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Criteria for the evaluation of climate protection scenarios

Substudy Report

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Criteria for the evaluation of climate protection scenarios

Substudy Report

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Abstract: Criteria for the evaluation of climate protection scenarios

Climate protection scenarios are a key part of long-term climate policy planning, which has been given a further boost by the Paris Agreement. The modelling performed in such scenarios informs the development of 2050 national climate strategies—which themselves serve as roadmaps for the decarbonisation of the economy. By early 2020, all EU Member States were called to deliver some form of a national climate strategy for 2050, but these will likely vary substantially in ambition, scope and content, in large part also due to the different content inputs provided by respective national policy scenarios and emission pathways modelling. This document outlines a catalogue of criteria for the comparative and normative evaluation of long-term climate protection scenarios, both in Europe and internationally.

Kurzbeschreibung: Kriterien zur Evaluierung von Klimaschutzszenarien

Mit dem Übereinkommen von Paris ist das Thema langfristige, strategische Planung für die Erreichung transformativer Klimaschutzziele in den Fokus gerückt. Klimaschutzszenarien spielen eine entscheidende Rolle in der langfristigen Klimaschutzplanung. Die Modellierung—die in solchen Szenarien durchgeführt wird—informiert die Entwicklung von 2050 Klimaschutzstrategien, die der Politik als Richtschnur für die Entwicklung hin zu einer klimaneutralen Gesellschaft dienen können. Alle EU Mitgliedstaaten waren aufgefordert, bis Anfang 2020 solche nationale Klimaschutzstrategien vorlegen. Aufgrund von inhaltlichen und methodischen Unterschieden der entsprechenden Klimaschutzszenarien und deren zugrundeliegenden Modellierungen, unterscheiden sich diese Strategien wesentlich in Hinsicht auf Ambition, Umfang und Inhalt. Um dieser Vielfalt Struktur zu geben, beschreibt dieser Bericht einen Kriterienkatalog für die vergleichende und normative Auswertung langfristiger Klimaschutzszenarien, so wohl in Europa als auch weltweit.

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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
ETS	Emissions trading system
EU	European Union
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
UNFCCC	United Nations Framework Convention on Climate Change
WISE	Warsaw Institute for Economic Studies

Summary

The lead up to and adoption of the Paris Agreement in 2015 served as a clear catalyst for long-term climate planning. More specifically, Article 4.19 of the agreement calls on all parties to "strive to formulate and communicate long-term low greenhouse gas emission development strategies" with a view towards 2050. The EU's commitment to the long-term perspective of the Paris Agreement 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 of January of 2020. By the end of 2018, approximately half of EU Member States have delivered some form of a national climate strategy for 2050.

Nevertheless, the state of national climate planning differs substantially in ambition, scope and content due to a myriad of reasons. First, some countries are in the early stages of development, and others are in the process of preparing background analysis and organising the planning exercise. Additionally, while national circumstances and political acceptance may influence the general ambition of long-term climate action, domestic resource availability and renewable energy potential can influence which mitigation options are available for a country to choose from. Even the scientific basis that informs policy making can differ from country to country. Climate protection scenarios are a key part of long-term climate policy planning. The modelling performed in these studies informs policy makers and stakeholders in the development of 2050 national climate strategies, and thus the fundamental importance of climate protection scenarios cannot be overstated.

This document outlines a catalogue of criteria for the systematic evaluation of long-term climate protection scenarios developed in the context of the UBA-funded project, "Supporting the development of ambitious climate change scenarios in Europe." Catalogue development was informed by previous work done compiling data on six existing scenarios as well as insights from project workshops. The criteria were chosen based on four guiding questions pertaining to the level of mitigation foreseen, how that mitigation is achieved, contextual circumstances and the methodological strength of the underlying modelling. Importantly, the catalogue allows for a comparative scoring of scenarios using a 'nested' descriptive-normative structure—many elements are not only descriptive but also indicative of a scenario's quality.

Criteria are organised along eight dimensions. *Ambition* and *scope* investigate the level and timeframe of the emission reduction pathways as well as their sectoral coverage. The *mitigation options* dimension probes which technologies and strategies are employed to meet the targets while the *sustainability* dimension determines whether the scenario considers the sustainability concerns and environmentally harmful effects of some mitigation strategies. The two contextual dimensions, *national context* and *multilateral dimensions,* look at the social and economic circumstances of the country and whether cross-border issues, such as imports and exports are taken into consideration. Finally, the dimensions *appropriateness* and *robustness* check the methodological strength of the scenario's underlying modelling.

An exemplary application of the catalogue to a German and a French long-term scenario study shows how the criteria can be used in practice to compare and assess the validity of climate protection scenarios. The two studies differ foremost in terms of their comprehensiveness—the German case includes more detailed information on mitigation pathways by considering negative emissions and LULUCF. The mitigation strategies modelled in each scenario were strikingly different with the French case prioritising behavioural and structural change. A comparative analysis of climate protection scenarios, such as the preliminary assessment described here, is helpful to highlight the numerous pathways that exist to achieve emissions reductions depending on national circumstances.

Zusammenfassung

Die Vorbereitung und Verabschiedung des Pariser Abkommens im Jahr 2015 hat als Katalysator für langfristige Klimaplanung gewirkt. Insbesondere in Artikel 4.19 des Abkommens werden alle Parteien aufgefordert, "langfristige Strategien für niedrige Treibhausgasemissionen zu formulieren und zu kommunizieren", mit Blick auf 2050. Die Unterstützung der EU für die langfristige Perspektive des Übereinkommens von Paris spiegelt sich in Artikel 15 der Governance Verordnung der Energieunion (EU 2018/1999) wider, die die Mitgliedstaaten verpflichtet, bis zum 1. Januar 2020 langfristige Klimaschutzstrategien zu entwickeln. Bis Ende 2018 hatte etwa die Hälfte der EU-Mitgliedstaaten eine nationale Klimastrategie für 2050 vorgelegt.

Dennoch unterscheidet sich der Stand der nationalen Klimaplanung in der EU aus mehreren Gründen bezüglich Anspruch, Umfang und Inhalt erheblich. Das hat verschiedene Gründe. Offensichtlich befinden sich Länder in unterschiedlichen Stadien des Planungsprozesses. Dazu kommen unterschiedliche nationale Gegebenheiten und politische Akzeptanz für langfristige Klimaschutzziele, die die nationalen Prozesse beeinflussen können. Länderspezifische Kontexte wie die Verfügbarkeit nationaler Ressourcen und das Potenzial erneuerbarer Energien bestimmen zudem, welche GHG Minderungsoptionen einem Land zur Auswahl stehen. Auch Qualität und Quantität der wissenschaftlichen Analysen, die als Input für die Politikgestaltung zur Verfügung stehen, kann von Land zu Land unterschiedlich sein.

Klimaschutzszenarien sind eine wichtige Grundlage für langfristige Klimaschutzplanung. Die in entsprechenden Studien durchgeführte Modellierung ist eine zentrale Informationsquelle für Entscheidungsträger und Interessenvertreter bei der Entwicklung nationaler Klimaschutzstrategien für das Jahr 2050. Ihre Rolle und ihr Einfluss sollten entsprechend nicht unterbewertet werden.

In diesem Bericht wird ein Kriterienkatalog zur systematischen Bewertung langfristiger Klimaschutzszenarien skizziert, der im Rahmen des vom UBA geförderten Projekts "Unterstützung bei der Entwicklung ambitionierter Klimaschutzszenarien in Europa" entwickelt wurde. Die Katalogerstellung wurde durch frühere Arbeiten zur Zusammenstellung von Daten aus sechs bestehenden Szenarien sowie durch Erkenntnisse aus Projektworkshops unterstützt. Die Kriterien wurden auf der Grundlage von vier Leitfragen ausgewählt, die sich auf den Grad der vorgesehenen Minderung, die Art und Weise, wie diese Minderung erreicht wird, die Kontextbedingungen und die methodische Stärke der zugrunde liegenden Modellierung beziehen. Wichtig ist, dass der Katalog eine vergleichende Bewertung von Szenarien mit einer "verschachtelten" deskriptiv-normativen Struktur ermöglicht - viele Elemente sind nicht nur deskriptiv, sondern auch ein Indikator für die Qualität eines Szenarios.

Die Kriterien sind in acht Dimensionen unterteilt. *Ambition* und *Umfang* untersuchen das Niveau und den Zeitrahmen der Emissionsminderungspfade sowie deren sektorale Abdeckung. Die Dimension *Minderungsoptionen* untersucht, welche Technologien und Strategien zur Erreichung der Ziele eingesetzt werden, während die *Nachhaltigkeitsdimension* bestimmt, ob das Szenario die Nachhaltigkeitsbelange und umweltschädlichen Auswirkungen einiger Minderungsstrategien berücksichtigt. Die beiden übergreifenden Dimensionen, *nationaler Kontext* und *multilaterale Dimensionen*, betrachten die sozialen und wirtschaftlichen Gegebenheiten des Landes und die Frage, ob grenzüberschreitende Fragen wie Importe und Exporte berücksichtigt werden. Schließlich überprüfen die Dimensionen *Angemessenheit* und *Robustheit* die methodische Stärke der unterliegenden Modellierung des Szenarios.

Eine exemplarische Anwendung des Katalogs auf je eine deutsche und eine französische Langzeitstudie zeigt, wie die Kriterien in der Praxis zum Vergleich und zur Bewertung der Validität von Klimaschutzszenarien herangezogen werden können. Die beiden Studien unterscheiden sich vor allem in ihrer Vollständigkeit—der deutsche Fall enthält detailliertere Informationen über Minderungspfade unter Berücksichtigung negativer Emissionen und LULUCF. Die in jedem Szenario modellierten Minderungsstrategien waren sehr unterschiedlich, wobei der französische Fall den Verhaltens- und Strukturwandel priorisierte. Eine vergleichende Analyse von Klimaschutzszenarien, wie die hier beschriebene Vorabbewertung, ist hilfreich, um die zahlreichen Wege aufzuzeigen, die es gibt, um je nach nationalen Gegebenheiten Emissionsreduktionen zu erreichen.

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 thus 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 1), which were described in depth in the report "Analysis of selected climate protection scenarios for European countries", published in 2017.[1] 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 1: Overview of country studies to be evaluated

Country	Organisation/Name of study	Year
France	Association négaWatt, *Scenario négaWatt 2011 – 2050*	2013
German y	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.

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

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).[2]

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.

[2] 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 four key guiding questions about climate scenarios 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[3]. 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 1 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.[4] 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 more

[3] Ibid.
[4] 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).

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)[5] 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,

[5] 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.[6]

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.[7] 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 2: 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

[6] 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.
[7] 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. and several 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 3: 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 3 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[8] 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

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

4/5 and an unemployment rate of 4% or below is rated 5/5. High unemployment rates receive a 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).[9]

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

[9] 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.

environment, available infrastructure, annual capacity additions, the age of existing capital stock 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.[10] RES potential is evaluated using a scale based around the EU avg. potential in 2030.

Table 4: 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[11]

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%).[12] The criteria catalogue marks scores above 80 green, scores between 40 and 79 yellow and scores below 40 red.

[10] 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.
[11] 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.
[12] 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 5: 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).[13] 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

[13] 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 6: 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 (good). Most studies only qualitatively discuss the sensitivity of their findings (okay), while others do not address the issue at all (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 percentage 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 scenarios in the Commission's 2050 vision. [14]

[14] 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 7 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.[15] 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.

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

Table 7: 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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A Appendix: Criteria Catalogue

Figure 1: Criteria catalogue

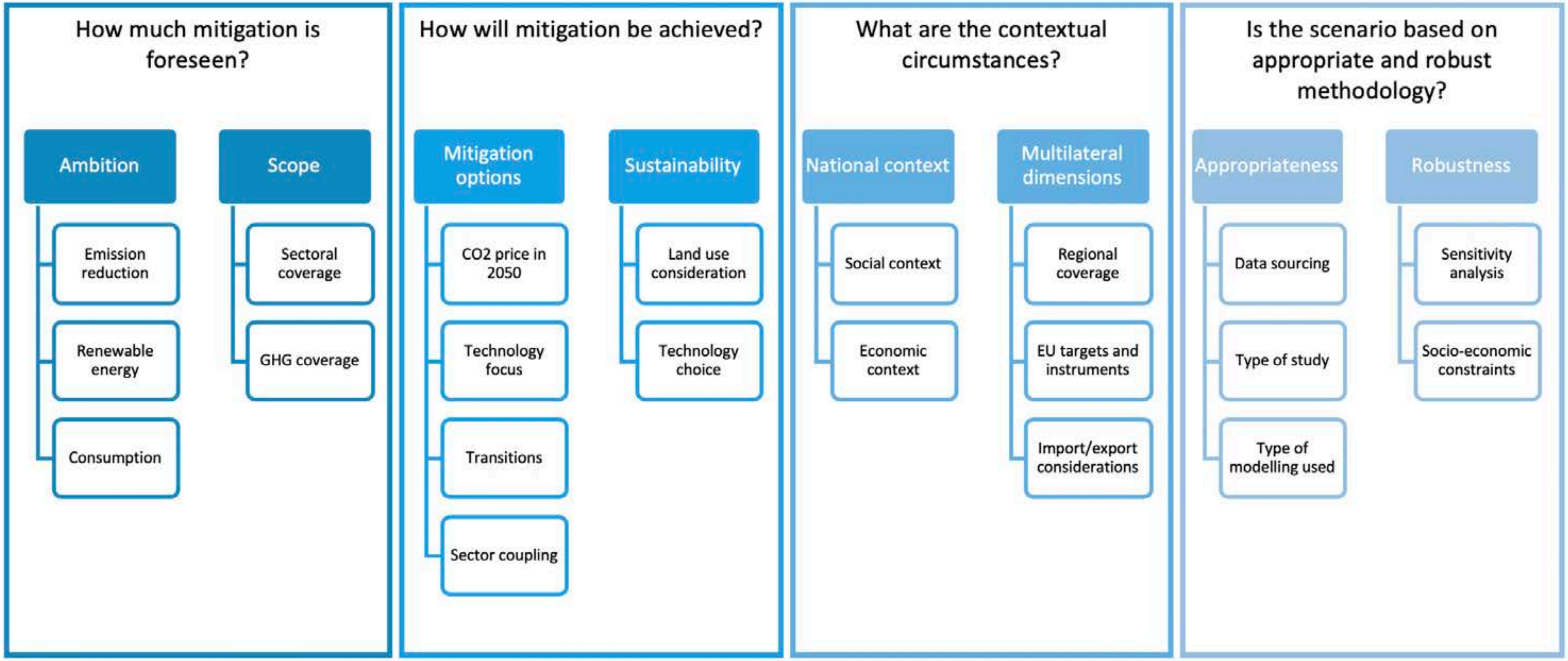

Table 8: Full criteria catalogue, including scale and scoring methodology

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; tCO_2e p.c. or tCO_2 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