confirmed) Matthias Gustavsson, “Energy Roadmap 2050 for Sweden” (Sweden) (confirmed) Martin Kemp, “Zero Carbon Britain - Rethinking the Future” (United Kingdom) (confirmed) Open exchange on pros and cons of different approaches and parameters
12:30 – 13:30	Lunch
13:30 – 15:00	World Café: Assumptions and key elements of climate protection scenarios
15:00 – 15:15	Coffee Break
15:15 – 16:15	Presentation of results + experiences in different EU Member States Fraunhofer-ISI and Ecologic Institute
16:15 – 16:30	Final remarks and the way forward Dr. Guido Knoche, Umweltbundesamt

Moderation: Matthias Duwe, Ecologic Institute

Table A2: Ambitious climate protection scenarios in Europe workshop – List of participants

First Name	Name	Organisation
Tobias	Brenner	Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB)
Maciej	Bukowski	Warsaw Institute for Economic Studies
Oliver	Deke	German Federal Ministry for Economic Affairs and Energy (BMWi)

First Name	Name	Organisation
Lena	Donat	Ecologic Institute
Vicki	Duscha	Fraunhofer Institute for Systems and Innovation Research ISI
Matthias	Duwe	Ecologic Institute
Lukas	Emele	Öko-Institut
Mathias	Gustavsson	IVL Swedish Environmental Research Institute
Benno	Hain	German Environment Agency (UBA)
Martin	Kemp	Centre for Alternative Technology
Almut	Kirchner	Prognos AG
Guido	Knoche	German Environment Agency (UBA)
Anja	Kollmuss	CAN Europe
R. Andreas	Kraemer	Institute for Advanced Sustainability Studies (IASS Potsdam)
Philip	Litz	Agora Energiewende
Birgit	Lode	Institute for Advanced Sustainability Studies (IASS Potsdam)
Yves	Marignac	WISE France
Mark	Meyer	Institute of Economic Structures Research (GWS) Osnabrück
Diana	Nissler	German Environment Agency (UBA)
Mark	Nowakowski	German Environment Agency (UBA)
Roberta	Pierfederici	Institute for Sustainable Development and International Relations (IDDRI)
Sascha	Samadi	Wuppertal Institute
Fabian	Sandau	Fraunhofer Institute for Wind Energy and Energy System Technology (IWES)
Oliver	Seel	German Environment Agency (UBA)
Maria Rosa	Virdis	Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)
Jakob	Wachsmuth	Fraunhofer Institute for Systems and Innovation Research ISI
Martin	Weiß	Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB)
Christoph	Wolff	European Climate Foundation

B Appendix: Criteria for the evaluation of climate protection scenarios[17]

1 Background-

This document outlines a catalogue of criteria, intended to be used for the evaluation of national long-term climate protection scenarios.

In the context of the project in which these criteria have been developed, the results of the application of this catalogue to a set of specifically chosen European national scenarios should inform the next step, the development of a typology of such national climate protection scenarios. However, the criteria catalogue should be universally applicable to similar types of scenarios – and can be used in other contexts, too.

In the following, we underscore the methodological considerations that went into the development of the criteria as well as the descriptive/normative framework in which the criteria catalogue operates. An example of the evaluative output is presented using data from two national scenarios.

The scenarios in question are two out of a set of six selected studies (see Table B1), which were described in depth in the report "Analysis of selected climate protection scenarios for European countries", published in 2017.[18] The six country studies were chosen specifically in a preliminary assessment for having met essential conditions, including *inter alia* an adequate level of detail, broad sectoral coverage and a long-term time horizon—plus a relatively high overall transformational character.

Table B1: Overview of country studies to be evaluated

Country	Organisation/Name of study	Year
France	Association négaWatt, *Scenario négaWatt 2011 – 2050*	2013
Germany	Öko Institute, *Climate protection scenario 2050 – Second round*, 2015	2015
Italy	SDSN/IDDRI, *Pathways to deep decarbonisation in Italy. IT 2015 Report*	2015
Poland	Warsaw Institute for Economic Studies (WISE)/Institute for Sustainable Development, *2050.pl – The journey to the low-emission future*	2013
Sweden	IVL Swedish Environmental Research Institute, *Energy Scenario for Sweden 2050*	2011
UK	Centre for Alternative Technology, *Zero carbon Britain – Rethinking the future*	2014

The criteria are, however, brought together in the setting presented here, to allow, in principle, for an individual and comparative evaluation of other, similar such long-term climate scenarios, including from other parts of the world.

[17] This report has also been published as a stand-alone document: Duwe, M. et al (2021): Criteria for the evaluation of climate protection scenarios. Substudy Report. Umweltbundesamt Climate Change Series 57/2021. 37p.

[18] Duscha, Vicki; Wachsmuth, Jakob; and Lena Donat (2017): Analysis of selected climate protection scenarios for European countries. Interim Report. Umweltbundesamt. Climate Change Series 10/2017. P 40.

2 Methodology

The proposed catalogue is both descriptive and normative, insofar as it facilitates a comparative analysis (e.g. of the six scenarios) as well as an evaluation of individual scenario quality. Most but not all criteria lend themselves to this 'nested' descriptive-normative evaluative framework. The descriptive evaluation of a criterion highlights divergences and convergences as well as possible learning points but does not evaluate quality or attach positive or negative weight. However, the same criterion can also be viewed through a normative lens, allowing for a subjective scoring of scenarios based either on a best practice ideal (as identified by the evaluator) or determined relative to the other scenarios (i.e. the most ambitious scenario sets a benchmark under which all further scenarios are scored).[19]

2.1 Selection of criteria

The objective of this analysis is to enhance and complete a set of proposed criteria set forth in the description of work for the evaluation of (European) long-term climate scenarios. The original description of work suggested nine criteria to serve as a starting point for the development of a more comprehensive criteria catalogue:

- Sustainability
- Resilience
- Import dependence
- Land use
- Role of specific economic sectors
- Role of specific emitting sectors (i.e. heating, power)
- Technology development
- Behavioural change
- Regional and cross-border considerations

As part of the work undertaken that is presented in this report, we have reviewed this list and come to a final set, which is ready for implementation in future steps of the project – and for other future use.

We identified multiple factors enhancing and expanding the initial list.

- First, the final criteria catalogue facilitates a transparent comparative analysis, highlighting differences, similarities and possible starting points for integration and exchange.
- Second, to ensure a transparent and robust evaluation, it is important that each criterion can be logically justified and reliably scored (where appropriate) based on data provided in the respective documents.

[19] For a similar approach to comparative policy evaluation, upon which the work in this study built on, see Duwe, M; Evans, N.; Donat, L. and Schock, M. (2016). Submission of a Final Tool Concept for the Assessment of Low-Carbon Development Strategies. Maximiser, WWF EPO.

► Third, the suggested criteria are not independent from one another, and thus is it important to consider synergies as well as how the different criteria interact to meet the objectives of the scenario.

Finally, it is important to target not only the end goals of the climate protection scenarios but also the driving factors and measures taken to reach those goals. To begin the process, we identified the following four key guiding questions about the climate scenarios that that best underscore the purpose of the subsequent analysis and evaluation:

1. How much mitigation is foreseen?
2. How will mitigation be achieved?
3. What are the contextual circumstances?
4. Is the scenario based on appropriate and robust methodology?

In other words, *what* does the scenario entail, *how* is it achieved, are broader considerations included and is the scenario methodologically valid? These guiding questions helped to select and categorize the criteria and breakout indicators of the final catalogue.

Criteria were identified with the guiding questions in mind and based on (1) numerous discussions among project partners, including the workshop proceedings from April 2016 and (2) data provided in the analysis of the six reports published in 2017[20]. Points of divergence and similarity between the six scenarios were identified using the summary tables and the qualitative descriptions in the previous project report. Framing the selection of criteria around the set of questions adds to transparency and helps to justify the criterion choice. For instance, the level of mitigation could be given by looking solely at the degree of ambition regarding foreseen emissions reductions, but a more comprehensive evaluation also includes the scope of mitigation (i.e. what type of emissions, from which sectors etc.). The four key guiding questions and their respective criteria are discussed in more detail in subsections 2.2.1 through 2.2.4.

The twenty-one criteria are grouped into eight overarching constructs or dimensions—ambition, scope, mitigation options, sustainability, national context, multilateral dimensions, appropriateness and robustness—and sometimes further sub-divided into sub-criteria. A proposed evaluation catalogue, which includes the guiding questions, criteria, sub-criteria and a set of scales for each criterion or sub-criterion, is depicted in its entirety in Figure B1 in the annex. Section 3 provides an exemplary analysis and discussion on the basis of two European climate protection scenarios.

2.1.1 Guiding question one: How much mitigation is foreseen?

To answer the first guiding question, evaluation criteria are grouped into two core dimensions: *scope* and *ambition.*

Scope

The first dimension assesses the scope of scenarios—in which economic sectors climate mitigation is foreseen and which of the so-called “Kyoto gases” are included.[21] Climate protection scenarios can either focus narrowly on the energy-related emissions, which includes emissions from energy use in the buildings, transport and the industry sector, (or even subsets of that) or can take an “economy-wide” approach, which includes waste, industrial processes and agriculture and LULUCF as well. Generally speaking, broader sectoral coverage provides a

[20] Ibid.

[21] Six GHGs are covered by the Kyoto Protocol: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6), and nitrogen triflouride (NF_3).

more holistic picture of emission reductions. Additionally, while some scenarios focus only on the most prevalent of greenhouse gases (GHGs), carbon dioxide (CO_2), others account for additional GHGs. Most commonly, these include methane (CH_4), nitrous oxide (N2O) and the F-gases. Sectoral and GHG coverage go hand in hand; focusing solely on the energy sector neglects other potent GHGs, such as methane, which arises primarily from agriculture and waste. Thus, an assessment of scope considers the number of sectors and GHGs considered by the scenario, with broader sectoral coverage and the inclusion of all or multiple GHGs leading to a better assessment – and vice versa.

Ambition

The second dimension assesses the overall ambition of scenarios, by focusing on each scenario's stated or implicit emission reduction, renewable energy and energy consumption targets by means of different sub-criteria. Thus, the assessment focuses on whether scenarios account for the three general pillars of EU climate policy, as laid out in the 20-20-20 targets and the 2030 framework—GHG emission reductions, renewable energy and energy efficiency.

As emission reduction targets are defined differently between scenarios, we divided this criterion into three parts: a) the *net emission reduction target*, b) the *gross emission reduction* and c) *negative emissions*. The net reduction a) is defined as the sum of b) and c). Thus, it equals the gross emission target *plus* any negative emissions accounted for in the scenario.

Although the creation of negative emissions—through sinks, carbon capture and storage (CCS) or a combination of the two, i.e., bioenergy CCS (BECCS)—as a means of reducing overall atmospheric greenhouse gas concentration could be considered under guiding question two, "how will mitigation be achieved", the inclusion/exclusion of negative emissions can also mark the ambition of a scenario. This is the case because it may be easier (and potentially controversial) to achieve an emissions reduction target by accounting for storage technologies and carbon sinks. For one, Anderson and Peters (2016)[22] argue that negative emissions are an "abstract concept" and – depending on the accounting technique used – may reduce the ambition of near-term measures. Furthermore, the authors caution that storage technologies such as CCS are still in development, and it remains to be seen whether they can be deployed at scale in an effective manner. Nevertheless, following the adoption of the Paris Agreement, which called for net zero emissions by 2050, many countries have shifted their focus to carbon and GHG *neutrality*, emphasising the importance of negative emissions. As an example, Sweden aims to be carbon neutral by 2045 but qualifies this target claiming that it translates to an 85% *gross* reduction in carbon emissions (using the terminology of the proposed criteria catalogue, with their net target being 100%).

The emission reduction criteria are evaluated as follows. High ambition is indicated by higher foreseen emission cuts measured as a percent decrease over a base year. While a scenario's general consideration of negative emissions is evaluated positively for presenting a more holistic picture of emission pathways, net emission reductions are evaluated on the same scale as gross emission reductions to indicate the level of actual foreseen emission cuts. Therefore, theoretically a scenario could 'score' high on foreseen gross emission reductions but lower on net emission reductions once negative emissions are accounted for.

The criteria catalogue further considers the emissions reduction *base year*, i.e., the starting point of the scenario modelling; the *timeframe* outlined in the scenario, i.e., the timeframe in which the target should be met and the inclusion of *milestones and interim targets*. In terms of evaluation,

[22] Anderson, K., & Peters, G. (2016). The trouble with negative emissions. *Science*, *354*(6309), 182–183. https://doi.org/10.1126/science.aah4567

the inclusion of milestones and interim targets raises a scenario's ambition, but base year and timeframe are not factored into the assessment.[23]

In many cases, per capita targets provide a more equitable assessment of ambition between scenarios. This criterion is evaluated on a scale ranging from less than one to greater than three tonnes of CO_2e (tCO_2e) with lower per capita emissions rated as more ambitious.[24] In the EU, the majority of GHG emissions originate from the production and consumption of energy, and therefore the criterion energy-sector target is included to determine whether a scenario lays out sector-specific objectives for energy. The energy sector target is evaluated on a scale similar to the headline targets described above; high ambition is marked by a higher percent decrease in emissions over a base year.

Table B2: Guiding question one: Criteria and sub-criteria

ID	Criterion name	Scale	Valuation
1	**Ambition**		
1.1a	Net emission reduction target (*incl.* negative emissions)	scale: +100% to > (-100)% compared to base year	< (-80)% / ≥ (-80) and ≤ (-95)% / > (-95)%
1.1b	Gross emission reduction target (*excl.* negative emissions)	scale: +100% to (-100)% compared to base year	< (-80)% / ≥ (-80) and ≤ (-90)% / > (-90)%
1.1c	Negative emissions	yes / no	yes / no
1.1.1	Base year	open	no valuation
1.1.2	Timeframe	open	no valuation
1.1.3	Milestones (interim targets)	yes / no	yes / no
1.1.4	Per capita target	open; tCO2e p.c. or tCO2 p.c.	< 1 / ≥ 1 and ≤ 3 / > 3
1.1.5	(Net) Energy-sector target	scale: +100% to -100% compared to base year	< (-80)% / ≥ (-80) and ≤ (-95)% / > (-95)%
1.1.6	Paris Agreement compatibility	No / Cancun / Paris	No / Cancun / Paris
1.1.7	Considers long term (2050 or beyond)	< 2050 / 2050 / >2050	< 2050 / 2050 / > 2050
1.2	Renewable energy target	share of RES in electricity in 2050	< 33% / ≥ 33 and ≤ 66% / > 66%
1.2.1	Timeframe	open	no valuation

[23] The level of ambition of an emission reduction, renewable energy or energy consumption target depends to a significant extent on the base or reference year the future values are being compared to. This is particularly for shorter time spans. In the case of the six climate protection scenarios assessed here, the base year was consistently 2010—this year was used as a reference year for all six models. Accounting for potential variation in the base year, while possible, would drastically increase the complexity of the criteria catalogue. Moreover, since the criteria are designed for application to long-term scenarios, the difference between different absolute target levels achieved relative to the respective base year starts to shrink. While they are thus not entirely comparable, the order of magnitude (a reduction of 80% compared to a reduction by 95%, for example) can provide an initial level of comparison for countries with similar profiles. For a comparison of countries with different historic emission trends and different reference years, a comparative analysis would need to be done outside of the information provided through the criteria in this catalogue.

[24] The unit tCO_2 will be used for scenarios that only account for carbon dioxide emissions.

ID	Criterion name	Scale	Valuation
1.2.2	Milestones and interim targets	yes / no	yes / no
1.3	Consumption target	scale: +100% to -100% compared to base year	positive / ≥ 0 and ≤ (-30)% / > (-30)%
1.3.1	Timeframe	open	no valuation
1.3.2	Milestones and interim targets	yes / no	yes / no
2	**Scope**		
2.1	Sectoral coverage	Energy, buildings, transport, waste, industry, agriculture, LULUCF	all = very good / 4-5 = good / 3 = okay / 0-2 = poor
2.2	GHG coverage	CO2, CH4, N2O, F gases	4 = very good / 3 = good / 2 = okay / 0-1 = poor

The criterion "Compatibility with the Paris agreement" probes whether a scenario takes into account the internationally agreed upon objective to limit the global mean temperature increase to (well) below two degrees Celsius, and to pursue efforts to limit the temperature increase to 1.5 degrees Celsius. The criteria catalogue evaluates strategies which are compatible with the Paris agreement as green, strategies which are compatible with Cancun yellow and strategies which are not compatible at all red. Relatedly, consideration of long-term reductions (2050 and beyond) also raises the ambition level of a scenario. These two criteria are included to determine the degree to which a scenario falls in line with the stated objectives of the United Nations Framework Convention on Climate Change (UNFCCC), specifically those stipulated in the 2015 Paris Agreement. The Paris Agreement not only enshrines the two-degree target but also stipulates that parties should develop long-term-low greenhouse gas emission development strategies. The criterion applied in this catalogue includes the long-term focus of Paris (which includes a perspective into the second half of the century): it evaluates strategies considering a term shorter than 2050 red, a term until 2050 yellow and a term longer than 2050 green.

Some scenarios also include targets for *renewable energy* and *energy consumption*. Therefore, separate criteria are included in the dimension of ambition to further account for the plurality of scenarios; it is possible for a scenario to be based principally around foreseen increases in the share of renewable energy or source a majority of emission cuts from increased energy efficiency. The renewable energy target is assessed as the share of renewable energy sources (RES) in electricity in 2050, with higher shares indicating higher ambition. This is due to the fact that several scenarios only provide details for electricity production, but most scenarios analysed that provide a figure for the renewables share in final energy consumption also provide a figure for electricity. Similarly, consumption targets are evaluated as a decrease in energy usage over a reference or base year. Like the emission reduction target criterion, both the renewable energy and consumption target criteria include the sub-criteria for timeframe and milestones. These are evaluated in the same way as for emission reduction targets.

2.1.2 Guiding question two: How will mitigation be achieved?

Simply determining the level of mitigation action leaves open a variety of questions, most importantly the question of how mitigation will be achieved. In answering this question, we distinguish between the dimensions: mitigation options and sustainability.

Mitigation options

The mitigation options dimension assesses whether a scenario incorporates measures to decarbonize and thus transform the economy. The following criteria are included:

1. future carbon prices;
2. a technology focus on energy efficiency and/or renewable energy;
3. transitions, including behavioural and structural change;
4. options for sector coupling (i.e. power-to-gas, power-to-liquid, electrification of heating and electrification of transport).

Price-based instruments to mitigate climate change—such as emissions trading systems (ETS), carbon taxes, offset mechanisms and results-based finance—put an implicit and easily comparable price on carbon emissions. These instruments are generally considered efficient and environmentally robust, which is why many countries use them today or plan to make use of them in the future. Most long-term scenarios will not include instrument specific information, but many use carbon prices to identify where and when reductions happen (to achieve a certain emission level/pathway). The CO_2 price criterion thus does not assess the use of carbon pricing instruments but seeks to allow a comparison between the cost calculations of different modelling results. In individual cases (e.g. in case of conceptual scenarios, without use of top down modelling), such carbon prices may be decided by other means and could be associated with pricing tools.

RES and energy efficiency are the two key strategies for reducing GHGs from the energy, industry and building sectors. The promotion of cleaner forms of energy reduces the reliance on fossil fuels, and energy efficiency measures, such as product standards, lower energy demand. Some scenarios may pursue one technological path more vigorously than the other even though it is possible to simultaneously promote renewable energy production and energy efficiency. In terms of normative evaluation, scenarios that include at least three forms of renewable energy production are viewed more positively as those that consider fewer or no forms of renewable technologies. Energy efficiency measures are evaluated qualitatively based on whether there is some discussion of reducing energy demand or increasing efficiency, and scenarios are assessed on the scale: yes/partly/no.

Table B3: Guiding question two: Criteria and sub-criteria

ID	Criterion name	Scale	Valuation
3	**Mitigation options**		
3.1	CO2 price in 2050	open	no valuation
3.2a	Technology focus: Energy efficiency	yes / partly /no	yes / partly / no
3.2b	Technology focus: Renewable energy	yes = at least three renewable technologies envisioned partly = at least one type no = 0	yes / partly / no
3.3a	Transitions: Behavioural change	e.g. nutrition changes, lifestyle changes, transport mode shift yes = at least three types of behavioural change envisioned partly = at least one type	yes / partly / no

ID	Criterion name	Scale	Valuation
		no = 0	
3.3b	Transitions: Structural change	e.g. change of industrial processes, structural shift to service sector, more regional production yes = at least three types of structural change envisioned partly = at least one type no = 0	yes / partly / no
3.4a	Sector coupling: Power-to-gas/power-to-liquid	yes / no	yes / no
3.4b	Sector coupling: Electrification of heating	yes / no / N/A	yes / no
3.4c	Sector coupling: Electrification of transport	yes / no	yes / no
4	**Sustainability**		
4.1	Land use consideration	yes / no	yes / no
4.2a	Technology choice: Shale gas	yes / no	no valuation
4.2b	Technology choice: Nuclear	yes / no	no valuation
4.2c	Technology choice: Biofuels	yes / no	no valuation
4.2d	Technology choice: Biomass	yes / no	no valuation
4.2e	Technology choice: CCS	yes / no	no valuation
4.2f	Technology choice: BECCS	yes / no	no valuation

Behavioural and structural transitions include changes in individual behaviours (e.g. driving, dietary habits, etc.) and changes in industrial or system processes (e.g. use of new kinds of materials in the construction sector). Such transitions can lead to further GHG emission reductions over and above a technological focus on energy efficiency or renewable energy and also get at emissions originating from other economic sectors (e.g. behavioural change measures promoting sustainable meat consumption have the potential to decrease agriculture sector emissions). The transition criterion is evaluated qualitatively; depending on the degree to which behavioural and structural transitions seem to be included, scenarios are scored on the scale: yes/partly/no.

In contrast, sector coupling has only recently gained growing attention and many of the relevant developments are still in their infancy. In the future, however, sector coupling will become more important—the more challenging it becomes to reduce emissions from current production and consumption patterns, the more relevant it becomes to focus on structural changes in order to reach mitigation targets. Sector coupling means to achieve GHG reductions and/or efficiency gains by exploiting those from another sector. One common example is the electrification of mobility. Four forms of sector coupling are included in this catalogue for evaluation: power-to-gas, power-to-liquid, electrification of heating, electrification of transport. Scenarios are evaluated positively on a yes/no scale for each form of sector coupling they include.

Sustainability

The second dimension of sustainability is represented by the criteria: *land use consideration* and *technology choice*. Land use consideration probes whether the scenario considers the sustainability concerns and environmentally harmful effects of some mitigation strategies, such as the production of biofuels in place of food crops. A qualitatively superior climate protection scenario considers the side effects of mitigation strategies, and as such scenarios that account for sustainable land use are evaluated more positively. Conversely, the criteria technology choice looks directly at whether a scenario includes certain controversial or unsustainable technologies, such as nuclear energy, shale gas, biofuels, biomass, CCS and BECCS. As there is still much discussion concerning the relative benefits or disadvantages of what we deem here to be "unsustainable technology choices", no normative evaluation is done for this criterion.

2.1.3 Guiding question three: What are the contextual circumstances?

The two dimensions included to answer guiding question three are the *national context* and *multilateral dimensions*.

National context

The current national context is an important point of comparison because national circumstances provide the guard rails to determine the specific restrictions under which decarbonisation needs to take place, including essential domestic parameters for the starting point of the transformation. Nationally specific characteristics may impact the type of technologies chosen, the timing and magnitude of the targets being set, etc. Under the national context, we consider both economic and social criteria. Data on these contextual issues must be extracted from external sources (see Table B3 for a list). The wide range of possible indicators determining the national context of a country obliged us to identify and focus on the most relevant ones, which we defined as either social or economic.

Social context

There is a wide variety of indicators available to assess the social context of a country. Some indicators, such as the Gini Coefficient or the Lorenz Curve, measure the inequality distribution within one region (or country) among all social strata. Other indicators, such as unemployment or poverty rates, focus on one specific social stratum. They provide a good insight on the poor and most vulnerable sections of the population, which are highly affected by both the impacts of climate change and by shifts in political decisions. Therefore, they are critical for developing and pursuing long-term climate strategies

From the list of possible social indicators, we have identified unemployment and poverty[25] rates as proxies for the definition of the current social context in the country. Relatively high unemployment and/or poverty can serve as an indication for potential political opposition to the adoption of ambitious climate scenarios but can also signal the need for a transformation strategy that needs to pay particular attention to transitions that focus on job generation opportunities and vocational training programmes to support both social and climate objectives. The criteria catalogue rates the unemployment rate of a country in comparison to the EU average (7.1% in March 2018) on a scale from 1 to 5. If the unemployment rate is similar to EU average (6.1% - 8.1%), it is rated 3/5. An unemployment rate between 4.1% and 6.1% is rated 4/5 and an unemployment rate of 4% or below is rated 5/5. High unemployment rates receive a

[25] The AROPE rate is a headline indicator used to monitor progress on the EU 2020 Strategy poverty target.

low ranking. If the unemployment rate is between 8.1 and 10.1%, it is rated 2/5; unemployment rates above 10.1% are rated 1/5.

The criteria catalogue also uses the APROPE rate defined by the European Commission, which measures the amount of people either at risk of poverty, severely materially deprived or living in a household with a very low work intensity. Individual APROPE rates are evaluated on a five-point scale, similar to the evaluation scale for the unemployment rate. If the APROPE rate of a specific country is between 21.5% and 25.5% and thus close to EU average (which was 23.5% in 2016), it is rated 3/5. Low APROPE rates are rated high: if the APROPE rate of a country is between 17.5% and 21.5%, it is rated 4/5. If it is below 17.5%, it is rated 5/5. On the contrary, high APROPE rates are rated low: if the APROPE rate is between 25.5% and 30.5%, it is rated 2/5. If it is above 30.5%, it is rates 1/5.

Economic context

The criterion *economic context* breaks out into a variety of indicators: carbon intensity, energy intensity, energy import dependency, RES potential, emissions and GDP share of agriculture, transport and industry sector and the country's credit rating. Carbon and energy intensity are defined as the ratio of GDP (in dollars power purchasing parity, PPP $) to carbon dioxide emissions (tCO_2) or gross inland energy consumption (kg of oil equivalent, kgoe), respectively. Decoupling carbon emissions and/or energy consumption from economic growth can provide economic growth and environmental protection at the same time and may result from improving production processes or from shifting from one (environmentally harmful) product to another. For this reason, these two criteria are of high importance to assessing improvement potential and by extension the quality of the respective scenario. Current values for carbon and energy intensity can be sourced from the Eurostat databases and compared using a five-degree scale based around the EU averages, with a three on the scale pertaining to a range plus or minus 0.5 relative standard deviations (SD) around the EU average (i.e. between 78.5% and 121.5% of the EU average for carbon intensity and 84% and 116% for energy intensity).[26]

Energy import dependence determines a country's reliance on imports of natural gas, solid fuels and petroleum from within or outside the EU and is measured as the percentage of imports in total energy consumption. Energy dependence is a major factor influencing the ability of a country to engage in climate mitigation efforts. A high reliance on energy imports can act as an impetus for domestic renewable energy production or energy efficiency measures.

The share of emissions and GDP from large sectors like agriculture, transport and industry give further indication of a country's economic situation. While these define the starting point for any country embarking on a decarbonisation pathway – and shape the specific road the country may take – they are not included in the normative evaluation. Further insights are provided by the potential for RES. The RES potential becomes important especially in the mid- and long-term future, with the rise of RES shares in total final energy consumption. A country with high RES potential may be able to embark on a decarbonisation pathway more easily than others. RES potential is not only limited to resource availability (e.g. solar irradiation) but also market readiness, investment climate and the structure and political economy of the domestic electricity market. For the analysis we use the 2030 REmap renewable energy potential methodology developed by IRENA. REmap determines RES potential by considering resource availability, access to finance, human resource needs and supply, manufacturing capacity, policy environment, available infrastructure, annual capacity additions, the age of existing capital stock

[26] Relative standard deviation (RSD) is a measurement of how far a given value falls from the mean of a sample taking into account the sample's variability. It is calculated as the sample standard deviation (SD) divided by the absolute value of the sample mean (M) multiplied by 100 (SD/M*100) and is thus expressed as a percentage. We chose to use RSD because it is a more transparent metric than SD.

as well as the costs of technologies. It then provides each country with its potential share of RES in total final energy consumption for 2030 under an "accelerated" renewable production scenario.[27] RES potential is evaluated using a scale based around the EU avg. potential in 2030.

Table B4: Potential external data sources for assessing national context

(Sub) Criterion	Data source
Social context: Long-term unemployment rate	German Federal Statistics Agency, Eurostat
Social context: Poverty rate	Eurostat
Economic context: Carbon intensity	World Bank
Economic context: Energy intensity	World Bank, Eurostat
Economic context: Energy import dependency	World Bank, Eurostat
Economic context: Emissions share of agriculture, transport and industry	World Resources Institute, Eurostat
Economic context: GDP share of agriculture and industry	Eurostat
Economic context: RES potential	IRENA (REmap)
Economic context: Country credit rating	Trading Economics[28]

A country's sovereign credit rating is an additional overarching economic indicator describing the big picture of a country's wellbeing and in particular its access to finance. Rating agencies assess the likelihood of a borrower defaulting on its obligations by using a complex mixture of quantitative and qualitative methods. Analysing the determinants of the credit ratings assigned by two of the leading U.S. agencies Moody's and Standard & Poors, Cantor and Packer (1996), find that the following six main determinants, which the agencies appear to weight similarly, appear to play an important role in determining the final assignments: per capita income, GDP growth, inflation, external debt, level of economic development, and default history (Cantor and Packer, 1996).

Credit ratings have become increasingly important as more and more countries tap international bond markets. The most popular and influential sovereign rating agencies are Fitch, Moody's and Standard & Poors. However, for the criteria catalogue, we decided to use the Trading Economics (TE) credit rating. Unlike the three major credit agencies, the TE credit rating is numerical and thus easier to understand and more insightful when comparing multiple countries. It shows the credit worthiness of a country between 100 (riskless) and 0 (likely to default). The TE credit ranking bases on the ratings from the three major credit rating agencies (each one makes up 20% of the TE credit ranking) mixed with leading economic indicators (20%) and financial markets (20%).[29] The criteria catalogue marks scores above 80 green, scores between 40 and 79 yellow and scores below 40 red.

[27] The REmap 2030 value is compared to a REmap 2030 reference share that represents a business-as-usual projection given countries' current national targets and policies as well as the current state of energy markets.
[28] Trading Economics provides an aggregate metric of the four major international credit agencies—S&P, Moody's, Fitch and DBRS—on a 100-point scale.
[29] For a more detailed description of the TE credit ranking see https://tradingeconomics.com/.

Multilateral dimensions

The multilateral dimensions provide background on geographical scope and broader considerations of the scenario. The *regional coverage* criterion is assessed qualitatively and indicates whether the scenario has solely a national focus or whether it considers local and regional dimensions. There is no evaluation done for this criterion. If a scenario has local, national and regional components then all three should be indicated. The criterion *EU targets and instruments* probes whether a scenario explicitly accounts for EU climate and energy policy and potential developments at the EU level; it is not evaluated. The criterion *imports/exports* measures the degree to which a climate protection scenario takes into account trade between the country in question and the international community—this may but not necessarily be limited to the energy sector. This criterion is evaluated based on the number of economic sectors considered and whether the scenario includes both imports *and* exports.

Table B5: Guiding question three: Criteria and sub-criteria

ID	Criterion name	Scale	Valuation
5	**National context**		
5.1a	Social context: Long-term unemployment rate (in % of population)	0 - 100% EU average in 2017: 3.4%	no valuation
5.1b	Social context: Poverty rate (APROPE rate in % of population)	0 - 100% EU average in 2017: 23.5%	no valuation
5.2a	Economic context: Carbon intensity (kg/PPP $ of GDP)	EU average in 2014: 0.2 kg/PPP $ of GDP	no valuation
5.2b	Economic context: Energy intensity (EUR/kgoe)	EU average in 2016: 8.4 EUR/kgoe	no valuation
5.2c	Economic context: Energy import dependency (% of imports in total energy consumption)	0 - 100% EU average in 2016: 53.6%	no valuation
5.2d	Economic context: Emissions share of agriculture, transport and industry (% of total emissions)	0 - 100% EU averages in 2016 Agriculture: 9.7% Transport: 21.0% Industry: 8.4%	no valuation
5.2e	Economic context: Gross value added of agriculture and industry (% of total gross value added in current prices)	0 - 100% EU averages in 2017 Agriculture: 1.6% Industry:19.7	no valuation
5.2f	Economic context: RES potential (2030 REmap potential)	0 - 100% (no EU average available)	no valuation
5.2g	Economic context: Country credit rating	0 - 100 points (EU average in 2017: 72.3)	no valuation

ID	Criterion name	Scale	Valuation
6	**Multilateral dimensions**		
6.1	Regional coverage	regional / national / local	no valuation
6.2	EU targets and instruments	yes / no	no valuation

6.3	Import/export considerations	very good = imports AND exports multiple sectors; good = imports AND exports one sector;
		okay = imports OR exports one sector;
		poor = no or limited consideration of imports/exports
			very good / good / okay / poor

2.1.4 Guiding question four: Is the scenario based on appropriate and robust methodology?

Different methodological aspects are considered to answer guiding question four. With regard to the appropriateness, these include the data sourcing, the type of study (normative backcasting, explorative forecasting etc.) and the type of modelling (simple accounting framework, more complex modelling approaches including bottom up vs. top-down, optimisation vs. simulation, etc.) used.

The appropriateness of the data sources a study is based on refers to the transparency and the relevance of the study. For a study to be of relevance with regard to the national and international climate policy, it has to take into account the official datasets, in particular the GHG data reported under the UNFCCC protocol and the national energy balances. For a study to be transparent, both its input data and its output data for socio-economic, energy and climate parameters (e.g. annual economic activity, energy consumption and GHG emissions for each sector) should be publicly available. Furthermore, other assumptions driving the results such as implementation of certain policies should be clearly mentioned. Consequently, the data sources of a study are classified as “based on official sources and data fully public” (good), “based on official sources and key data public” (okay) or “non-official sources or non-public scenario data” (poor).

With regard to the type of study, we follow the classification of scenarios by Börjeson et al. (2006).[30] There, scenarios are classified as either explorative, i.e. looking at what would happen under the assumption of certain conditions and/or actions, or normative, i.e. leading to a certain endpoint that is chosen based on normative considerations. Explorative scenarios are further split up into external and strategic scenarios. Explorative climate-protection scenarios will usually belong to the latter category, i.e. looking at the amount of emission reductions achieved by strategic actions. Normative scenarios are further characterized as either transforming or preserving. While preserving scenarios assume that today’s values and lifestyles will persist, transforming scenarios make normative choices also with regard to future values and lifestyles. In consequence, the type of study is classified as “explorative”, “normative preserving” or “normative transforming”. As we assume no general preference for a type, no valuation is foreseen.

The type of modelling used is classified with regard to four dimensions: modelling and forecasting approach as well as temporal and geographical scale applied. There are different

[30] Börjeson L, Höjer M, Dreborg KH, Ekvall T, Finnveden G (2006): Scenario types and techniques: Towards a users guide. Futures 38:723–739.

approaches to the modelling of energy supply and demand of an economy, which is a central part of climate protection scenarios. A general equilibrium model covers the total economy and considers the macroeconomic consequences of a climate protection pathway. An energy system model considers only the parts of the economy with a direct relation the supply and use of energy assuming that there is a partial equilibrium with regard to the remaining economy. An agent-based bottom-up model looks at each sector individually and mimics the microeconomic decisions by the sectoral actors, in particular their investment decisions and preferences with regard to energy carriers. Finally, some studies do not apply any of such kind of models, but only use an accounting framework to keep track of evolutions of GHG emission and its driving forces. The forecasting approach refers to the question how the model evolves a system into the future. While simulation models consider the system's behaviour under certain external conditions, optimisation models design the system pathways based on the maximisation of a certain target function. The optimisation can be based on perfect foresight about the future development ("intertemporal optimisation") or on limited foresight about a fixed time horizon ("myopic optimisation"). Furthermore, there are models that are based only on the annual average of climate and energy variables, while others also consider seasonal or even intraday changes, at least for certain variables such as electricity generation. Taking into account shorter time scales may lead to different conclusions about the required mitigation options. Similar considerations apply to the geographical scale, where the inclusion of sub-national scales enables to reflect regional constraints. In all dimensions of the type of modelling used, combinations of the different approaches may occur within one study. Furthermore, all approaches have certain benefits and drawbacks so that no general valuation of one approach to the other is possible.

With regard to the robustness criterion, the proposed catalogue checks whether or not sensitivity analyses of important assumptions and input parameters are being provided and whether or not socio-economic constraints are taken into account.

Table B6: Guiding question four: Criteria and sub-criteria

ID	Criterion name	Scale	Valuation
7	**Appropriateness**		
7.1	Data sourcing	based on official sources and data fully public / based on official sources and key data public / non-official sources or non-public scenario data	based on official sources and data fully public / based on official sources and key data public / non-official sources or non-public scenario data
7.2	Type of study	normative preserving / normative transforming / explorative	no valuation
7.3	Type of model used	a) agent-based bottom-up model / energy system model / general equilibrium model / accounting framework b) simulation / myopic optimisation / intertemporal optimisation c) hourly / daily / annual resolution d) national / regional resolution	no valuation
8	**Robustness**		
8.1.	Sensitivity analysis	quantitative / qualitative / no	quantitative / qualitative / no

ID	Criterion name	Scale	Valuation
8.2	Socio-economic constraints	quantitative / qualitative / no	quantitative / qualitative / no

In the long time period considered by climate protection scenarios, there is high uncertainty about the development of technology, the society, the economy and environment itself. The scenario approach deals with these uncertainties by focussing on the implications of assumptions about the uncertain developments. Still, there are uncertainties about the system's reaction to the external conditions, so-called modelling uncertainties. In this regard, it is important for climate protection pathways to be robust, i.e. not to be sensitive to the modelling uncertainties. This can be tested by a sensitivity analysis, which varies the central parameters related to the model uncertainties. In the best-practice case, the ranges resulting from a sensitivity analysis are provided by a study (score = good). Most studies only qualitatively discuss the sensitivity of their findings (score = okay), while others do not address the issue at all (score = poor).

The transformation of an economy is a complex issue limited by certain socio-economic constraints such as path dependencies resulting from the infrastructure in place and investment requirements. While explorative studies usually reflect such constraints, some of the normative studies choose an endpoint and assume that the system changes from its current state to this endpoint without taking into account those constraints. In this case, the achievable rate of change can be overestimated. This may entail either that the pathway is implausible or even that the endpoint itself is not chosen in a plausible way. In general, there may still be ways to overcome the constraints, e.g. stranded investments could be compensated in a certain way. Nevertheless, these kinds of consequences of a pathway need to be made transparent. We value the inclusion of such constraints as "good", its qualitative discussion as "okay", and its complete ignorance as "poor".

2.2 Future considerations

Insights drawn from project meetings and workshops highlighted numerous potential modifications and changes to take into consideration for potential future iterations of the catalogue.

First among these was the addition of an "access to energy" or "access to electricity" criterion under the social context dimension. This would be most relevant in international contexts, i.e., outside of the EU, thereby enhancing the catalogue's generalisability to other national contexts and circumstances. The energy access criterion could be measured as a percent of the population with adequate energy access and scored relative to a global baseline, i.e., average. In general, feedback on the catalogue suggested that in the future additional attention should be given to contextual circumstances, such as access to energy but also political acceptance and feasibility as well as resource availability. To date, these have been difficult to work into scenario modelling.

Another point for future consideration is the integration of a "circularity" criterion, meaning a check regarding the way in which circular economy potential has been taken into account in the scenario in question. Its potential added value is evidenced for example by the inclusion of a "circular economy" scenario as a key mitigation option in the European Commission's draft long-term strategy for the EU. This mitigation dimension is then also used to supplement other mitigation options to form one of only two net-zero emissions scenario in the Commission's 2050 vision. [31]

[31] European Commission (2018) Clean Planet for all. A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy" COM(2018) 773.

3 Exemplary application

Table B7 shows an exemplary application of the criteria catalogue to scenarios for two countries, namely Germany and France. While both scenarios seem quite ambitious at first sight, they differ from each other to some extent in each of the assessed dimensions.

Looking at the net GHG reduction targets and/or the per capita GHG targets suggests that both countries' climate protection scenarios can be considered ambitious. However, it also suggests that the German scenario (with 95% reduction in 2050 compared to 2008/2010 levels and a per capita GHG target of 0.8 tCO2e p.c.) is more ambitious than the French (with 84% reduction in 2050 compared to 2010 levels and a per capita GHG target of 1.21 tCO2e p.c.). This may not be the case because the ambition of a scenario depends not only on the headline target, but also on various other criteria such as negative emissions and the national context. Even though both are industrialized countries with relatively low poverty rates and high credit ratings, their national context differs in unemployment rates (to the advantage of Germany) as well as in carbon intensity and import dependency rates (to the advantage of France). The scenarios for the two countries differ in particular because the scenario for Germany includes negative emissions, while the scenario for France does not. This complicates comparison because negative emissions generally make it easier to achieve ambitious emission reductions. However, even without negative emissions the envisaged emission reduction in the German scenario is more ambitious than the one in the French scenario. The same is true for the (absolute) per capita target (0.8 compared to 1.21 tCO_2 p.c.) as well as for the (relative) energy sector (96% compared to 93%) and the renewable energy target (96% compared to 94%). The German scenario is also more detailed in some aspects, as it includes all greenhouse gases as well as different milestones.

Focussing on guiding question two, both scenarios appear quite detailed as they include almost all mitigation options (the German scenario partly misses behavioural change and the French scenario misses sector coupling in the areas of power to liquid (fully) and electrification to transport (partly)). Concerning sustainability, the German study considers land use change, while the French study does not. Both studies include biofuels and biomass, but only the German considers BECCS as well. Shale gas and nuclear are not considered in any of the two scenarios. While the French scenario also excludes CCS completely, the German scenario does so only for electricity generation but allows its use in industry.

A glimpse at the contextual circumstances reveals that poverty rates are low and access to electricity rates are high in both countries, leading to good and very good (respectively) evaluations on these criteria. The unemployment rate in France is considerably higher than the one in Germany, leading to a lower valuation (okay compared to very good). Thus, the social context finds in total some but minor advantages in Germany compared to France. The situation changes when focusing on the economic context. While energy intensity levels are similar in both countries, France does better when it comes to carbon intensity and to energy import dependency. The carbon intensity level of France is 0.11 kg per PPP$ GDP, the carbon intensity level of Germany is 0.19 – leading to a "good" evaluation of France and an "okay" valuation for Germany (data for 2014). Germany's energy import dependency is at 64%, thus considerably higher than the import dependency in France (47%). This leads to a red signal for Germany and a yellow signal for France.

The emissions and gross value added shares of agriculture, transport and industry provide some indication on the economic structure of a country. Data highlights that the share of agriculture and transport are significantly higher in France compared to Germany for both gross value added and emissions. The ratio between emissions and gross value added is identical.[32] These figures indicate that in general, these two sectors are more important in France than in Germany. The opposite is true for the industrial sector, which accounts for a larger share in Germany compared to France for both emissions and gross value added. For industry, it is interesting to notice that the ratio between gross value added and emissions is smaller in Germany than it is in France (i.e. industry in Germany is less emissions intensive per percentage of gross value added). RES potential and the country credit ranking are both slightly more positive in Germany then they are in France. Germany RES potential is estimated to be at 35%, which compares to 30% in France. Both of these RES potentials received a yellow light, indicating an average value. The German country credit ranking is at 100/100, which is excellent. The rating of France is at 90/100, which is still a good value. Both countries received a green light for these values.

Concerning multilateral dimensions, only the import/ export criterion is valuated. Since the German strategy includes both imports and exports for multiple sectors, it receives a green light valuation. The French strategy does not include much detail in this regard, leading to a "red light" valuation. Both studies do not consider EU targets and instruments. The German study covers only the national scale, while the French one also considers the local scale.

Both the German and the French scenario are normative scenarios that derive pathways to a given target. The German scenario is mostly normative preserving in the sense that it assumes that consumption patterns and industry structure do not change unless absolutely necessary to achieve the target. Contrary to that, the French scenario is normative transforming in the sense that the analysis of each sector starts with detailed sufficiency considerations that imply changes of today's consumption patterns and industry structure. Their model setup is very similar: both use bottom-up sector models with annual time scale, national geographic scale and myopic optimisation. In addition, both apply hourly models to cover the balance of electricity production and demand as well as global equilibrium models to analyse macroeconomic impacts such as job creation. With regard to the data sourcing and transparency, both scenarios are based on official and public sources and provide detailed data on the model assumptions and results. For the French scenario, however, the data on carbon emissions is insufficient, as data is provided in the form of a graph and only aggregated over all sectors. Therefore, the French scenario receives a yellow flag with regard to this indicator, while the German scenario receives a green flag.

With regard to the robustness dimension, the German scenario covers socio-economic constraints quantitatively in all the bottom-up sector models, but it shows quantitative results from sensitivity analyses only for a few key parameters focussing on the macroeconomic impacts. Hence, a green flag is attributed to the indicator on socio-economic constraint, and yellow flag is attributed to the indicator on sensitivity analyses. The French scenario is similar in its coverage of sensitivities, as it uses two different models to show the robustness of the macroeconomic impacts but contains only qualitative arguments otherwise. Different from the German scenario, socio-economic constraints are taken into account only for certain aspects such as the French fleet of nuclear power plants, but not in an integrated manner. Therefore, the French scenario obtains a yellow flag for both robustness sub-criteria.

[32] Due to missing data it was not possible to identify values for gross value added from the transport sector in France or Germany.

Table B7: Exemplary evaluation for German and French scenarios

ID	Criterion name	Germany: “Climate Protection Scenario 2050 – second round”	France: “Scenario négaWatt”
	How much ambition is foreseen?		
1	**Ambition**		
1.1a	Net emission reduction target (*incl.* negative emissions)	95%	84%
1.1b	Gross emission reduction target (*excl.* negative emissions)	90%	84%
1.1c	Negative emissions	yes	no
1.1.1	Base year	2010	2010
1.1.2	Timeframe	2008/2010-2050	2010-2050
1.1.3	Milestones (interim targets)	yes	no
1.1.4	Per capita target	0.80	1.21
1.1.5	(Net) Energy-sector target	96%	93%
1.1.6	Paris Agreement compatibility	yes	population-based GHG goal
1.1.7	Considers long term (≥ 2050)	no	no
1.2	Renewable energy target	96%	94%
1.2.1	Timeframe	2008/2010-2050	2010-2050
1.2.2	Milestones and interim targets	yes	yes
1.3	Consumption target	55%	66%
1.3.1	Timeframe	2008/2010-2050	2010-2050
1.3.2	Milestones and interim targets	yes	yes
2	**Scope**		
2.1	Sectoral coverage	very good	very good
2.2	GHG coverage	very good	good
	How will mitigation be achieved?		
3	**Mitigation options**		
3.1	CO2 price in 2050	200	N/A

ID	Criterion name	Germany: “Climate Protection Scenario 2050 – second round”	France: “Scenario négaWatt”
3.2a	Technology focus: Energy efficiency	yes	yes
3.2b	Technology focus: Renewable energy	yes	yes
3.3a	Transition: Behavioural change	partly	yes
3.3b	Transition: Structural change	yes	yes
3.4a	Sector coupling: Power-to-liquid/power-to-gas	yes	no
3.4b	Sector coupling: Electrification of heating	N/A	N/A
3.4c	Sector coupling: Electrification of transport	yes	partly
4	**Sustainability**		
4.1	Land use consideration	yes	no
4.2a	Technology choice: Shale gas	no	no
4.2b	Technology choice: Nuclear	no	no
4.2c	Technology choice: Biofuels	yes	yes
4.2d	Technology choice: Biomass	yes	yes
4.2e	Technology choice: CCS (conventional)	no	no
4.2f	Technology choice: BECCS	yes	no
What are the contextual circumstances?			
5	**National context**		
5.1a	Social context: Long-term unemployment rate (in % of population)	1.6%	4.2%
5.1b	Social context: Poverty rate (APROPE rate in % of population)	19.7%	18.2%
5.2a	Economic context: Carbon intensity (kg/PPP $ of GDP)	0.2 kg/PPP $ of GDP	0.1 kg/PPP $ of GDP
5.2b	Economic context: Energy intensity (EUR/kgoe)	9.0 EUR/kgoe	8.5 EUR/kgoe

ID	Criterion name	Germany: “Climate Protection Scenario 2050 – second round”	France: “Scenario négaWatt”
5.2c	Economic context: Energy import dependency (% of imports in total energy consumption)	64%	47%
5.2d	Economic context: Emissions share of agriculture, transport and industry (% of total emissions)	Agriculture: 7.0% Transport: 17.8% Industry: 6.6% (2016 data)	Agriculture: 16.1% Transport: 27.9% Industry: 9.1% (2016 data)
5.2e	Economic context: Gross value added of agriculture and industry (% of total gross value added in current prices)	Agriculture: 0.8% Industry: 26.1% (2017 data)	Agriculture: 1.7% Industry: 14.0% (2017 data)
5.2f	Economic context: RES potential (2030 REmap potential)	35%	36%
5.2g	Economic context: Country credit rating	100	90
6	**Multilateral dimensions**		
6.1	Regional coverage	national	local, national
6.2	EU targets and instruments	no	no
6.3	Import/exports	very good	poor
	Is the scenario based on appropriate and robust methodology?		
7	**Appropriateness**		
7.1	Data sourcing	based on official sources and data fully public	based on official sources and key data public
7.2	Type of study	normative preserving	normative transforming
7.3	Type of model used	a) agent-based bottom-up + general equilibrium models b) myopic optimisation c) annual resolution, hourly for electricity d) national resolution	a) agent-based bottom-up + general equilibrium models b) myopic optimisation c) annual resolution, hourly for electricity d) national resolution
8	**Robustness**		
8.1.	Sensitivity analysis	qualitative	qualitative
8.2	Socio-economic constraints	quantitative	qualitative

4 List of references

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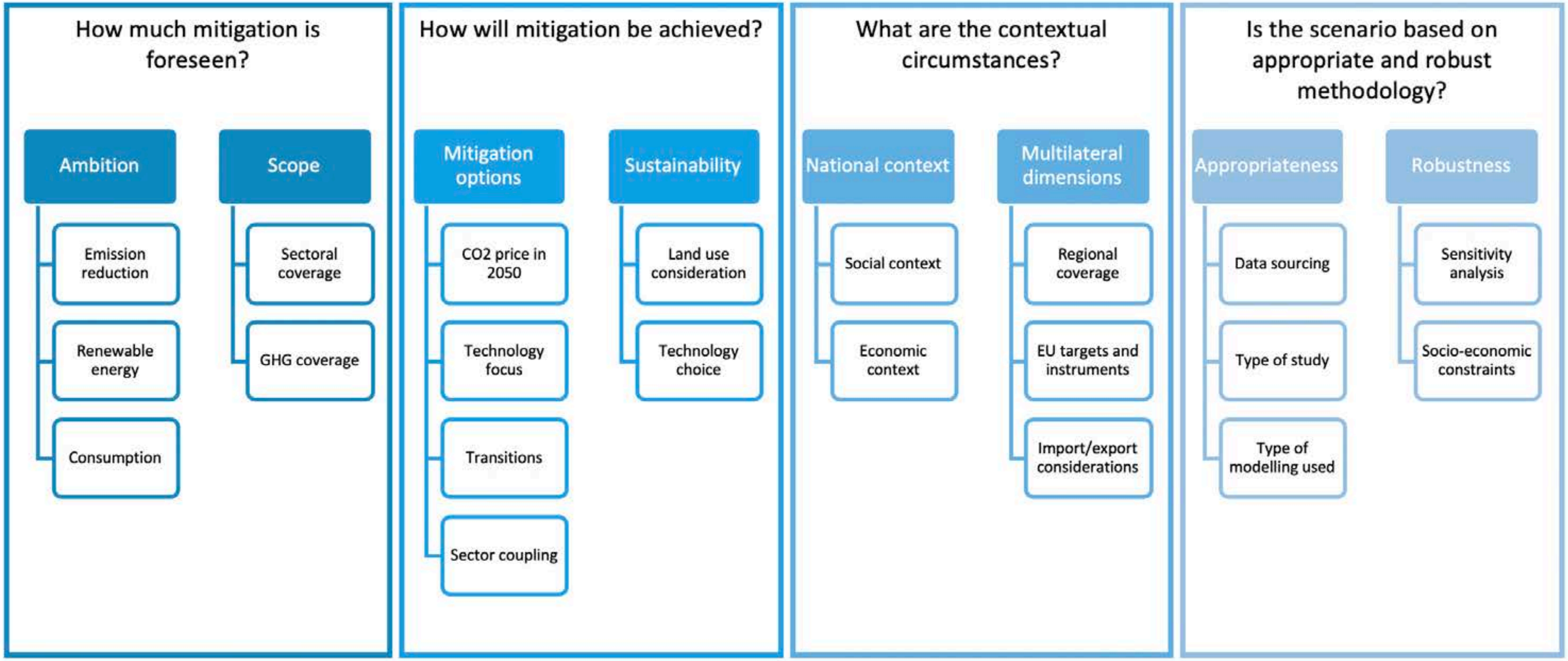
Duscha, V.; Wachsmuth, J.; Donat, L. (2017): Analysis of selected climate protection scenarios for European countries. 10/2017, Umweltbundesamt, Dessau-Roßlau, pp. 1-40.

Duwe, M; Evans, N.; Donat, L. and Schock, M. (2016). Submission of a Final Tool Concept for the Assessment of Low-Carbon Development Strategies. Maximiser, WWF EPO.

European Commission (2018) Clean Planet for all. A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy" COM(2018) 773.

Appendix: Criteria Catalogue

Figure B1: Criteria catalogue



Source: Duwe, Matthias, et al (2021): Criteria for the evaluation of climate protection scenarios. Umweltbundesamt Climate Change Series 57/2021. 37p. (https://www.umweltbundesamt.de/publikationen/criteria-for-the-evaluation-of-climate-protection)

Table B8: Full criteria catalogue, including scale and scoring methodology

ID	Criterion/indicator name	Scale	Valuation
		How much mitigation is foreseen?	
1	**Ambition**		
1.1a	Net emission reduction target (*incl.* negative emissions)	scale: +100% to < -100% compared to base year	< (-80)% / ≥ (-80) and ≤ (-95)% / > (-95)%
1.1b	Gross emission reduction target (*excl.* negative emissions)	scale: +100% to -100% compared to base year	< (-80)% / ≥ (-80) and ≤ (-90)% / > (-90)%
1.1c	Negative emissions	yes / no	yes / no
1.1.1	Base year	open	no valuation
1.1.2	Timeframe	open	no valuation
1.1.3	Milestones and interim targets	yes / no	yes / no
1.1.4	Per capita target	open; tCO2e p.c. or tCO2 p.c.	< 1 / ≥ 1 and ≤ 3 / > 3
1.1.5	(Net) Energy-sector target	scale: +100% to -100% compared to base year	< (-80)% / ≥ (-80) and ≤ (-95)% / > (-95)%
1.1.6	Paris Agreement compatibility	yes / no	yes / no
1.1.7	Considers long term (≥ 2050)	yes / no	yes / no
1.2	Renewable energy target	share of RES in electricity in 2050	< 33% / ≥ 33 and ≤ 66% / > 66%
1.2.1	Timeframe	open	no valuation
1.2.2	Milestones and interim targets	yes / no	yes / no
1.3	Consumption target	scale: +100% to -100% compared to base year	positive / ≥ 0 and ≤ (-30)% / > (-30)%
1.3.1	Timeframe	open	no valuation

ID	Criterion/indicator name	Scale	Valuation
1.3.2	Milestones (interim targets)	yes / no	yes / no
2	**Scope**		
2.1	Sectoral coverage	Energy, buildings, transport, waste, industry, agriculture, LULUCF	all = very good / 4-5 = good / 3 = okay / 0-2 = poor
2.2	GHG coverage	CO2, CH4, N2O, F gases	4 = very good / 3 = good / 2 = okay / 0-1 = poor
		How will mitigation be achieved?	
3	**Mitigation options**		
3.1	CO2 price in 2050	open	no valuation
3.2a	Technology focus: Energy efficiency	yes / partly /no	yes / partly / no
3.2b	Technology focus: Renewable energy	yes = at least three renewable technologies envisioned partly = at least one type no = 0	yes / partly / no
3.3a	Transitions: Behavioural change	e.g. nutrition changes, lifestyle changes, transport mode shift yes = at least three types of behavioural change envisioned partly = at least one type no = 0	yes / partly / no
3.3b	Transitions: Structural change	e.g. industrial processes, sector coupling yes = at least three types of structural change envisioned partly = at least one type no = 0	yes / partly / no
3.4a	Sector coupling: Power-to-liquid/power-to-gas	yes / no	yes / no

ID	Criterion/indicator name	Scale	Valuation
3.4b	Sector coupling: Electrification of heating	yes / no / N/A	yes / no
3.4c	Sector coupling: Electrification of transport	yes / no	yes / no
4	**Sustainability**		
4.1	Land use consideration	yes / no	yes / no
4.2a	Technology choice: Shale gas	yes / no	no valuation
4.2b	Technology choice: Nuclear	yes / no	no valuation
4.2c	Technology choice: Biofuels	yes / no	no valuation
4.2d	Technology choice: Biomass	yes / no	no valuation
4.2e	Technology choice: CCS	yes / no	no valuation
4.2f	Technology choice: BECCS	yes / no	no valuation
		What are the contextual circumstances?	
5	**National context**		
5.1a	Social context: Long-term unemployment rate (in % of population)	0 - 100% EU average in 2017: 3.4%	no valuation
5.1b	Social context: Poverty rate (APROPE rate in % of population)	0 - 100% EU average in 2017: 23.5%	no valuation
5.2a	Economic context: Carbon intensity (kg/PPP $ of GDP)	EU average in 2014: 0.2 kg/PPP $ of GDP	no valuation
5.2b	Economic context: Energy intensity (EUR/kgoe)	EU average in 2016: 8.4 EUR/kgoe	no valuation

ID	Criterion/indicator name	Scale	Valuation
5.2c	Economic context: Energy import dependency (% of imports in total energy consumption)	0 - 100% EU average in 2016: 53.6%	no valuation
5.2d	Economic context: Emissions share of agriculture, transport and industry (% of total emissions)	0 - 100% EU averages in 2016 Agriculture: 9.7% Transport: 21.0% Industry: 8.4%	no valuation
5.2e	Economic context: Gross value added of agriculture and industry (% of total gross value added in current prices)	0 - 100% EU averages in 2017 Agriculture: 1.6% Industry:19.7	no valuation
5.2f	Economic context: RES potential (2030 REmap potential)	0 - 100% (no EU average available)	no valuation
5.2g	Economic context: Country credit rating	0 - 100 points (EU average in 2017: 72.3)	no valuation
6	**Multilateral dimensions**		
6.1	Regional coverage	regional / national / local	no valuation
6.2	EU targets and instruments	yes / no	no valuation
6.3	Import/exports	very good = imports AND exports multiple sectors good = imports AND exports one sector okay = imports OR exports one sector poor = no or limited consideration of imports/exports	very good / good / okay / poor
		Is the scenario based on appropriate and robust methodology?	
7	**Appropriateness**		

ID	Criterion/indicator name	Scale	Valuation
7.1	Data sourcing	based on official sources and data fully public / based on official sources and key data public / non-official sources or non-public scenario data	based on official sources and data fully public / based on official sources and key data public / non-official sources or non-public scenario data
7.2	Type of study	normative preserving / normative transforming / explorative	no valuation
7.3	Type of model used	a) agent-based bottom-up model / energy system model / general equilibrium model / accounting framework b) simulation / myopic optimisation / intertemporal optimisation c) hourly / daily / annual resolution d) national / regional resolution	no valuation
8	**Robustness**		
8.1.	Sensitivity analysis	quantitative / qualitative / no	quantitative / qualitative / no
8.2	Socio-economic constraints	quantitative / qualitative / no	quantitative / qualitative / no

C Appendix: Workshop proceedings – Insights from a comparative analysis of long-term climate policy scenarios

A presentation of results from ongoing research projects

Monday, 01 October 2018, 13:00-16:30

European Climate Foundation, Brussels, Rue de la science 23, 1040

Insights drawn from the panel discussion and audience participation highlighted also potential modifications and changes to take into consideration for potential future iterations of the criteria catalogue:

- The addition of an “access to energy” or “access to electricity” criterion under the social context dimension. This would be most relevant in international contexts, i.e., outside of the EU, thereby enhancing the catalogue’s generalisability to other national contexts and circumstances. The energy access criterion could be measured as a percent of the population with adequate energy access and scored relative to a global baseline, i.e., average.
- Integration of a “circularity” criterion, meaning a check regarding the way in which circular economy potential has been taken into account in the scenario in question.

In general, feedback on the catalogue suggested that in the future additional attention should be given to contextual circumstances, such as access to energy but also political acceptance and feasibility as well as resource availability. To date, these have been difficult to work into scenario modelling.

Figure C1: Insights from the workshop

Source: Ecologic Institute

Table C1: Insights from a comparative analysis of long-term climate policy scenarios – Agenda

Time	Description
13:00	Start of the conversation over light lunch served at the premises

Time	Description
14:00	**Welcome and introduction** *Erica Hope, Senior Associate, European Climate Foundation* *Guido Knoche, German Environment Agency - Umweltbundesamt*
14:10	**Presentation 1:** "Analysing long-term scenarios in a structured fashion: a comparative criteria catalogue and ambitious national scenario examples" *Matthias Duwe, Ecologic Institute & Jakob Wachsmuth, Fraunhofer ISI* followed by reactions from the audience
14:50	**Presentation 2:** "Long-term low-carbon scenarios for Europe: a comparative analysis" *Felix Matthes, Öko Institut & Vicki Duscha, Fraunhofer ISI* followed by reactions from the audience
15:40	Structured discussion with reactions from invited speakers **Tom van Ierland,** HoU C1 Strategy & Economic Assessment, DG CLIMA, European Commission **Nicola Rega**, Climate Change and Energy Director, Confederation of European Paper Industries **Imke Lübbeke**, Head EU Climate and Energy Policy, WWF European Policy Office **Rachel Ward**, Head of Policy, Institutional Investors Group on Climate Change (IIGCC) **Guido Knoche,** Energy Strategies and Scenarios, German Environment Agency - Umweltbundesamt *Moderator: Matthias Duwe, Ecologic Institute*
16:30	Conclusion & end of the workshop

Table C2: Insights from a comparative analysis of long-term climate policy scenarios – List of participants

First Name	Name	Organisation
Ulriikka	Aarnio	Climate Action Network Europe
Shradha	Abt	BASF
Laura	Aho	Finnish Permanent Representation to the EU
Angelina	Bartosik	ePURE
Luc	Bas	IUCN European Regional Office
Aurélie	Beauvais	SolarPower Europe
Carlos	Calvo Ambel	Transport & Environment
Miguel	Castroviejo	Spanish Permanent Representation to the EU
Bert	D'Hooghe	ERT
Vicki	Duscha	Fraunhofer ISI
Matthias	Duwe	Ecologic Institute

First Name	Name	Organisation
Milan	Elkerbout	CEPS
Mona	Freundt	Ecologic Institute
Noriko	Fujiwara	CEPS
Quentin	Genard	E3G
Eva	Gerhards	European Commission, DG Energy
Mariano	Guillen	SolarPower Europea
Ales	Hilcer	Czech Permanent Representation to the EU
Erica	Hope	European Climate Foundation
Mark	Johnston	EU energy policy expert
Natasa	Kacic-Bartulovic	Croatian Permanent Representation to EU
Guido	Knoche	German Environment Agency
Agatha	Kuhn	European Climate Foundation
Sanni	Kunnas	VCI
Linda	Leja	Permanent Representation of Latvia to the EU
Giulio	Longo	Insurance Europe
Anna	Lorant	IEEP
Charles	Low	Insurance Europe
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