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# A review of the bandwidth and environmental discourses of future energy scenarios: Shades of green and gray

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A B S T R A C T

Energy scenarios are often used to investigate various possible energy futures and reduce the uncertainty that surrounds energy transition. However, scenario construction lacks consistent and adequate methodological standards, resulting in limited insight into the actual bandwidth covered by current energy scenarios and whether various perspectives on future energy development pathways are all adequately represented. Our research deployed a non-mathematical clustering approach to identify general trends in future energy scenarios and assess the role of Cornucopian and Malthusian oriented world views therein. We found that the futures communicated in quantified future energy scenarios overlap to a large extent and represent only a narrow bandwidth of moderate world views. We argue that the underrepresentation of extreme representations of world views and environmental discourses in energy scenarios skews the overall outlook on possible energy futures. This implies that scenario-informed policy design and decision-making risks bias towards the status-quo.



**Contents**



## 1. Introduction

Driven by the double bind of declining fossil fuel reserves and concern over greenhouse gas emissions, the global energy system is going through a gradual transition towards a new energy paradigm. This energy transition may involve, amongst others, a shift away from fossil energy sources towards an energy supply involving a larger share of energy from renewable sources, a more important role for energy efficiency, or a combinations of those [1–4]. The outlook on the magnitude of those changes is fraught with uncertainty. Using scenarios to investigate various possible energy futures may reduce some of the uncertainty associated with energy transition, facilitate future-proof strategic policy-making, and support the diffusion and integration of sustainable energy technology [5–8].

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Scenario planning is a structured method to explore alternative futures resulting from different choices in current and future strategic decision making [9]. In recent years, the use of scenarios as a strategic planning tool has become a widespread practice in a broad range of fields, including energy-related science, business and policy [10]. However, an absence of methodological standards has led to a proliferation of diverse approaches to and applications of the concept of scenario planning. A number of suboptimal practices in the development and use of scenarios appears to persist, such as historic determinism [11] and insufficient attention to institutional constraints and overemphasis of best-case policy options [7]. Some authors argue the frequent use and abuse of scenarios is a cause for concern as it may weaken the value of scenario planning techniques [12,13]. One of the objectives of this study is to assess whether effects of suboptimal scenario practices are reflected in the characteristics and trends prevailing in current future energy scenarios.

Effective scenario planning benefits from the exploration and comparison of diverse alternatives and multiple extremes [14]. With regard to energy and sustainability, such extremes are represented by two prevalent opposing environmental discourses: Cornucopian and Malthusian. Cornucopians perceive the world as a place of infinite resources, either tangible or intangible. The Malthusian discourse is the polar opposite: the world is considered a finite and fragile body that requires careful management to ensure proper sustainability (see [15] for a comprehensive background of energy and sustainability discourses).[1] Environmental discourses and associated world views may affect the quintessence of future energy scenarios. For instance, scenarios providing an optimistic perspective on the potential of technology advancement, may result from world views associated with the Cornucopian discourse. Malthusian oriented world views may result in scenarios that, for example, put stronger emphasis on finding sustainable equilibrium states.

Environmental discourse labels are often not self-applied, and the willingness of scenario authors to explicate discourse support or associated world views, varies. As such, scenario authors may not always be actively aware of how their world views affect the tone of and sentiments within scenarios. Many future energy scenario publications only implicitly incorporate aspects of different world views and associated environmental discourses by defining and discussing multiple scenarios: one 'business-as-usual' reference scenario and one or more alternatives that highlight the prospects of deviating from a 'business-as-usual' path. With this study, we aim to make the role of environmental discourses in current future energy scenarios more explicit.

The combination of an extensive and ever growing body of future energy scenario publications with heterogeneous scenario characteristics and inconsistent or unclear methodological approaches hampers a sound understanding of which futures are actually being communicated and how they relate to one another. Over the past decade, scholars have a posteriori defined scenario typologies to improve the overview and shared understanding of scenarios used in futures studies [16–18]. One approach differentiates scenarios according to three different aspects: project goal, process design and scenario content [18]. For each of these aspects, several underlying parameters add further detail to a scenario's typological fingerprint. These include (but are not limited to) inclusion of norms, vantage point, time scale, quantitative or qualitative data and temporal nature. An alternative approach is to categorize scenarios as predictive, explorative or normative/backcasts. Predictive scenarios are either forecasts or what-if-scenarios; explorative scenarios can be external or strategic; normative scenarios include preserving or transforming scenarios [16]. None of these typologies, however, explicitly take into account the author's background and world views, or include explicit means for inter-scenario comparisons.

Several recent studies of energy and climate-oriented scenarios include inter-scenario comparisons, and have sought to explain the differences and similarities between various future energy scenarios (e.g. [6,7,19–23]). Some of those meta-analyses focus primarily on scenario parameters and causal relationships between variables that distinguish scenarios from another (e.g. [6,19,22,23]). Of these, [6] is the only one considering a substantial number of different scenarios. Their findings include that future energy scenarios differ in how renewable energy is handled, and that they report a broad range of futures for renewable energy. Other studies, such as [7,20,21], provide more detailed analyses of underlying drivers of trends and implicit developments. Findings from those studies include critiques on scenario processes and more nuanced views about potential future developments. For instance, [20] conclude that a lack of attention to supply-side parameters results in unrealistic visions on energy futures. According to [7], insufficient attention to institutional constraints and overemphasis of best-case policy options weakens the value of energy scenarios. In [21], the complexity of future energy system development is highlighted to emphasize the difficulty to accurately foresee such developments.

The insights gained from earlier studies notwithstanding, existing energy scenario reviews and meta-analyses tend to use an inward perspective. Outward perspectives and more high-level views of energy futures are generally missing. Moreover, little attention has been paid to what general trends are present in energy scenarios at large and how those relate to prevailing energy-related world views and environmental discourses. As a result, whether the bandwidth covered by the current body of energy scenarios represents all perspectives on future energy development pathways, remains unclear. This study reviews a large set of diverse future energy scenarios in a context of (extreme manifestations of) environmental discourses.

This study adds to the current body of energy scenario meta-analysis by providing a novel perspective on future energy scenarios at large. The novelty of this study consists of two aspects. First, we provide an outward-looking, high-level review of a large and characteristically diverse set of recently published long-term future energy scenarios. Second, our environmental discourses context improves the understanding of the role and influence of world views on the bandwidth of future energy scenarios. We use a non-mathematical scenario clustering approach to identify and evaluate general trends in quantified energy scenarios with a global outlook and a long-term time horizon. These trends are then explained in a Malthusian-Cornucopian dichotomy context. We investigate the variance within and between (clusters of) future energy scenarios relative to extreme manifestations of environmental discourses to evaluate the bandwidth of energy futures presented in current scenarios.

The structure of this paper is as follows. Section 2 provides an overview of the methodology used in this study, including details on the scenario clustering approach. Section 3 outlines the clusters of future energy scenarios we identified. Section 4 provides a quantitative analysis of the identified clusters and describes general trends and bandwidths discernible therein. Section 5 expands on the observed general trends and bandwidths in an

[1] Dryzek [15] applies the Promethean/Survivalism terminology to represent different environmental discourses. To a large degree, the distinction between Promethean and Survivalism discourses reflects the differences between Cornucopian [15,p. 51] and Malthusian [15,p. 29] perspectives on energy and sustainability, respectively. I prefer to use the Cornucopian/Malthusian terminology, for it better conveys whether energy futures thinking is subject to certain physical or non-physical limits.

environmental discourse context. Section 6 provides a discussion on this study. Section 7 presents our conclusions.

## 2. Methods

This study focuses on the identification and analysis of general trends in current future energy scenarios. The first step in the identification of general trends involves clustering a large set of scenarios according to temporal dynamics of specific aspects of scenario's reported energy mix. To adequately capture the dynamic behavior of the developments reported in energy scenarios, we propose a non-mathematical clustering approach. That approach breaks down into five consecutive procedures: literature collection, data preparation, data analysis, scenario cluster synthesis and scenario cluster analysis. The first three procedures are foremost preparatory, and briefly explained below. Cluster synthesis and cluster analysis follow in the subsequent sections.

### 2.1. Literature selection

To find the general trends in current future energy scenarios, this study relies on data derived from a large number of scenarios. By increasing the scenario sample size, the effect of individual scenarios on the big picture becomes smaller. With the aim of creating an as large as possible pool of scenarios to draw data from, we generated the list of scenarios in a two-stage process. First, we compiled an initial 'long list' of literature by using the literature search engines of Web of Science [24] and Google Scholar [25] in combination with suggestions offered by project participants with a consultancy background. No a priori selection criteria were applied to the publications found in this stage. This led to a long-list containing 58 publications. Second, we applied the following set of selection criteria to reduce the list of publications to those which offered usable data: geographical scale, time horizon, and data availability. In terms of geographical scale, scenarios selected for further processing included only those that offered at least a global perspective in order to transcend current geopolitical and geophysical limitations, and to reflect the global nature of energy and environmental issues. To ensure scenarios included sufficient time for a broad range of developments in the energy sector, we selected only the scenarios for which the time horizon extends to the year 2030 or beyond. With regard to data availability, we also filtered for scenarios that provided data in accordance to the minimal requirements of the approach used in this study: quantified and absolute data for a primary and/or final energy mix subdivided into at least oil, coal, gas, nuclear energy and renewables. The combined application of these selection criteria reduced the list to 14 publications, encompassing a total of 30 usable scenarios. Table 1 in Section 3 provides an overview of the selected scenarios and a number of key characteristics.

### 2.2. Data preparation

Considering the focus of this study on energy futures outlined in published literature, we exclusively relied on the data provided in those publications. In those publications, data was available in tables, graphs or a combination of both. For data reported in tables, the accuracy of the extracted values was directly linked to the rounding accuracy of the provided values. The accuracy of data extracted from graphs was dependent on the resolution of the graph in the original, digitally available publication and the accuracy of the image analysis software used in the extraction process. Scenarios that provided data both in tables and in graphs

**Table 1**
Overview of investigated scenarios, key parameters/characteristics, and clustering.

| Cluster | Study | Scenario title | Back-ground | Time horizon | Process[a] | Ethic[b] |
|---|---|---|---|---|---|---|
| 'Green' | Azar et al. [27] | n/a | Academia | 2100 | B | N |
| | BP [28] | n/a | Business | 2030 | F | D |
| | Greenpeace [29] | Energy [R]evolution | NGO | 2050 | F | N |
| | Greenpeace [29] | Advanced Energy [R]ev. | NGO | 2050 | F | N |
| | IEA [26] | 450 ppm Policies | IGO | 2035 | B | N |
| | IPCC [30] | A1B-AIM | IGO | 2100 | F | D |
| | IPCC [30] | A2-ASF | IGO | 2100 | F | D |
| | Krewitt at al. [31] | 2C | Academia | 2050 | B | N |
| | Leimbach et al. [32] | 400 ppm | Academia | 2100 | B | N |
| | OPEC [33] | n/a | Business/ IGO | 2035 | F | D |
| | Shell [34] | Scramble | Business | 2050 | F | D |
| | Shell [34] | Blueprints | Business | 2050 | F | D |
| | WWF [35] | n/a | NGO | 2050 | B | N |
| 'Gray' | EIA [36] | Reference | IGO | 2035 | F | D |
| | EIA [36] | High Oil Price | IGO | 2035 | F | D |
| | EIA [36] | Low Oil Price | IGO | 2035 | F | D |
| | ExxonMobil [37] | n/a | Business | 2030 | F | D |
| | Greenpeace [29] | Reference | NGO | 2050 | F | N |
| | IEA [38] | Gas | IGO | 2035 | F | D |
| | IEA [38] | New Policies WEO2010 | IGO | 2035 | F | D |
| | IEA [26] | Current Policies | IGO | 2035 | F | D |
| | IEA [26] | New Policies | IGO | 2035 | F | D |
| | IPCC [30] | B1-IMAGE | IGO | 2100 | F | D |
| | IPCC [30] | B2-MESSAGE | IGO | 2100 | F | D |
| | Krewitt et al. [31] | Reference | Academia | 2030/ 2050 | B | N |
| | Leimbach et al. [32] | Reference | Academia | 2100 | B | D |
| | European Commission [39] | Reference | IGO | 2050 | F | D |
| | European Commission [39] | Carbon Constraints | IGO | 2050 | F | D |
| | European Commission [39] | Hydrogen | IGO | 2050 | F | D |
| | Shell [40] | Signals & Signposts | Business | 2030 | F | D |

[a] F: forecasting; B: backcasting.
[b] N: normative; D: descriptive.

allowed for a comparison of the accuracy of both extraction methods. We found the error margin related to data extraction fairly minimal and acceptable with respect to the study's purpose.

The time intervals and horizons for which data was reported varied between different scenarios. Most scenarios report data on a five- or ten-year time interval. Some scenarios do not report data on a fixed time interval, or only report for a handful of selected years, e.g. 2010, 2020 and 2035. The absence of a uniform data reporting time interval across the set of scenarios impedes sound comparison of different scenario's data. Therefore, wherever required we used linear interpolation to rearrange a scenario's dataset into a 5-year time interval. To keep to the original dataset's time horizon, we did not extrapolate. Most scenarios used the year 2050 as a time horizon. Some scenarios limited the time horizon to 2030 or 2035, and others extended their horizon to the year 2100. Those time horizons were not adapted to a standard end year for two reasons. First, choosing the earliest time horizon out of the set of scenarios as the standard and clipping additional years of longer datasets would severely reduce the available data and detract from the long-term outlook purpose of this study. Second, extending shorter datasets to match the longer time horizons was considered inappropriate as it would imply adding unfounded and most likely incorrect data to an existing dataset through extrapolation.

Another aspect for which scenarios differ between one another is the units in which energy is expressed. Across scenarios, energy was found to be expressed in tons of oil equivalent (toe), British thermal units (Btu) or the SI-unit joules (J). To normalize these various reporting units, all data was converted to joules using the standard IEA conversion factors: 1 toe equals $4.1868*10^{10}$ J, and 1 Btu equals $1.0551*10^{3}$ J [26]. For improved readability, this paper reports those values in exajoules (EJ, $10^{18}$ J). A selection of key data used in this study is provided in Table A1 in Appendix A.

All scenarios report the calculated future energy mix in terms of absolute primary energy supply, but to better communicate the dynamics of the presented future energy mixes we converted the given figures to annual growth rates. Growth rates capture the direction of trends and amplify subtle changes therein. Moreover, data for both absolute and relative energy mixes can be recalculated into average annual growth rates. Such conversion reduces different data bandwidths between and within scenarios to a single uniform standard, thus allowing for a more reliable comparison. The data provided in the scenarios were recalculated to uniform growth rates using the compound annual growth rate (CAGR) method:

$$\mathrm{CAGR}(t_1,t_2) = (V_{t2}/V_{t1}) \wedge (1/(t_2 - t_1)) - 1$$

where $t_1$ = starting year of time frame $t_2$ = end year of time frame $V_{t1}$ = data value for the starting year of the time frame $V_{t2}$ = data value for the end year of the time frame

The compound annual growth rate method results in a growth percentage that is constant for every year in the time frame. Start and end years of a time frame were chosen such that the resulting time frame spans exactly the period between two available data points.

### 2.3. Data analysis & cluster composition

Of key interest for this study was the manifestation of the transition towards a more sustainable energy system, or energy transition as it is often referred to. To illustrate different perspectives on this subject, we focused on two aspects for which the scenarios were sorted: the share of renewables in the energy mix, and the overall total global primary energy demand. The share of renewables in the energy mix was a key focus aspect since it reflects the essence of energy transition: a shift away from a conventional, fossil-fuel dominated energy mix towards an energy mix in which sustainable, renewable energy sources play a greater role. Positive growth rates for the share of renewables imply growth in the share of renewable energy relative to energy from non-renewable sources, whereas negative growth rates imply a declining share of renewables relative to non-renewables. Primary energy demand served as the other key focus aspect since it reflects the role of energy efficiency, and to some extent, technologic advances as part of a transition towards a more sustainable energy system. Positive or negative growth rates for total primary energy demand are independent of the composition of the energy mix and relate to an absolute increase or decrease, respectively, of the total amount of energy consumed on a global scale. Further analysis and comparison of the scenario's datasets involved visual inspection of the growth rate time series of the share of renewables and the total primary energy demand rendered in line charts.

To identify different clusters of scenarios, we applied a two-level classification approach in which scenarios are classified using the growth rate time series of the two key focus aspects, the share of renewables and primary energy demand. For each key focus aspect we defined thresholds to separate the set of scenarios into subsets of distinct growth rate ranges. That threshold was chosen such that it differentiates between scenarios with negative, zero or low growth rates, and scenarios with mostly medium or high growth rates. The scenarios were then assigned a discrete 'low' or 'high' label according to the magnitude of the average growth rate relative to the differentiation threshold. For the share of renewables, the set of scenarios could be split into 'low' and 'high' categories using an annual growth percentage of 1,5% as a threshold. Scenarios for which the average annual growth rate was less than 1,5% were labeled 'low'. Scenarios with average annual growth rates over 1,5% were labeled 'high'. For the primary energy demand aspect, a threshold of 1,26% average annual growth was used. The growth rates of some scenarios varied substantially over the scenario's time span. Some growth rates were below the threshold for early projection years and/or above the threshold in their long-term projection years or vice versa. Others straddled the threshold, changing between above or below the threshold multiple times. Such scenarios were manually assigned a secondary and tertiary label to reflect their changing position relative to the threshold. The final classification of the scenarios was a combination of the awarded labels, whereby the primary classification label was considered leading over the secondary, and the secondary over the tertiary. This classification approach was performed for each of the investigated key focus aspects separately.

To separate the scenarios into two clusters, we sorted the classification matrix by assuming a leading differentiating role for the share of renewables, and a secondary role for total primary energy demand. Differentiation on the basis of (annual growth of) the share of energy from renewable sources in the energy mix separated the scenarios suggesting a business-as-usual development from the scenarios with a focus on a more sustainable energy supply. The other differentiating factor, (annual growth of) the overall total primary energy demand, set apart the scenarios that follow a non-limiting approach with respect to available energy supply from the scenarios that foresee a long-term slowdown of total energy demand growth, maybe leading to stabilization or even decline of total primary energy demand. The composition of the identified clusters is outlined in Section 3, and further quantified and analyzed in Section 4.

## 3. Clusters of energy scenarios

The characters of the clusters formed largely reflect the choice of energy mix aspects used for the classification of the set of investigated scenarios. One cluster, from here on in referred to as 'green' (see Table 1), suggests a relatively strong growth and large increase of the role of energy from renewable sources in the energy mix combined with a clear trend towards stabilization of total primary energy demand in the long run. The second cluster, referred to from here on in as 'gray' (see Table 1), suggests that future energy development pathways are likely to continue more or less along current trends, with only comparatively moderate growth of the role of energy from renewable sources in the energy mix.

Although declining energy demand is often associated with transitions towards a greater role for energy from renewable sources, the two differentiating factors used in this research were found not to be mutually exclusive with regard to the clustering of scenarios. Although most of the scenarios with relatively high annual growth rates for the share of renewable energy also showed comparatively low average annual growth rates for total primary energy demand, several scenarios show combinations of higher growth rates for renewables and relatively high growth rates for total primary energy demand. Similarly, some overlap appeared between scenarios with high average annual growth rates for total primary energy demand: some scenarios coupled this with comparatively low growth rates for the share of energy from renewable sources, while others coupled high total energy demand growth rates with high growth rates for the share of renewables.

Scenarios in the 'green' cluster include most of the scenarios from the investigated set that would be considered 'alternative' or 'non-business-as-usual'. Several of the scenarios in this cluster are typical emission-constrained backcasting scenarios, such as the IEA's "450 ppm Policies"-scenario [26]. Considering the high impact and strong development often associated with such scenario, these scenario's inclusion in the 'green' cluster is fairly self-evident. The 'gray' cluster, by contrast, includes a substantially smaller number of backcasting scenarios. Instead the 'gray' cluster includes most of the reference-scenarios present in the investigated set. A similar remark can be made about the distinctions between the two clusters with regard to the normative or descriptive ethics represented. The share of normative scenarios is markedly larger in the 'green' cluster than in the 'gray' cluster. An explanation for this observation may be found in the nature of strong transition scenarios: a more sustainable future is generally communicated as the desirable whereas a continuation of current trends is often not promoted as the preferred future. Moreover, we observed that the raison d'etre for many of the investigated scenario publications was highlighting the potential of transitioning towards a more sustainable, desirable energy future, while using business-as-usual to provide necessary contrast.

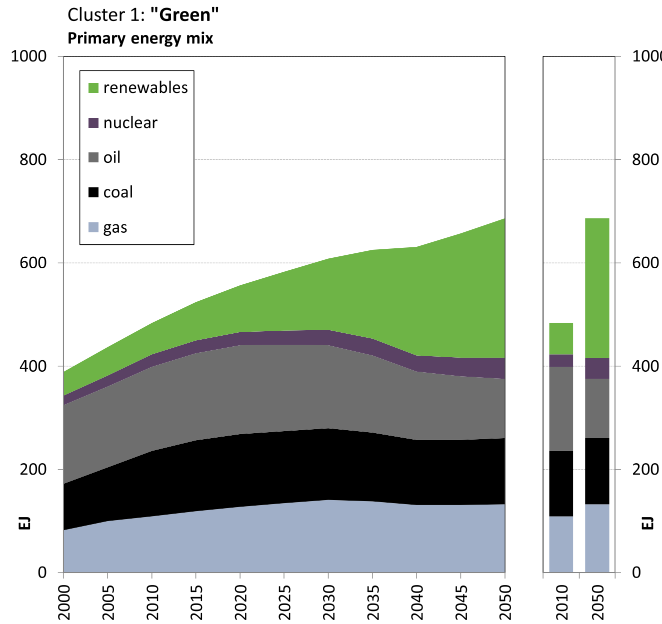


**Fig. 1.** Average energy mix for the 'Green' cluster.

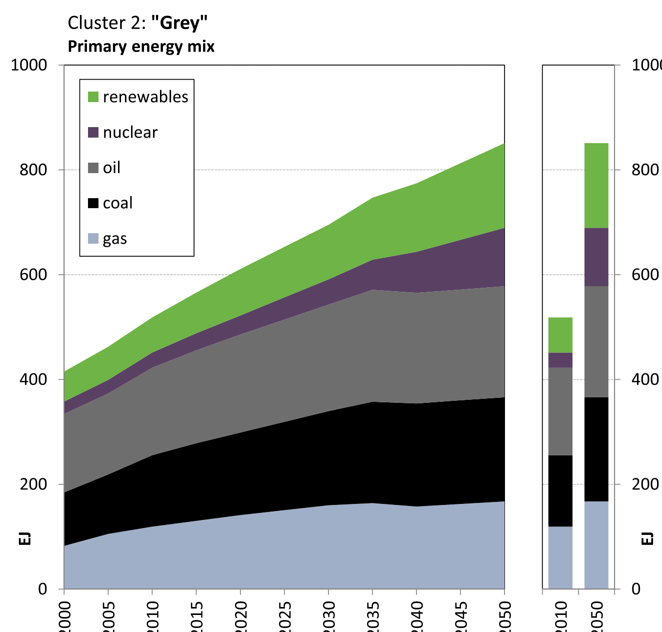


**Fig. 2.** Average energy mix for the 'Gray' cluster.

## 4. General trends and bandwidths

The clusters of scenarios presented in Table 1 are abstract representations of the two different types of energy futures often found in future energy scenario publications: one reflecting a relatively sustainable energy future ('green'), and one reflecting a more business-as-usual energy future ('gray') (see Table 1). For each of the two clusters, we calculated the average future energy mix by averaging the values of each element of the energy mix separately, using the original data of all the scenarios in a cluster as input (See Figs. 1 and 2). We used the same approach to calculate the standarddeviations of each element of the energy mix for the years 2010, 2030, and 2050 to explore the variance and uncertainty implicit in the cluster's averages (see Figs. 3 and 4).

Despite our attempts to separate the scenarios such that the resulting clusters were as dissimilar as possible, investigation of the quantified future energy outlooks shows that both clusters are not substantially different but merely offer different shades of green and gray. Both clusters suggest an absolute increase of renewable energy, and a decline of the share of energy from fossil sources in the energy mix. Both clusters also show signs of a long-term stabilization of the absolute amount of fossil energy in the energy mix. Nevertheless, these trends are more pronounced in the 'green' cluster than in the 'gray' cluster.

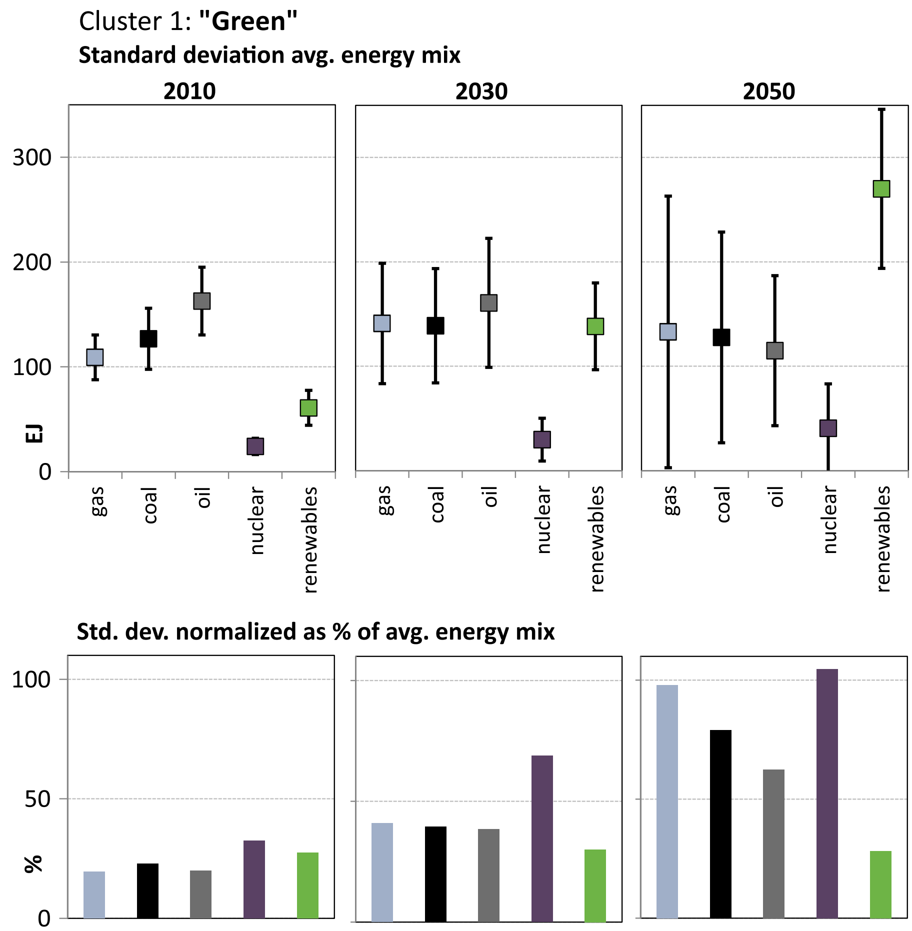


**Fig. 3.** Standarddeviations for elements of the average energy mix for the 'Green' cluster.

The total amount of renewable energy in the 'green' cluster increases over fourfold between 2010 and 2050. The increase of renewable energy is less for the 'gray' cluster, but still considerable. Between 2010 and 2050, the 'gray' cluster suggests that renewable energy may increase between two and threefold. From a relative perspective, the differences in the composition of the energy mixes of both clusters become more pronounced. In the 'green' cluster, renewable energy may contribute well over one third of the total primary energy mix by 2050. Over the period between 2010 and 2050, the 'green' cluster suggests that renewable energy effectively replaces oil. In the 'gray' cluster, this share is about half that of the 'green' cluster. Moreover, the share of renewables in the energy mix of the 'gray' cluster increases only marginally in the period between 2010 and 2050, remaining relatively constant at a contribution of about one fifth of the total primary energy demand.

For energy from fossil sources, both clusters suggest a long-term stabilization of absolute quantities, and a decline in the relative shares. In the 'green' cluster, the stabilization of absolute fossil energy quantities occurs from around the year 2025. In the years thereafter, the quantities of fossil energy even decline, followed again by stabilization from around the year 2040. In the 'gray' cluster, signs of stabilization of the absolute quantities of fossil energy only occur from around the year 2035. Unlike the 'green' cluster, the 'gray' cluster does not suggest any decline. From a relative perspective, the 'green' cluster suggests a pronounced and continuous decline for fossil energy, whereas the 'gray' cluster suggests only a moderate decline.

Nuclear energy bridges between the absolute and relative trends of renewable and fossil energy seen for both clusters. In terms of absolute change, nuclear energy grows twofold in the 'green' cluster between 2010 and 2050, whereas the in the 'gray' cluster that increase is almost twice as large. The relative share of nuclear energy in the 'green' cluster shows almost no change. For the 'gray' cluster the relative share of nuclear energy in the energy mix increases twofold, effectively filling the gap resulting from moderate increases of renewables and stabilization of fossil energy.

Each of the clusters is composed out of a number of future energy scenarios, no two of which suggests exactly identical energy futures. As a result, the average energy mixes of the clusters represent a range of quantitative developments. We can illustrate the amount of deviation from the average by deriving the standard deviations of each element in the energy mixes of both clusters. However, sound comparison of the variance of both clusters requires normalization of the standard deviations. We normalized the standard deviations to a percentage value relative to the average calculated over the same set of input values. Thus, for each element x of the energy mix, the normalized standard deviation is calculated using the following method:

$$\mathrm{var}_{\mathrm{normalized}}(\mathrm{x}) = \left(\mathrm{x}_{\mathrm{average}} \pm \mathrm{var}(\mathrm{x})\right)/x_{\mathrm{average}}$$

The standard deviations and normalized standard deviations were calculated for each element of the energy mix for each of the clusters for the years 2010, 2030, and 2050 (se Figs. 3 and 4).

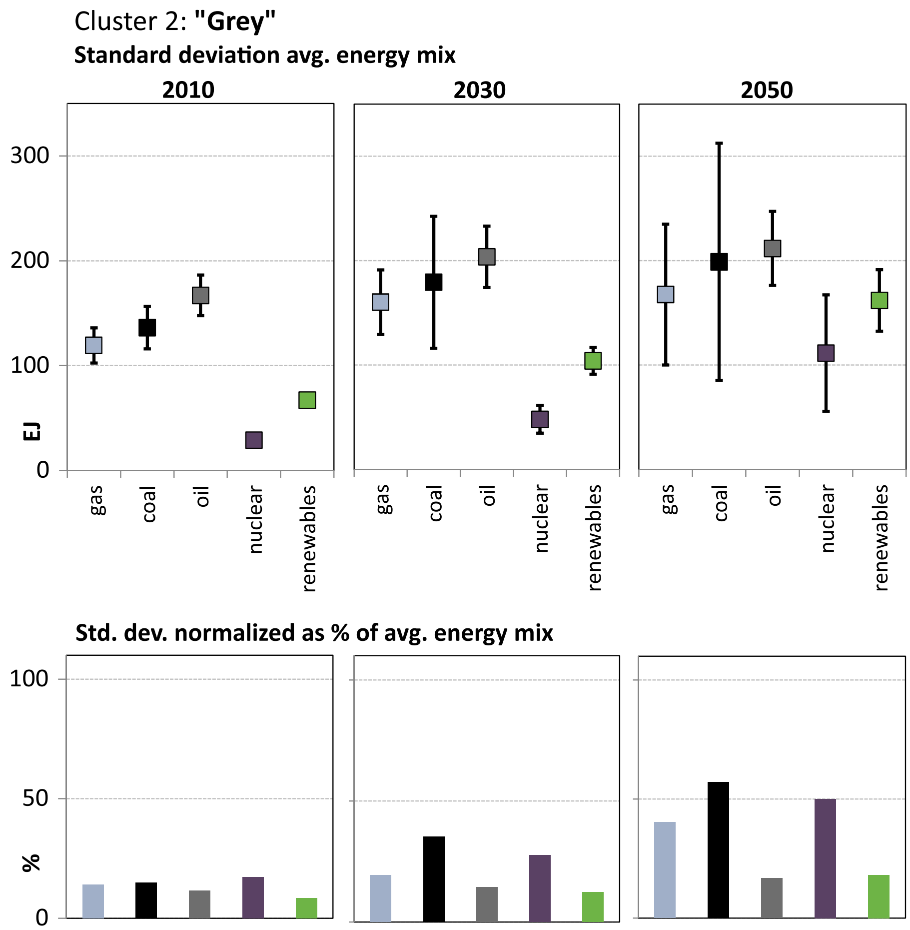


**Fig. 4.** Standarddeviations for elements of the average energy mix for the 'Gray' cluster.

The first general notion we get from analysis of the variance of the data with the clusters, is that the absolute and normalized standard deviations are substantially larger for the 'green' cluster than for the 'gray' cluster. The scenarios in the 'green' cluster appear to agree to a lesser extent on the outlook on energy futures than the scenarios in the 'gray' cluster. These differences in consensus can be related to the inclusion of many 'business-as-usual'-scenarios in the 'gray' cluster, which are typically defined through extrapolation and/or continuation of current trends and developments, without taking into account considerable deviations from those trends. Scenarios in the 'green' cluster, however, typically revolve around pathways for which dissimilarity relative to a 'business-as-usual'-development is key.

The second general notion is that in both clusters, the normalized standard deviation for renewable energy is always either the smallest, or the second smallest after oil. Although absolute standard deviations for renewables differ between the two clusters, the scenarios in the two clusters appear to agree on the role of renewables relative to other elements of the energy mix. This indicates that renewables are an essential element in the future energy mix regardless of general visions of future energy developments.

Considering each element of the energy mix separately, we can see that both gas and oil take up a distinct positions in the future energy mix. For natural gas, it appears that the scenarios in the 'green' cluster are all but agreeing on the long-term future role of gas in the energy mix. The large variance suggests that within the 'green' cluster, various scenarios suggest widely different future roles for natural gas. The 'gray' cluster apparently has a different perspective on natural gas. The variance for natural gas in the 'gray' cluster increases over time as well, but substantially less than in the 'green' cluster. This suggests that scenarios in the 'gray' cluster are, to some extent, on the same line with regard to the future potential of natural gas. For oil, variance increases far stronger for the 'green' cluster than for the 'gray' cluster. The hardly diverging standard deviations as well as the almost unchanging normalized standard deviation for oil in the 'gray' cluster indicate that oil holds a special position in those scenarios and suggests a strong consensus over the role of oil in the future energy mix. The markedly different variances for oil in the 'green' and 'gray' clusters may relate to a coupling between oil and the transportation sector. Scenarios in the 'green' cluster typically suggest a strong growth of the role of non-fossil fuel powered vehicles, whereas scenarios in the 'gray' cluster are less pronounced with regard to transitions in the transportation sector.

## 5. Discourse representation in energy scenarios

This research was carried out to assess the bandwidth of potential global long-term future energy development pathways reported in a variety of scenarios published in recent years. The outcomes of this research should improve the perception of scenarios from different backgrounds, or with different goals, aims, or messages. The characters of scenarios are often closely linked to their origins. As such, varying backgrounds of future energy scenarios would imply varying scenario characteristics. Moreover, it could be argued that the essence of using scenarios as a planning tool is plurality – accentuating a variety of different futures and analyzing the variables that support or prevent the materialization thereof [11,14]. However, contrary to our expectations, the prevailing trends identified from clustered future energy scenarios analyzed in this research offered only limited variety in terms of substantially different energy futures.

Despite various backgrounds and perspectives on energy futures, the vast majority of the future energy scenarios investigated in this research occupied a middle field, suggesting moderate global energy development pathway dynamics. Both the cluster of more sustainable future energy scenarios and the cluster of more business-as-usual scenarios suggested an increase in the amount of renewable energy in the energy mix, and a stabilization of the role of fossil energy. Although such trends were found to be somewhat more pronounced in one cluster relative to the other, the differences can be considered fairly marginal. The general impression that we got was that the vast majority of scenarios investigated in this research were little more than subtle variations on the same theme, affirming earlier critiques on scenarios with regard to their potential to accommodate change (e.g. [11]). We can identify two types of explanations for our observation: practical/functional bias relating to scenario modeling and quantitative data availability, and incomplete institutional representation.

The global energy supply system is characterized by a complex coupling of technical, social, economic and political factors. The result of this characterization is that the global energy system is inherently slow to react on external as well as internal stimuli [41]. Changes in the periphery of energy may take (very) long to become apparent on a global scale. Correct modeling of energy systems would take the associated complexity into account. Since the vast majority of recently published energy scenarios are associated with modeling exercises, those scenarios would – or perhaps, should – reflect certain inertia. The exception to this may be backcasting scenarios, which take a point in the future and draw backwards from there. Such an approach would inevitably have to allow some degree of flexibility with regard to the ability or inability of the current energy system to react to changing environments. The composition of the set of scenarios investigated during this research confirms this notion: the few scenarios that suggest futures distinct from variations on current developments are typically backcasting scenarios.

Typically, the more a scenario is a radical departure from current trends and developments, the more difficult it becomes to adequately outline the required changes in peripheral variables, and thus to set such variables in a model, and eventually to produce credible quantitative data [42]. We may therefore argue that quantitative future energy scenarios that are the result of a modeling exercise are inherently limited by the realistic spectrum of different states of the world that define the scenario's context. The focus of this research on quantitative data thus precludes to some extent scenarios that represent a strong departure from current trends and developments, unlikely futures, or perhaps controversial visions of future energy system development pathways. As such, the absence of extreme 'outlier' scenarios in the set of scenarios analyzed is a logical consequence of the focus of this research. However, the focus of this research on quantitative data only partially accounts for the rather subtle differences between (the clusters of) scenarios investigated.

The striking shortage of more extreme future energy scenarios can be related to institutional aspects. Considering the influence of the authoring party and its background on a scenario's characteristics, it is important to realize which backgrounds are represented in a set of scenarios in order to truly assess its particular characteristics. At the most basic level, scenarios exist at the mercy of the applicable world views. In the context of energy, the distinction is between two basic world views: Cornucopian and Malthusian (see [15]). Neither extreme Cornucopians nor extreme Malthusians are likely to be involved in scenario thinking. The former assumes no intervention is required, since the world provides sufficient surplus and redundancy to overcome all issues of energy and sustainability. The latter would hold the pessimistic view that disaster will be the eventual outcome regardless of any intervention, and as intervention would be useless, so would scenario planning.

Although extreme incarnations of Cornucopian and Malthusian discourses define two ends of a scale, manifestations of those discourses often represent moderate of hybrid versions from the middle of the scale. The separation between the two discourses is usually not very explicit and the two world views may, in moderation, overlap [42]. Although moderate Cornucopian and Malthusian world views may both agree with interventions to alter future prospects, the Cornucopian world view appears to be largely underrepresented in the realm of future energy scenarios. Some scholars have argued that under- or overrepresentation of particular world views skews the outlook on energy futures and hampers a full view on the range of possibilities [43]. They point out that analysis of past projections compared with subsequent realities indicates that Cornucopian perspectives on future energy pathways were closer to eventual reality than Malthusian perspectives.

Most scenarios investigated in the context of this research incorporate elements of Malthusian discourses. Some scenarios integrate Malthusian views on limits to growth through explicitly stressing the finiteness of fossil resources, while others use limitations to greenhouse gas emissions as a starting point for normative backcasting scenarios. Cornucopian elements are mostly limited to future technologic breakthroughs such as carbon capture and storage, hydrogen and synthetic natural gas, and advances in energy storage. Suggestions of unlimited availability of renewable energy are usually only mentioned in a context of limitations with regard to fossil energy and/or greenhouse gas emissions. Over the set of scenarios investigated in this research, the distinction between opposing world views appears markedly softened. The different environmental discourses converge into a more subtle, narrow bandwidth of institutional convictions.

This convergence can be coupled to cultural theory and its definition of different premises with regard to sustainability disputes. Cultural theory mapped these premises into a fourfold typology: egalitarianism, hierarchy, individualism, and fatalism (see [44]). Of these four, only individualist world views would consider a world along a Cornucopian discourse. Malthusian discourses relate to hierarchic or egalitarian world views, while fatalists are somewhere in between. Only hierarchists and egalitarians consider a world that allows control and management, and as such would find the use of scenarios as a strategic decision tool purposeful.

Inclusion of particular (extreme incarnations of) environmental discourses in the realm of energy scenarios relates to a large extent to the way advocates of such discourses perceive utility and necessity of scenario planning, and their views on control, management, and viability of alternative energy futures. Underrepresentation of extreme environmental discourses in future energy scenarios is likely unintentional: scenario planning may never have been on the agenda. Nevertheless, limited representation of extreme discourses and overrepresentation of moderate discourses unwittingly coerces scenario-informed strategic decision-making into a limited bandwidth of possible futures.

## 6. Discussion

In this study, we identified and analyzed clusters of future energy scenarios available in current, published literature. We found that many scenarios share general trends and developments, and extreme manifestations of environmental discourses are underrepresented. From this observation we argue that the body of future energy scenarios is lacking the heterogenity essential for effective use of scenarios as a tool for strategic planning and policymaking.

The strengths of this study lie in the different approach used relative to most other meta-analyses of energy scenarios, resulting in a unique and novel perspective on energy scenarios. Rather than dissecting and unraveling scenarios and centering the analyses around details, this study abstracts details in order to get a more high-level perspective on general trends in the realm of future energy scenarios at large. Methodologically, we deployed a tailor-made, two-pronged approach involving a data normalization and scenario clustering process followed by a discussion of quantitative analysis results in a qualitative environmental discourses context. The involvement of environmental discourses and world views in general matches with the objective of this study to provide a high-level and abstract perspective on energy scenarios. The value of this study's approach is reflected in its finding of an implicit weakness in energy scenarios at large that jeopardizes effective scenario planning: most scenarios only represent moderate manifestations of environmental discourses and thus a limited bandwidth of energy futures.

The foundation of the analysis presented in this study is the selection of usable scenarios. One of the selection criteria is the requirement of a scenario to provide quantitative data. We argued in this study that scenarios suggesting a more radical departure from current trends and developments are inherently more difficult to supplement with reliable quantitative data. The underrepresentation of extreme scenarios in the selection used for this study may thus be a direct consequence of the applied selection criteria.

Manifestations of environmental discourses at the very extremes of the range between Malthusian and Cornucopian may only represent a minority share of all environmental discourse manifestations. However, arguing that the underrepresentation of scenarios representing extreme manifestations of environmental discourses is thus irrelevant would only be correct in quantitative terms. Effectiveness of scenario planning through heterogenity of scenarios is a qualitative issue – absence of extreme views and overexposure of moderate views results in a reduced scope regardless of density differences. Consideration of extreme views, or awareness of the existence of such views, would strengthen the foundation of the scenario planning process. It would not, however, inevitably result in different strategic decisions or other scenario planning outcomes.

Nevertheless, unawareness of the range represented by a subset of scenarios in scenario-based policymaking processes may increase the risk of creating self-limiting feedback loops. We may reason that policymaking based on scenarios suggesting only subtle change likely result in subtle policy, resulting in the suggested subtle change. The feedback loop would be closed by the next generation of scenario authors. Taking clues about policy effectivity and change potential from actual transition efforts, new scenario design efforts would again be constrained by considerations of plausibility related to subtle policy measures. Whether such feedback loops are (part of) an explanation for the current inability of policy to adequately govern energy transition is difficult to assess in the absence of studies focused on such topics. We found no empirical study was available on the artifacts of environmental discourses and (under)representation extreme manifestations thereof in actual energy transition policy. Additional research in that subject area would be required to augment the findings in this review.

## 7. Conclusions

This research assessed the role and representation of different environmental discourses in future energy scenarios by identifying and analyzing general trends and dynamics in clusters of recently published, quantified future energy scenarios. We found limited divergence with regard to the spectrum of possible energy futures reported in the investigated scenario clusters – differences merely appear as shades of green and gray. Both a more renewables-oriented cluster of scenarios and a more 'business-as-usual'-cluster of scenarios suggest an increasing role for renewable energy in the energy mix, and both clusters suggest a long-term stabilization of the role of fossil energy.

Scenarios from different backgrounds or with different intentions do not appear to suggest substantially different futures. Scenarios involving explicit revolutions or turning points do not appear to constitute a significant part of the body of future energy scenario literature. We suggest two explanations for this observation: difficulties with regard to capturing extreme future energy visions in model parameters to define and evaluate associated scenarios, and a limited role and influence of extreme manifestations of environmental discourses coupled with overrepresentation of moderate and/or hybrid discourses.

Differences in world views and environmental discourses notwithstanding, sound scenario-informed strategic decision-making benefits from plurality, and as such from heterogenic representation of environmental discourses. We argue that the shortage of extreme manifestations of environmental discourses implies that not the full bandwidth of imaginable energy futures is represented in the body of current future energy scenarios. Few scenarios suggest radical departures from current development paths. Instead, most energy futures that are suggested are limited to what could be considered plausible, and do not require strong breaks from current trends. The practical implications from such self-imposed limitations may include incomplete policy information, with inadequate policymaking and weak energy transition governance as a result.

With regard to the currently available body of future energy scenarios, the influence of environmental discourses appears mostly marginal and subtle. Users of such scenarios to inform strategic decision-making and long-term energy planning should be aware of the narrow bandwidth of discourses and premises represented in current future energy scenarios, and the possible risk of bias towards the status-quo.

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## Appendix A

See Table A1.

**Table A1**
Overview of selected key data of investigated scenarios.

| Study | | Total | | | Gas | | | Coal | | | Oil | | | Nuclear | | | Renewables | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2010 | 2030 | 2050 | 2010 | 2030 | 2050 | 2010 | 2030 | 2050 | 2010 | 2030 | 2050 | 2010 | 2030 | 2050 | 2010 | 2030 | 2050 |
| Azar et al. [27] | n/a | 417 | 478 | 545 | 84 | 76 | 100 | 94 | 84 | 42 | 151 | 160 | 147 | 13 | 8 | 25 | 75 | 150 | 231 |
| BP [28] | n/a | 506 | 696 | n/a | 120 | 181 | n/a | 153 | 192 | n/a | 166 | 193 | n/a | 26 | 42 | n/a | 40 | 88 | n/a |
| European Commission [39] | Reference | 517 | 706 | 933 | 132 | 171 | 171 | 123 | 166 | 238 | 165 | 225 | 250 | 31 | 60 | 133 | 65 | 83 | 141 |
| European Commission [39] | Carbon Constraints | 517 | 648 | 821 | 133 | 164 | 160 | 123 | 123 | 110 | 165 | 208 | 205 | 31 | 61 | 178 | 65 | 93 | 168 |
| European Commission [39] | Hydrogen | 514 | 677 | 856 | 132 | 166 | 159 | 126 | 122 | 121 | 159 | 220 | 217 | 32 | 83 | 196 | 64 | 87 | 163 |
| EIA [35] | Reference | 553 | 761 | n/a | 125 | 171 | n/a | 152 | 205 | n/a | 187 | 229 | n/a | 31 | 50 | n/a | 59 | 106 | n/a |
| EIA [35] | High Oil Price | 550 | 817 | n/a | 124 | 180 | n/a | 152 | 235 | n/a | 185 | 241 | n/a | 30 | 50 | n/a | 59 | 111 | n/a |
| EIA [35] | Low Oil Price | 557 | 730 | n/a | 125 | 160 | n/a | 153 | 183 | n/a | 189 | 235 | n/a | 31 | 50 | n/a | 60 | 101 | n/a |
| ExxonMobil [37] | n/a | 469 | 599 | n/a | 103 | 149 | n/a | 115 | 121 | n/a | 162 | 197 | n/a | 28 | 49 | n/a | 62 | 82 | n/a |
| Greenpeace [29] | Reference | 511 | 674 | 783 | 108 | 142 | 166 | 146 | 204 | 225 | 158 | 192 | 225 | 31 | 40 | 48 | 68 | 95 | 119 |
| Greenpeace [29] | Energy [R] evolution | 502 | 511 | 460 | 109 | 122 | 71 | 138 | 97 | 38 | 155 | 124 | 82 | 29 | 9 | 0 | 71 | 160 | 269 |
| Greenpeace [29] | Advanced Energy [R]ev. | 501 | 501 | 466 | 110 | 114 | 34 | 136 | 70 | 8 | 155 | 115 | 52 | 29 | 8 | 0 | 72 | 193 | 372 |
| IEA [38] | Gas | 528 | 667 | n/a | 114 | 165 | n/a | 140 | 151 | n/a | 171 | 186 | n/a | 31 | 46 | n/a | 71 | 119 | n/a |
| IEA [38] | New Policies WEO2010 | 520 | 679 | n/a | 109 | 155 | n/a | 142 | 172 | n/a | 169 | 190 | n/a | 30 | 47 | n/a | 69 | 115 | n/a |
| IEA [26] | Current Policies | 520 | 719 | n/a | 109 | 161 | n/a | 142 | 212 | n/a | 169 | 201 | n/a | 30 | 43 | n/a | 69 | 102 | n/a |
| IEA [26] | New Policies | 528 | 667 | n/a | 112 | 148 | n/a | 141 | 160 | n/a | 172 | 191 | n/a | 32 | 49 | n/a | 71 | 119 | n/a |
| IEA [26] | 450 ppm Policies | 520 | 610 | n/a | 109 | 136 | n/a | 142 | 109 | n/a | 169 | 164 | n/a | 30 | 61 | n/a | 69 | 141 | n/a |
| IPCC [30] | A1B-AIM | 559 | 895 | 1347 | 147 | 298 | 465 | 134 | 179 | 186 | 209 | 239 | 214 | 16 | 53 | 123 | 53 | 125 | 360 |
| IPCC [30] | A2-ASF | 450 | 720 | 971 | 89 | 176 | 275 | 106 | 184 | 294 | 220 | 270 | 228 | 14 | 32 | 62 | 21 | 59 | 113 |
| IPCC [30] | B1-IMAGE | 508 | 710 | 813 | 108 | 153 | 173 | 120 | 163 | 167 | 176 | 230 | 228 | 22 | 49 | 105 | 82 | 115 | 141 |
| IPCC [30] | B2-MESSAGE | 479 | 667 | 869 | 107 | 194 | 297 | 98 | 96 | 86 | 195 | 240 | 227 | 11 | 23 | 48 | 68 | 115 | 212 |
| Krewitt et al. [31] | Reference | 487 | 640 | 809 | 172 | 218 | n/a | 108 | 155 | n/a | 110 | 146 | n/a | 31 | 30 | n/a | 66 | 90 | n/a |
| Krewitt at al. [31] | 2 °C | 428 | 415 | 422 | 144 | 111 | 87 | 99 | 107 | 93 | 90 | 52 | 32 | 23 | 1 | 0 | 72 | 145 | 210 |
| Leimbach et al. [32] | Reference | 519 | 724 | 881 | 100 | 58 | 46 | 186 | 387 | 445 | 137 | 133 | 130 | 29 | 30 | 72 | 68 | 115 | 189 |
| Leimbach et al. [32] | 400 ppm | 502 | 587 | 737 | 101 | 87 | 60 | 158 | 123 | 139 | 138 | 115 | 97 | 31 | 53 | 103 | 75 | 208 | 338 |
| OPEC [33] | n/a | 526 | 739 | n/a | 120 | 184 | n/a | 155 | 213 | n/a | 181 | 218 | n/a | 33 | 46 | n/a | 37 | 79 | n/a |
| Shell [35] | Signals & Signposts | 536 | 734 | n/a | 114 | 169 | n/a | 149 | 193 | n/a | 168 | 197 | n/a | 32 | 56 | n/a | 74 | 119 | n/a |
| Shell [34] | Scramble | 531 | 734 | 880 | 110 | 134 | 108 | 144 | 210 | 263 | 176 | 179 | 141 | 31 | 36 | 43 | 69 | 174 | 326 |
| Shell [34] | Blueprints | 524 | 692 | 769 | 109 | 143 | 122 | 137 | 186 | 208 | 177 | 192 | 157 | 30 | 34 | 50 | 70 | 138 | 232 |
| WWF [35] | n/a | 322 | 331 | 261 | 66 | 72 | 6 | 53 | 50 | 6 | 128 | 69 | 0 | 9 | 3 | 0 | 66 | 138 | 248 |

## References


[1] Hoffert MI. Farewell to fossil fuels? Science 2010;329(5997):1292–4.
[2] Kerr RA, Service RF. What can replace cheap oil - and when? Science 2005;309 (5731):101.
[3] Lovins AB. A farewell to fossil fuels – Answering the energy challenge. Foreign Aff 2012;91(2):134–46.
[4] Pacala S, Socolow R. Stabilization wedges: Solving the climate problem for the next 50 years with current technologies. Science 2004;305(5686):968–72.
[5] Hughes N, Strachan N, Gross R. The structure of uncertainty in future low carbon pathways. Energ Policy 2013;52:45–54.
[6] Martinot E, Dienst C, Weiliang L, Qimin C. Renewable energy futures: Targets, scenarios, and pathways. Annu Rev Environ Resour 2007;32:205–39.
[7] Söderholm P, Hildingsson R, Johansson B, Khan J, Wilhelmsson F. Governing the transition to low-carbon futures: a critical survey of energy scenarios for 2050. Futures 2011;43(10):1105–16.
[8] Unruh GC. Understanding carbon lock-in. Energ Policy 2000;28(12):817–30.
[9] Schwartz P. The art of the long view: planning for the future in an uncertain, world.Chichester: John Wiley & Sons Ltd; 1999.
[10] Ringland G. Scenario planning. 2nd ed. Chichester: John Wiley & Sons Ltd; 2006.
[11] Van't Klooster SA, Van Asselt MBA. Accommodating or compromising change? A story about ambitions and historic deterministic scenarios Futures 2011;43 (1):86–98.
[12] Durance P, Godet M. Scenario building: uses and abuses. Technol Forecast Soc 2010;77(9):1488–92.
[13] MacKay B, McKiernan P. Creativity and dysfunction in strategic processes: the case of scenario planning. Futures 2010;42(4):271–81.
[14] Thompson M. Cultural theory and integrated assessment. Environ Model Assess 1997;2(3):139–50.
[15] Dryzek JS. The politics of the earth: environmental discourses. Oxford: Oxford University Press; 2013.
[16] Van Notten PWF, Rotmans J, Van Asselt MBA, Rothman DS. An updated scenario typology. Futures 2003;35(5):423–43.
[17] Börjeson L, Höjer M, Dreborg K-H, Ekvall T, Finnveden G. Scenario types and techniques: Towards a user's guide. Futures 2006;38(7):723–39.
[18] McDowall W, Eames M. Forecasts, scenarios, visions, backcasts and roadmaps to the hydrogen economy: a review of the hydrogen futures literature. Energ Policy 2006;34(11):1236–50.
[19] Cochran J, Mai T, Bazilian M. Meta-analysis of high penetration renewable energy scenarios. Renew Sust Energ Rev 2014;29:246–53.
[20] Höök M, Tang X. Depletion of fossil fuels and anthropogenic climate change - A review. Energ Policy 2013;52:797–809.
[21] Martinot E. Renewables global futures report.Paris: REN21; 2013.
[22] Schmid E, Pahle M, Knopf B. Renewable electricity generation in Germany: a meta-analysis of mitigation scenarios. Energ Policy 2013;61:1151–63.
[23] Sveinn Vidar Gudmundsson SV, Anger A. Global carbon dioxide emissions scenarios for aviation derived from IPCC storylines: a meta-analysis. Transp Res D-TR E 2012;17(1):61–5.
[24] Webofscience.com [Internet]. Thomson Reuters; c2015. Available from 〈http://www.webofscience.com〉.
[25] Scholar.google.com [Internet]. Google; c2015. Available from 〈http://scholar.google.com〉.
[26] IEA. World energy outlook 2011. Paris: International Energy Agency; 2011.
[27] Azar C, Lindgren K, Andersson BA. Global energy scenarios meeting stringent $CO_2$ constraints - Cost-effective fuel choices in the transportation sector. Energ Policy 2003;31(10):961–76.
[28] BP. Energy Outlook 2030 [Internet]. BP; 2011. Available from 〈http://www.bp.com/energyoutlook〉.
[29] Greenpeace. Energy [R]evolution - A sustainable world energy outlook. Amsterdam: Greenpeace; 2010.
[30] IPCC. Emission Scenarios. Special Report. Geneva: Intergovernmental Panel on Climate Change; 2000.
[31] Krewitt W, Simon S, Graus W, Teske S, Zervos A, Schäfer O. The 2 °C scenario — A sustainable world energy perspective. Energy Policy 2007;35(10):4969–80.
[32] Leimbach L, Bauer N, Baumstark L, Lüken M, Edenhofer O. Technological Change and International Trade - Insights from REMIND-R. Energy J 2010;31:109–36.
[33] OPEC. World Oil Outlook. Vienna: Organization of the Petroleum Exporting Countries, Vienna; 2011.
[34] Shell. Energy Scenarios to 2050. the Hague: Shell International BV; 2008.
[35] WWF. The energy report: 100% Renewable Energy by 2050. Gland: WWF

International; 2011.
[36] EIA. International Energy Outlook. Washington: U.S. Energy Information Administration; 2011.
[37] ExxonMobil. The outlook for energy: A view to 2030. Irving: Exxon Mobil Corporation; 2009.
[38] IEA. Are we entering a golden age of gas? Special Report. Paris: International Energy Agency; 2011.
[39] European Commission. World Energy Technology Outlook – 2050 - WETO-H2. Luxembourg: European Communities; 2006.
[40] Shell. Signals and Signposts. The Hague: Shell International BV; 2011.
[41] Grubler A. Energy transitions research: insights and cautionary tales. Energ Policy 2012;50:8–16.
[42] Masini E. Rethinking futures studies. Futures 2006;38(10):1158–68.
[43] Chenoweth J, Feitelson E. Neo-Malthusians and Cornucopians put to the test: global 2000 and the resourceful Earth revisited. Futures 2005;37:51–72.
[44] Thompson M, Ellis R, Wildavsky A. Cultural Theory. Oxford: Westview Press; 1990.