Transition desirability in energy transition scenarios

Technical file #9 – Draft version

Information and recommendations for scenario producers

This document is part of a set of 12 technical files. These files have been produced by *The Shift Project* after one year and a half of research and experts consultations on the different aspects of energy transition and the future studies around these aspects.

Our project, "Power Systems 2050 – Guidelines for design," started in January 2018, with the participation of 10 experts who defined the key subjects which according to them have to be collectively tackled by future studies about the power transition. *The Shift Project* then investigated each of these subjects, consulting in total 40 experts, organizing 4 workshops, and reviewing a large bibliography, including a dozen of future studies about power (and energy) transition at different geographical scales.

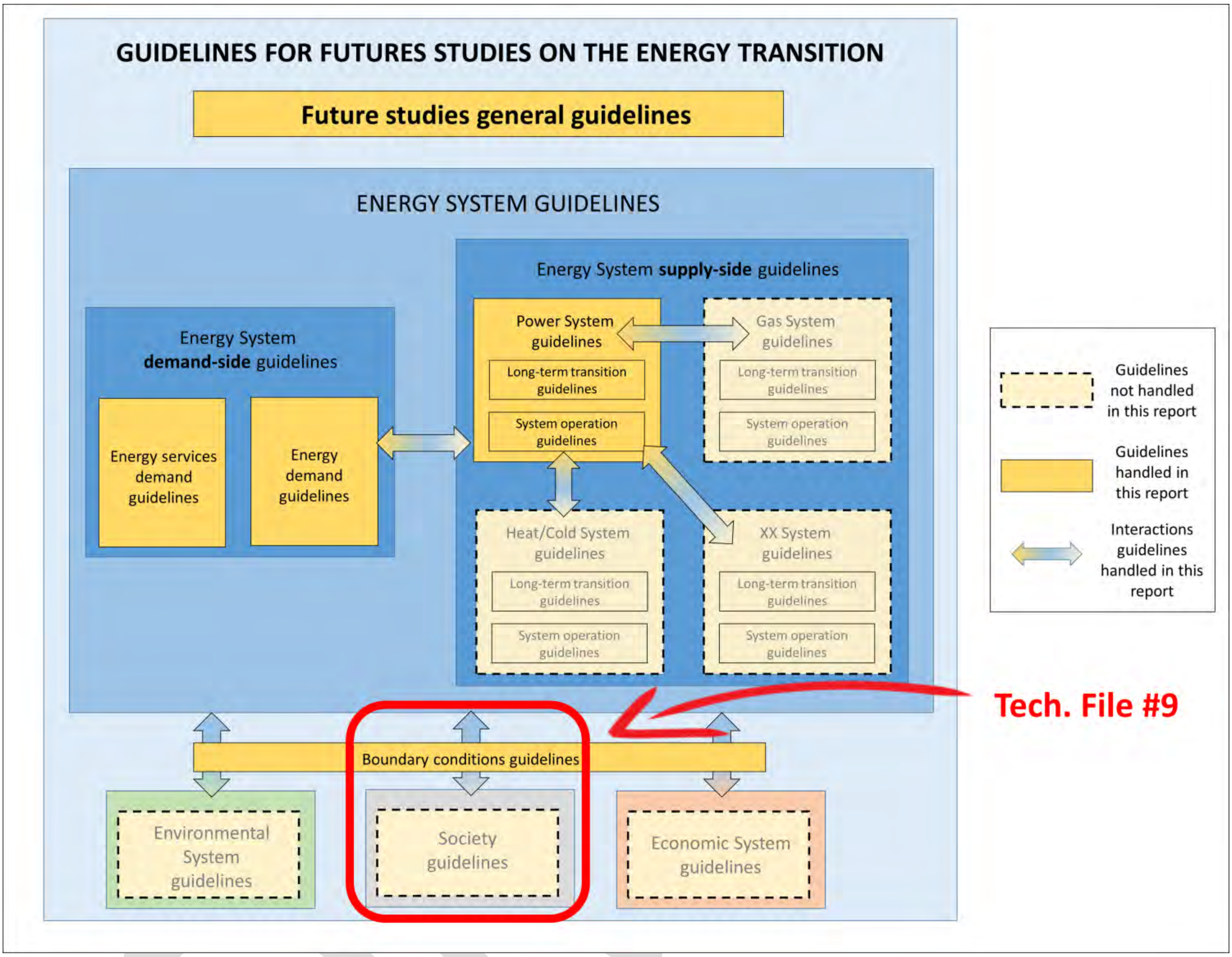
The goal of this project is to produce a set of guidelines addressed to scenario producers. These guidelines seek to foster transparency and consistency *within* future studies and to develop a common language *across* studies. By defining a number of important items which are key to deal with in future studies, we actually propose a study template which enables a better understanding of the location of each proposed scenario on the tree of possible transitions. Once again, the objective is not to *rank* studies, or scenarios, but rather to *compare* them to get a better collective overview of the different aspects of the transition (what are the differences between studies in terms of driving questions, hypotheses, models, methodology, results?).

Several aspects of the energy transition are handled in these technical files. However, on the energy supply-side only the power system has been studied. The main reason for this choice is that we had to start from somewhere with limited resources, and the power system seemed to be a key system to study in the energy transition context, towards a low-carbon economy, as shown by the growing number of future studies focusing on this system. However, the guidelines we propose could be completed by analyzes on the other energy supply-side systems (the gas system, oil system, heat system and so on).

Each technical file tackles several aspects of future studies for the power (and energy) transition. Here is the complete list of the technical files produced during the project:

#	**Technical file title**
1	Future studies on the energy transition
2	Energy transition models
3	Boundary conditions for energy transition scenarios
4	Long-term evolution of energy consumption in energy transition scenarios
5	Lifestyles and consumption behaviors in energy transition scenarios
6	Long-term evolution of the power system supply-side in energy transition scenarios
7	Power system operation in energy transition scenarios
8	Impact assessment in energy transition scenarios
9	Transition desirability in energy transition scenarios
10	Environmental assessment of energy transition scenarios
11	Economic evaluation of energy transition scenarios
12	Employment assessment of energy transition scenarios

Altogether, these files cover the fields described on the following map of the guidelines for future studies on the energy transition. The document you are reading covers the red-circled topics.



In addition to these technical files, three complementary notes have been produced as specific focuses on the following aspects: material criticality in energy transitions (in French, to be translated and added to technical file #10), levelized cost of electricity (LCOE) in energy transition future studies (in French) and discount rate in energy transition future studies (in French).

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Reading keys

Explanation box, containing key information for a better overall understanding of the subjects.

Recommendations to scenario producers:

These boxes contain the recommendations for scenario producers.

The word "should" means that scenario producers, if they are to follow the guidelines, must substantiate the corresponding point. The words "may" or "might" relates to suggestions, ideas to help the scenario producer respond to the point.

Questions in italic are examples of questions scenario producers might ask to substantiate the points. They are here in an illustration purpose.

Phrases in italic relate to words which are being defined and will be subsequently used in the framework.

Phrases which are highlighted in yellow refer to other technical documents of this series.

I. Transition desirability

Desirability of the transition refers to the fact that the transition is desirable for the different actors composing a society. In case a transition seems not desirable by some actors, they can raise acceptance questions and generate conflict with the transition planner(s).

By better understanding why such conflicts emerge in the real world, scenario producers can better take desirability and acceptability considerations into account in their scenarios.

A. Transition projects may lead to four types of conflicts between the general public and projects holders

Literature on acceptance is large as far as installation of technology infrastructure is concerned. However, for our energy transition subject, this concept is extended to the desirability of a complete transition.

(ADEME, 2011) proposes a frame which describes the different types of conflicts which may arise when a project is implemented. These conflicts express different types of oppositions from individuals to a project taking place within a transition.

- The *uncertainty conflict* emerges when opponents are afraid of the potential impacts of the projects on themselves, their local environment, their jobs and their ways of lives (as inhabitants of a territory and workers in a given sector).
- The *substantial conflict* emerges when opponents contest the nature of the proposed project in general (as citizens), such as a proposed global policy in case of a public project.
- The *structural conflict* emerges when the proposed project comes from an illegitimate actor, that is, an actor which is considered as not representing the general interest.
- The *procedure conflict* emerges when opponents contest the way of leading the project, typically when transparency on the project is not ensured or when dialogue with stakeholders is poor. In this document, we instead consider that good concertation procedures prevent from the other types of conflicts to happen by raising the associated risks beforehand.

Such conflicts are observed in real-life situations for transition projects, such as the installation of wind turbines or the installation of new high-voltage power lines.

As mentioned in the lifestyle section, social aspects are largely neglected in scenarios whereas transitions proposed may encounter great hurdles in the real world because of people possible reluctance towards these transitions or the way they are led.

Acceptance studies often focus on causes of uncertainty conflicts. These causes do not fully explain acceptance behaviors, hence some authors interpret it as volatile, as if partly irrational (Bertsch, Hall, Weinhardt, & Fichtner, 2016). Taking into account the other types of conflicts may improve the overall understanding on acceptance.

(Schubert, Thuß, & Möst, 2015) focuses on the acceptance of an energy transition. According to them, three main aspects should be considered in assessing the acceptance, or desirability, of an energy transition:

- Economic aspect, such as the evolution of costs for different actors, wealth redistribution, employment
- Security of supply for the different actors
- Environmental compatibility and technology risks

These aspects fit in the conflict frame proposed above.

Other stakeholders than individuals can trigger conflicts: corporations can pressurize governments towards reducing as most as possible the possible transition burdens they could bear, such as sunk costs. More generally, who bears the burden of sunk costs is a key question for transition desirability.

The next sections are based on the 4 different types of conflicts proposed by (ADEME, 2011), covering the three main aspects presented by (Schubert et al., 2015). The final section is dedicated to considerations on sunk costs.

Recommendations to scenario producers

Scenario producers should take acceptance aspects into account, as a way to prove the social desirability or to highlight the conflict risks associated with the proposed transition. Hence these risks can be better treated in scenarios. As a consequence scenario producers can explain why and how conflicts risks are negligible in their scenarios. The different types of conflicts this document handles should be considered while building scenarios.

B. *Uncertainty conflicts* are caused by the impacts of changes on individuals

Uncertainty conflict is sometimes described as the NIMBY ("Not in my backyard") syndrome. However, some authors argue that this depiction leads to discard the reasons of discontent by judging them as "egoistic" instead of understanding and tackling them (ADEME, 2011). Furthermore, NIMBY syndrome applies to reactions to the installation of new infrastructure, whereas we include in uncertainty conflicts all the impacts of an energy transition at the individual level. For example, uncertainty about one's job within a transition belongs to this type of conflict whereas job issues are not usually included in NIMBY considerations.

1. Energy is a basic need: its supply should be affordable when needed, secure, and of good quality, during the whole transition

The greater public sees energy as a basic need. Indeed energy is explicitly discussed among the general public as a basic need because of its perceived role in ensuring survival, good health, a decent life, and ability to engage in expected patterns of life. This is particularly salient when considering the wellbeing of vulnerable groups (Demski, Thomas, Becker, Evensen, & Pidgeon, 2019).

Access to energy is seen as a basic right that should be guaranteed because people have no choice but to use it. When "there is no choice" energy demand is described as "constrained" (Martin & Gaspard, 2016).

In this regard, access to energy services should be ensured for all groups of people so they can fulfill their needs when they need it. Hence energy services should remain affordable. If energy price increases (for example through a carbon price), the service should remain accessible using less, or another form of, energy, through low-consumption technologies or alternative technologies. In turn, access to these technologies should be ensured in a timely fashion so that basic needs are continuously fulfilled.

As time-of use pricing may result in high prices during peak times, it may lead to render energy unaffordable for some groups in society if they are not able to shift their demand. Smart metering may not be accepted if reassurance that new pricing would **not compromise people's access to energy when they needed it for** essential services is not provided (Demski et al., 2019). In economic words, constrained energy demand is barely elastic to price. Hence, on the short run, a price rise of constrained energy directly leads to a budget decrease for other expenses, as energy consumption does not decrease.

Along the same line of reasoning, energy security of supply is a key criteria for acceptance. Blackouts or power cuts are not accepted anymore in developed countries, neither by households nor by industries. Many of households' basic needs are enabled by power (food conservation, heating[1], cooking). For industries, power cuts prevent from working, which is not accepted especially in case of high unemployment rates. Some of societies basic needs are fulfilled through power: public lighting for individual security, health services, water system amenities and so on, require power to properly operate. The impacts of a lasting blackout in Western countries would be huge in the current state of affairs. To prevent the most catastrophic impacts of a blackout, infrastructure (such as hospitals, some power plants) are equipped with diesel generators or batteries to keep operating for a few days in case of a lasting power outage (Mark Elsberg, 2017). Réseau de Transport d'Electricité (RTE, the French power transmission operator) describes security of supply as a common good (RTE, 2017).

[1] Some rural households in Canada are equipped with individual diesel generators in case the power network undergoes failures during winter.

Similarly, power quality (a stable and neat tension and frequency wave) is an important criterion because it is needed for usual appliances to correctly work. Too low a power quality would be equivalent to a power cut.

Note that these acceptance issues could also be categorized in the substantial conflict category (that is, an opposition to a project for society level reasons), as people declare that lacking energy should not happen to anybody in the society they live in (Demski et al., 2019).

Recommendations to scenario producers

A scenario strategy about access to power uncertainty conflicts should be defined and justified. It should include considerations on the decision to study this subject or not. This choice depends on the Planning Question and on the study overall strategy. In case the subject is studied, the different aspects of it which are considered should be reported.

Considering those aspects may help to detect the situations in which conflicts about access to power could arise in some scenarios.

Hereunder are aspects of access to power uncertainty conflicts which may be reported about:

- Impacts on access to power generated by the transition: several aspects pertaining to access to power have been presented: affordability, time-of-use pricing and demand side management techniques, security of supply and quality of supply. For each of them, scenario producers should consider the following aspects:
- Type of needs which are impacted: needs are characterized as "basic" when the corresponding demand is constrained; in other words, a basic need is one which people have "no choice" but to fulfill it. Scenario producers should take special care when decreasing the fulfillment of such needs. For example, they may substantiate why the described transition is accepted in their scenarios in which such a decrease happens.
- Type of population which is impacted: different populations are differently exposed to the above-mentioned impacts because their needs may be different (e.g., some households may need to commute over long distances). Scenario producers may take into account the specificities of some populations (such as social categories or type of fabric they live in) when assessing the power accessibility impacts in their scenarios.
- Corrective measures or adaptation impacts: scenario producers may propose extra political measures in their scenarios to avoid conflicts risks related to energy access, such as wealth redistribution measures, wavers for specific populations, communication campaigns… Costs and impacts of such measures should be considered. Economic actors which face power accessibility problems may adapt by getting equipped with fuel-powered portable generators, batteries or any other solution. If they face power quality problems, they might adapt by getting equipped with protective devices. Such adaptation behaviors should be considered and their impacts (on total system costs, GHG emissions and so on) taken into account.

For example, such situations should be detected: a global increase of the power share in households', or companies', budgets; a sharp increase of the power share in a given population's budget due to time-of-use pricing; a significantly lower security of supply; a lower quality of supply. In these situations, scenario producers should substantiate how risks of conflicts are kept low. This might involve extra measures, or adaptations by agents. This may imply, in turn, extra costs or consequences, which may be assessed depending on the study strategy.

2. Transition involves work structure changes: impacts on workers should be considered

Fast transitions require fast changes in the structure of the workforce. Workers may have to face unemployment, undergo trainings to acquire new skills. Expertize may become useless, and the associated status disappear.

These situations may not be accepted by people as workers while they would be accepted as inhabitants, or vice versa (Bögel & Upham, 2018).

Recommendations to scenario producers

Scenarios in which workers have to radically change their professional activity or face unemployment should explain what measures they assume to make it acceptable for them.

The costs and impacts of these measures should be taken into account.

3. Transition involves infrastructure changes: impacts on inhabitants should be considered

The distance between places of dwellings and places of power infrastructure construction is key in local acceptance problems (Bertsch et al., 2016). This can be explained by local impacts on human ecology and by impacts on landscapes.

a. Impacts on human ecology

Most energy transitions within scenarios involve power infrastructure changes. These changes may happen close to dwellings and have impacts on individuals. In particular, power plants and power infrastructure or equipment have different local impacts for human life. For example, wind turbines generate noise (including infrasound), shadows, ice shedding (Scherhaufer, Höltinger, Salak, Schauppenlehner, & Schmidt, 2017). Smart meters have been shown to have (psychosomatic) health effects in France. Biogas infrastructure may generate smells. Fossil fuel power plants generate local air pollution, symbolized by smokestacks.

Some infrastructure represent local industrial risks which may lead to conflicts when being installed: nuclear accidents risks, explosion risks for gas installations (such as biogas production plants) (ADEME / OpinionWay, 2017), hydropower dam ruptures and so on.

Rejection may be explained in some cases by the "fear of the unknown". A study about acceptance of power installations in Germany notes that Power-to-gas technology faces a lower acceptability than other power installations and propose that it is because this technology is still largely unknown (Bertsch et al., 2016).

Following the same line of reasoning, people living close to wind turbines, or to a nuclear plant tend to be more positive about these technologies than people who do not. This effect might be explained by a better knowledge, or more simply by a habituation, to the impacts and risks of the technology by people who live close to it, or by the inverse causation: people who think these technologies are not risky may be more willing to live close to them than people who do not.

b. Impacts on landscape

Power plants, especially VRES ones, take space and as such they modify local landscapes for more people than traditional plants.

VRES development may also require high voltage grid reinforcement. Overhead lines modify local landscapes and this is one reason why they are sometimes rejected: 30% of the high-voltage lines planned in the 2012 Ten Years Network Development Plan (TYNDP) of the European Network of Transmission System Operators for Electricity (ENTSO-E) have delays because of acceptance issues (Véronique Beillan, Caroline Bono, Sophie Bouly De Lesdain, & Fabien Bricault, 2018).

As noted by a German study about acceptance of power infrastructure installation (Bertsch et al., 2016), landscape impacts are the main driving factor of local acceptance problems. This is confirmed by other studies showing the importance of landscape modification in acceptance (ADEME / OpinionWay, 2017; Scherhaufer et al., 2017).

This is linked to the concept of place attachment and to what the installed infrastructure represents for this specific place (Bögel & Upham, 2018). Presumably, if the installed infrastructure is seen as an asset for the territory, or is associated with a desirable vision of the future for its inhabitants, or comes from a local initiative benefiting the territory, landscape impact will be judged favorably; on the contrary, if they are perceived as imposed by a centralized actor with no consideration on local interests, landscape impacts may be judged negatively. Hence landscape impact, seen through the lens of place attachment, may be associated – up to a certain point – to the other causes of conflicts, or desirability (such as structure conflicts).

Recommendations to scenario producers

Scenario producers should assess if the infrastructure changes happening in their scenarios could constitute motives for uncertainty conflicts because of human ecology and landscape modifications, depending on their location relative to dwellings and their specific impacts and perceptions within society. If such risks are detected, producers should substantiate why the transition is still desirable in the scenario, for example by compensatory measures (wealth redistribution, communication campaigns…).

C. *Substantial conflicts* emerge when opponents (citizens) contest the nature of the proposed project in general

Conflict may emerge because of the overall policy context of the project being implanted, and/or because of global impacts on society or the environment, no matter if the project is closely located to one's dwelling. This type of conflict is sometimes called the "Not in Anybody's Backyard" syndrome (ADEME, 2011).

1. Transition inducing inconsistencies between policies and society traits may trigger conflicts

Austrian citizens reacting on wind power installation reported in a poll a lack of policy coherence and consistency across territory levels and policy measures. Providing a consistent global vision was deemed important: for example, the development of renewable energy would be seen as more desirable if it goes along the creation of charging stations for electric vehicles or with the refurbishment of street lighting (assumedly, for lowering its consumption) (Scherhaufer et al., 2017).

Individual comfort or discomfort generated by a transition is important (as described in the previous section), but is not enough to explain the emergence of conflicts. The way those discomforts are distributed over the population and economic actors highly matters and should be done with a sense of equity. For example, it is important that companies bear a part of the efforts along with citizens. This also raises the political question of how to accompany those who lose the most. In other words, a global consistent vision should include considerations on equity within society.

More generally, any energy transition policy may have impacts on social inequalities or may differently affect different population categories (owners of polluting cars, dwellers of energy inefficient buildings…), which may lead to acceptance issues raised by the losers in the proposed transition (Martin & Gaspard, 2016).

The overall consistency of the transition should be clear within policies but also within society. For example, as long as driving a car belongs to a particular class and gender culture which is fostered and maintained by manly image through advertisement, the press, and gender interactions, car use cannot be altered significantly (Uzzell & Rathzel, 2010). In other words, if society incentives are not in line with policy incentives, risks of conflicts against policies increase.

Recommendations to scenario producers

Most transformational scenarios assume a global consistency across policies and society incentives. They generally assume the transition they propose is desirable as a whole.

However, these assumptions should be made explicit and substantiated, e.g. by a storyline.

In this effort, scenario producers should consider the following aspects:

- Discomfort / effort distribution across the different economic actors and across the general population, with regard to the local culture and the risks of conflicts due to possible inequities.
- Possible measures to compensate / accompany those who lose the most, as well as the associated costs and consequences.
- Alignment between society incentives and policy incentives: in case behavior trends (also see section on behaviors) are reversed, substantiation of the reversal should be provided. For example, how does the advertisement environment evolve during a significant transition from car to public transportation?

2. Transition inducing global impacts on the environment may trigger conflicts

The environmental cause grows in European countries. For example, in the context of the implementation of a wind turbines project, Austrian stakeholders considered that the impacts on natural protected areas and on species such as birds and bats were important (Scherhaufer et al., 2017).

Hence environmental considerations can be at stake in the substantial conflicts emerging from a project, no matter if the project is installed closely to the respondents to a poll.

In the German case, importing more power from countries with high shares of nuclear and coal-based power generation could lead to acceptance issues. Indeed, such a transition would be inconsistent with the national objectives of phasing out coal and nuclear power (Agora Energiewende, IDDRI, 2018).

Such a transition may generate conflict whereas local impacts are not in Germany.

Hence such topics as climate change, impacts on protected areas and wildlife, nuclear waste generation and nuclear power potential industrial risks, or overuse of the underground (for Carbon Capture and Storage, gas storage, geothermal power production, underground power transmission lines, nuclear waste storage and so on) (Bertsch et al., 2016) may be evoked in substantial conflicts.

Recommendations to scenario producers

Scenario producers should assess if the global impacts on the environment happening in their scenarios could constitute motives for substantial conflicts. If such risks are detected, producers should substantiate why the transition is still desirable in the scenario, for example by compensatory measures (communication campaigns…).

D. *Structural conflicts* emerge when projects are proposed and driven by non-legitimate actors.

1. More conflicts about public or private infrastructure building can be expected in Europe in the future

More than ever in EU countries, policies and public projects are criticized through the lens of legitimacy. Expertize and scientific facts, which used to be trusted and perceived as legitimate, have lost their influencing power through several mechanisms, as illustrated by the French case (Merad & Trump, 2018).

First, the public loses trust in the government's capacity and will to sustain critical services and to represent the general interest, because (a) large range of activities have shifted from the public to the private sectors, (b) government reactions to past events[2] have been poorly framed and poorly understood by the public, leading to distrust towards government experts (c) public value of projects is sometimes not discussed not even delineated, and (d) growing regulatory complexity increasingly prevents public understanding of how the system functions and why it represents common values.

In addition, the corporate world has lost legitimacy to represent the general interest after cases of "doubt manufacturing" (such as in the Tobacco industry case, or climate change topic) in which scientists have been paid to publish 'product-friendly' scientific studies. In addition, such cases shed doubt on the whole scientific fact.

(Merad & Trump, 2018) conclude: "Coupled with a lack of "citizen culture" and a perceived opacity of the governance and management of common and public affairs, industrial lobbying and collusion with politics has introduced distrust in politics that has contaminated the administrative credibility and reliability of various regulatory agencies in France and abroad."

As a result, more and more decisions to create infrastructure projects, which are based upon a mixture of scientific, business and political negotiations are perceived as not based on the civil perception of evidence because decision agents have lost legitimacy to represent the general interest.

No matter the nature and content of the proposed projects constitutive of the transition, an increasing number of conflicts can be expected as a general trend, finding their roots in legitimacy issues.

Recommendations to scenario producers

Scenario producers should make their strategy about legitimacy issues explicit: do their scenarios include considerations on this topic?

If the currently observed trend in loss of legitimacy of traditional project holders (the State and large/medium corporations) is reversed in the scenario, the storyline should explain why.

Otherwise, impacts of the continued loss of legitimacy should be assessed: is the governance of the transition modified and if so, what are the associated costs? Are transition projects modified? Do they cost more? Do they take more time to implement?

2. Transition may involve data management evolutions: impacts on citizens should be considered

Smart grids require more data about local power consumption, especially data about household's consumption. Data are collected by power distribution companies through automated smart meters (less costly than a human meter reader). This may lead to concerns by some people about the use of their data by these companies. This issue may be linked to a lack of legitimacy in the actors supposedly controlling the collected data.

Recommendations for scenario producers

Scenario producers should assess if the personal data management changes happening in their scenarios could constitute motives for uncertainty conflicts. If such risks are detected, producers should substantiate why the transition is still desirable in the scenario, for example by compensatory measures (management of the data by other, more legitimate bodies, communication campaigns…).

[2] "For example, after Chernobyl (1986), the French authorities in charge of radioprotection endorsed a controversial position in the media that radioactive material from the Chernobyl disaster stopped at the French border (implying that no public health consequences would be borne by the French people)." (Merad & Trump, 2018)

E. Project implementation procedures, such as concertation, may help avoiding conflicts

In order to avoid some of the abovementioned conflicts, local concertation procedures can be followed within territories before projects are launched. Such procedures can lead to improvements in the proposed local projects and to time saving in their implementations. For example, fair revenue distribution may be defined to reduce envy and distrust (e.g. between land owners, residential population, project holders) (Scherhaufer et al., 2017).

Some scenarios assess the impacts of such procedures through sensitivity analyses, coined as "low acceptance" scenarios (ADEME, 2015; ADEME / Artelys, 2018). Power mix modifications happen, which impacts the total cost of the system. However, the costs of organizing and running those local concertation procedures are not taken into account.

Recommendations for scenario producers

Energy transition scenarios in which acceptance issues may lead to conflict may propose, as a general tool, concertation procedures between local actors in territories where those risks arise. By doing so, associated costs (linked to the organization and running of the procedure) and possible consequences (such as different choices of infrastructures) should be taken into account[3].

F. Sunk costs derive from transition urgency and may rise desirability issues

Sunk costs is the part of the capital invested in an existing asset that has not been recovered when the asset is closed. Thus, sunk costs appear whenever an asset is closed before its economic lifetime. The asset is said to be "stranded".

Such situations can trigger conflicts depending on who handles the loss.

1. For society, sunk costs reveal an inconsistency between past choices and new objectives

From a society perspective, a power plant going stranded indicates that the decision to build the plant was an economically suboptimal choice. Indeed, it means the shutdown of the plant is now considered as the best decision despite the fact it could have still worked. Sunk costs arise when past choices are no longer compliant with society's current objectives. A typical example is the premature shutdown of a coal power plant due to its high air pollutant and/or GHG emissions, through regulation, market or tax. In such a (still fictional) case, the past decision of building the coal power plant, based on economic criteria, is considered by society as obsolete in light of climate change considerations. Other examples include car ban in some cities. People owning a car in such cities may undergo a strong loss of utility from their cars, because they cannot use it anymore and because it loses monetary value on the market at the same time.

Stranded assets risk is therefore strongly linked to the time horizon choice of a study (see future studies section) and its social objectives. As explained in the corresponding part, a CGDD study (2016) (CGDD, 2016) shows how some choices with short-term vision can enable to efficiently reach short-term objectives but be counterproductive on the long-term. Doing the same optimization with a long-term objective in mind changes their result: in their case, much more energy carrier changes are made to avoid lock-in after the end-date of the optimization. Thus, when using a marginal abatement cost curve, they recommend to choose carefully the time horizon(s).

[3] This recommendation sums up parts of previous recommendations, about the consequences of avoiding the different types of conflicts we presented.

2. Stranded assets burden sharing may rise desirability issues

By definition, risk of stranded assets rises with the rate (speed) of a transition. This is a typical transition risk. Thus, required changes to face 21st century challenges may put many assets in a stranded position. These sunk costs are a serious issue and well known debate, often cited as a key challenge of energy transition. Indeed, someone has to pay for it. It can be the company operating the stranded asset (e.g. a coal power plant being shut down by law), the user of an owned asset (e.g. a car forbidden to access an area), and/or the State (in case a compensation is provided when the asset gets stranded). In any case, it can raise serious desirability issues.

The perceived fairness of the burden sharing is key in its desirability.

Recommendations for scenario producers

Scenario producers should report about their strategies on stranded assets and sunk costs. Substantiation should be provided if the subject is not handled. If the subject is handled, the following aspects on sunk costs may be reported about:

- Total amount of sunk costs in the scenario. From a society point of view it gives the magnitude of acceptability issues arising from sunk costs. This can be reported in the storyline. *Is there any sunk costs in the scenario? Do they represent a large burden for society?*

- Burden sharing of the sunk costs. *Who loses money when an asset gets stranded in the scenario? The owner of the asset? The State?*

- Possible lack of desirability of the proposed transition due to sunk costs. *Regarding the burden sharing choices in the scenario, may the proposed transition feel unacceptable for some stakeholders?*

G. Better integrating desirability issues in scenarios

As previously argued, imposing elements of a transition through coercion might be extremely costly, would it be in terms of surveillance, propaganda and coercion means but also, evidently, in terms of health and social welfare. No scenario to our knowledge assumes such a coercion to accompany the described transition.

When desirability is explicitly considered, it is often seen as highly uncertain, leading to sensitivity analyses rather than being fully integrated in each scenario at the design stage ((ADEME, 2015; ADEME / Artelys, 2018) perform such sensitivity analyses). In the "high acceptance constraint" scenario from (ADEME, 2015), ground PV panels and on-shore wind turbines are constrained in terms of location: the land which is available for their installation is greatly reduced, assuming households would not desire them close to their houses. In (ADEME / Artelys, 2018), the "low acceptability for ground renewables" scenario assumes an extra cost for these technologies. (European Commission, 2011) provides different scenarios which depend on public acceptance of nuclear technology.

(ECF, 2010) sees desirability issues as an uncertainty which can drive up costs significantly if the described scenarios are to be implemented. But the study does not provide any estimate of the impacts if these issues would turn true.

Sometimes though, some technologies are assumed to be unacceptable and as such are excluded from the study. For example, (Agora Energiewende, IDDRI, 2018) considers in all its scenarios that very large on-shore wind turbines will not be installed in France or Germany because of acceptance issues.

Other studies, such as (Association négaWatt, 2014; Association négaWatt, 2017; Greenpeace, 2015) do not accept nuclear power in their transformational scenarios. By doing so, they are not exactly taking into account acceptance issues. Indeed, they do not only assume nuclear will face desirability issues if it is installed: they, as scenario producers, do not accept it. This directly affects the driving questions they seek to answer. "What could be the energy mix without nuclear power?" is one of them.

In all those cases where acceptability is explicitly considered, only uncertainty conflicts due to the building of new infrastructure are considered as a risk.

Recommendations to scenario producers

Here are some recommendations to properly include desirability issues in scenarios.

Conceptually, there are several ways to include desirability issues in scenarios:

- Desirability can be fully included in the study design, either by substantiating that all the transition elements which are implemented pose no desirability issue, or by detecting desirability issues and including in the results the consequences of these desirability issues. The consequences can be valued in terms of cost, CO_2 impacts and so on, depending on the adaptation by the various modeled actors to the transition elements they deem unacceptable. For example, households can get equipped with diesel generators if power security of supply is not ensured, which would lead to extra costs and, possibly[4], to emitting extra CO_2 emissions.
- As already done in some studies, desirability can be seen as highly uncertain and lead to sensitivity analyses. However, in scenarios in which acceptability is assumed to be low, the consequences of these acceptability issues should be described and their impacts assessed.
- Another way to handle the desirability issue is to provide *concrete*[5] assessment of the consequences of the proposed transition. Indeed, scenario producers cannot be fully informed about the possible desirability issues within complex and evolving populations and cultures. Beyond keeping in mind the recommendations presented above, a way to overcome these uncertainties is to be as concrete as possible about the evolution of lifestyles in the proposed scenarios (see section on lifestyles and behaviors). With concrete descriptions, scenario users can discuss the proposed lifestyles, and investigate their desirability. They can then provide feedback to scenario producers and to the rest of the scenario community so that remarks and knowledge be shared.

[4] Depending on the power mix
[5] See section on Future studies

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The Shift Project

The Shift Project, a non-profit organization, is a French think-tank dedicated to informing and influencing the debate on energy transition in Europe. The Shift Project is supported by European companies that want to make the energy transition their strategic priority & by French public funding.

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Environmental assessment of energy transition scenarios

Technical file #10 – Draft version

Information and recommendations for scenario producers

This document is part of a set of 12 technical files. These files have been produced by *The Shift Project* after one year and a half of research and experts consultations on the different aspects of energy transition and the future studies around these aspects.

Our project, "Power Systems 2050 – Guidelines for design," started in January 2018, with the participation of 10 experts who defined the key subjects which according to them have to be collectively tackled by future studies about the power transition. *The Shift Project* then investigated each of these subjects, consulting in total 40 experts, organizing 4 workshops, and reviewing a large bibliography, including a dozen of future studies about power (and energy) transition at different geographical scales.

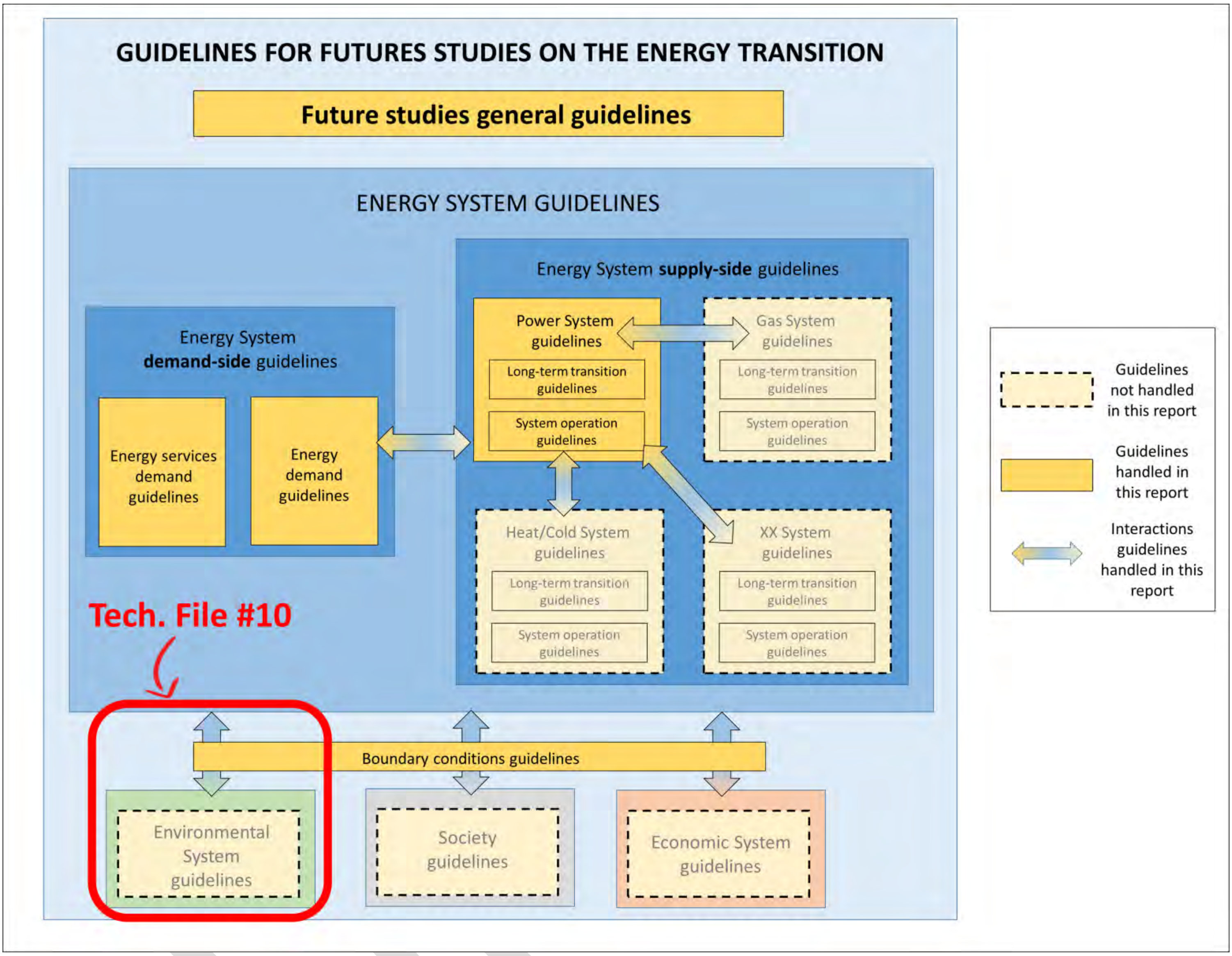
The goal of this project is to produce a set of guidelines addressed to scenario producers. These guidelines seek to foster transparency and consistency *within* future studies and to develop a common language *across* studies. By defining a number of important items which are key to deal with in future studies, we actually propose a study template which enables a better understanding of the location of each proposed scenario on the tree of possible transitions. Once again, the objective is not to *rank* studies, or scenarios, but rather to *compare* them to get a better collective overview of the different aspects of the transition (what are the differences between studies in terms of driving questions, hypotheses, models, methodology, results?).

Several aspects of the energy transition are handled in these technical files. However, on the energy supply-side only the power system has been studied. The main reason for this choice is that we had to start from somewhere with limited resources, and the power system seemed to be a key system to study in the energy transition context, towards a low-carbon economy, as shown by the growing number of future studies focusing on this system. However, the guidelines we propose could be completed by analyzes on the other energy supply-side systems (the gas system, oil system, heat system and so on).

Each technical file tackles several aspects of future studies for the power (and energy) transition. Here is the complete list of the technical files produced during the project:

#	**Technical file title**
1	Future studies on the energy transition
2	Energy transition models
3	Boundary conditions for energy transition scenarios
4	Long-term evolution of energy consumption in energy transition scenarios
5	Lifestyles and consumption behaviors in energy transition scenarios
6	Long-term evolution of the power system supply-side in energy transition scenarios
7	Power system operation in energy transition scenarios
8	Impact assessment in energy transition scenarios
9	Transition desirability in energy transition scenarios
10	Environmental assessment of energy transition scenarios
11	Economic evaluation of energy transition scenarios
12	Employment assessment of energy transition scenarios

Altogether, these files cover the fields described on the following map of the guidelines for future studies on the energy transition. The document you are reading covers the red-circled topics.



In addition to these technical files, three complementary notes have been produced as specific focuses on the following aspects: material criticality in energy transitions (in French, to be translated and added to technical file #10), levelized cost of electricity (LCOE) in energy transition future studies (in French) and discount rate in energy transition future studies (in French).

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Table of content

Reading keys

Explanation box, containing key information for a better overall understanding of the subjects.

Recommendations to scenario producers:

These boxes contain the recommendations for scenario producers.

The word "should" means that scenario producers, if they are to follow the guidelines, must substantiate the corresponding point. The words "may" or "might" relates to suggestions, ideas to help the scenario producer respond to the point.

Questions in italic are examples of questions scenario producers might ask to substantiate the points. They are here in an illustration purpose.

Phrases in italic relate to words which are being defined and will be subsequently used in the framework.

Phrases which are highlighted in yellow refer to other technical documents of this series.

I. Environmental assessment

A. The environment is a surrounding system for human societies

The environment is considered in this report as a *surrounding system*. In this report, the *core system* is the energy system or some of its components (such as the power system); surrounding systems are systems in which the core system operates (society, the economy, or the environment).

However, the environment has a special position among surrounding systems, as it surrounds both the core system and economic and social systems. By surrounding, we mean that the environment also contains the other systems.

Environment can be defined as follows (André, Delisle, & Revéret, 2009): environment is an organized, dynamic and evolving system composed of natural elements (physical, chemical and biological) and of human elements (economical, political, social and cultural) in which living organisms operate (including human activities) and in which they affect these living organisms (and human activities) either directly or indirectly, immediately or on the longer term.

This definition highlights the inclusiveness of the environment. It also highlights its complex and dynamic nature: organisms act within the environment, which in turn affects the environment, and these environmental changes may affect back the organisms directly or indirectly, following complex feedback loops structures with different temporalities.

Seen from human societies, the effects back on humans may be delayed (such as carcinogenic effects of air pollution, or extreme weather events due to GHG emissions), may happen remotely (such as effects of gaseous emissions in the atmosphere), they can be combined (such as climate change effects and habitat fragmentation effects on biodiversity, in turn affecting crop productivity), they can be non-linear with threshold effects (such as climate change with regards to the amount of GHG emissions).

Environment can be described along different space scales:

- Micro environment is at the level of the individual (its habitat for non-human living organisms, its dwelling or neighborhood for human beings)
- Meso environment is at the level of a group of individuals, or society (enlarged habitat, city, region or State)
- Macro environment is at the continent or world level (biosphere, human life)

Human beings have different decision processes and levers at these different scales to perform activities. These activities may interact with their micro or meso environment (local impacts, such as air pollution) or on their macro environment (global impacts, such as climate change or sea level rise, stratospheric ozone depletion, ocean acidification and so on).

In this section, we tackle the following interactions between the energy system evolution and the environment: greenhouse gases (GHG) emissions; impacts on the biosphere; land use; air pollution; water use; solid wastes; and noise. Note that questions on resource availability and criticality are dealt with in section about Boundary conditions.

Studies we reviewed generally include considerations on GHG emissions; a few consider air pollution; a few consider mineral resources use. Other impacts are rarely talked about, and never quantified.

B. Greenhouse gases (GHG) emissions

Greenhouse gases emissions have several global impacts such as climate change and sea level rise. These impacts are global because the atmosphere blends within about a year. Hence no matter where they are emitted, they quickly get blended all around the Earth.

Technically speaking, greenhouse gases are atmospheric gases which intercept infrared radiations from the Earth surface. Some of them are naturally present in the atmosphere, some others only come from human activities; some are naturally present but human activities significantly increase their amount in the atmosphere on the long-term. Increasing their amount on the long-term leads to modify (on the long-term) the radiative balance of the

Earth, storing more energy within the Earth system, in turn modifying the stable environment in which ecosystems developed.

The consequences of these processes are various: increase of the global average temperature, sea level rise (because of water dilatation due to this temperature increase and because of ice sheets melting); increase of the frequency and/or magnitude of extreme weather events (droughts, heat waves, storms…)… These consequences are usually called "physical risks"[1].

Future studies logically focus on those GHGs which are emitted by human activities and for which those emissions lead to a significant increase of their amount in the atmosphere. Several practices can be found in future studies when it comes to GHG considerations. They all depend on the driving questions and perimeter of the study.

Within our scope, one study does not consider greenhouse gases (GHG) at all. Its driving questions are about technical aspects of prototypical power systems, and costs of these different systems (ADEME, 2015). All the other studies include considerations on GHGs.

The differences between these studies pertain to the GHG emissions models (that is, their computation in a consistent way vis-à-vis the proposed core system evolution within each scenario) which are used.

Some studies model *energy-related* CO_2 emissions only (ADEME / Artelys, 2018; Agora Energiewende, IDDRI, 2018; ENTSOG/ENTSO-E, 2018). Energy-related CO_2 emissions are those emissions produced when carbon-based fuels are burnt, such as within ICE vehicles, in gas or fuel boilers, in gas or coal power plants, in gas industrial ovens and so on. Usually, the studies considering only energy-related CO_2 emissions focus on the power system only, or on the energy system only.

Some other studies model *process-related* CO_2 emissions and other GHG emissions, in addition to energy-related CO_2 emissions (ADEME, 2012; ANCRE, 2013; ECF, 2010; European Commission, 2011; Greenpeace, 2015; OECD/IEA, 2017; SFEN, 2018)[2]. Process-related CO_2 emissions are those emissions due to some transformation processes within the industry, such as cement or glass production which emit CO_2 during specific phases of their transformation. The other GHGs which are usually considered are those included in the UNFCCC framework for GHG reporting for countries (UNFCCC, 2014): carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF6) and nitrogen trifluoride (NF3). Those GHG are emitted from agriculture activities, operation of the energy system, some industrial processes and from the use of refrigerants (ANCRE, 2013). The core system of these studies usually is the whole energy system and the agriculture system together.

Some studies modeling energy-related CO_2 emissions only also roughly quantify the evolution of process-related CO_2 emissions and other GHG emissions in order to provide an all GHG reduction assessment (Association négaWatt, 2014; Fraunhofer ISE, 2015). This rough estimate is largely uncorrelated to the proposed energy system evolution, this is why these emissions cannot be said to be modeled.

Some studies also include, in addition, the CO_2 emissions or storage due to Land Use, Land Use Change and Forestry (LULUCF) (Association négaWatt, 2017; European Commission, 2016; IIASA, 2012). These emissions are those due to the fact that different types of lands contain different amounts of stored carbon, so changes in land use and forestry practices may release CO_2, or store carbon. The core system of these studies includes the energy system, the agriculture system as well as the different land uses.

The larger the core system of the study, the more comprehensive the GHG assessment can be.

One study we reviewed models energy-related CO_2 emissions only for the power system supply-side, but with a footprint approach (Hammond, Howard, & Jones, 2013). This approach further questions the choice of technologies used for the transition to produce, store, transport and distribute electricity.

[1] Another type of risk is often talked about: transition risks. These risks are actor specific and are linked to the fact of performing an energy transition. They are talked about in terms of inertia of the socio-technical systems which evolve during the transition (in the Future studies section), in terms of stranded assets and sunk costs (in the Economic evaluation section) as well as in terms of desirability (in the Desirability section and employment section).

[2] (Greenpeace, 2005; Greenpeace, 2012; Greenpeace, 2015; Greenpeace EREC, 2008) are not transparent enough to be sure about their approach.

Recommendations to scenario producers

A strategy about GHGs emissions assessment should be defined and substantiated with regards to the driving questions. The following aspects should be considered:

- Impact definition: GHGs which are included in the assessment
- Type of assessment approach which is used (territory, or footprint)
- Inventory: Activities and processes which are considered as sources of these GHGs emissions
- Modeling methodology

C. Impacts on biosphere

The biosphere is the set of all living organisms and their habitats, that is, the set of all ecosystems surrounding us. The biosphere is usually considered as important for human beings for the "ecosystem services" it brings to us.

These services are only the visible part of all the interactions within the biosphere. Within an ecosystem, species interact with each other, and within species individuals interact with each other. Ecosystem services are some of the emergent patterns of all those complex interactions. More specifically, they are the ones which are important to us as human beings. Focusing only on the last links providing the service (for example, focusing on bees for pollination instead of understanding the whole net of ecosystem interactions between bees and their environment, would it be physical, chemical or trophic environment) is a narrow view. It fails to see that the service is actually sustained by a whole set of processes and interactions with other elements of the biosphere. As such, the ecosystem services approach does not enable to uncover all the risks leading to the decline and extinction of the services it aims to study.

A classical measure of biosphere integrity is that of biodiversity, a concept which includes the genetic diversity within each species, the diversity of species, and the diversity of ecosystems.

The greatest causes of biodiversity losses are the following (IPBES, 2019):

- Habitat transformation through land use / sea use change. "Agricultural expansion is the most widespread form of land-use change, with over one third of the terrestrial land surface being used for cropping or animal husbandry. This expansion, alongside a doubling of urban area since 1992 and an unprecedented expansion of infrastructure linked to growing population and consumption, has come mostly at the expense of forests (largely old-growth tropical forests), wetlands and grasslands" (IPBES, 2019). Habitat transformation can also happen through habitat fragmentation (e.g. due to the road, or electricity networks), habitat space reduction (due to the proximity of human activities, noises).
- Overexploitation of animals, plants and other organisms mainly via harvesting, logging, hunting and fishing.
- Climate change. "The frequency and intensity of extreme weather events, and the fires, floods and droughts that they can bring, have increased in the past 50 years, while the global average sea level has risen by 16 to 21 cm since 1900, and at a rate of more than 3 mm per year over the past two decades. These changes have contributed to widespread impacts in many aspects of biodiversity, including species distributions, phenology, population dynamics, community structure and ecosystem function" (IPBES, 2019).
- Many types of pollution, as well as invasive alien species, are increasing, with negative impacts for nature. "Marine plastic pollution, untreated urban and rural waste, pollutants from industrial, mining and agricultural activities, oil spills and toxic dumping have had strong negative effects on soil, freshwater and marine water quality and the global atmosphere" (IPBES, 2019).

In freshwater ecosystems, a series of combined threats that include land-use change, water extraction, exploitation, pollution, climate change and invasive species, are prevalent.

No energy transition future study to our knowledge quantitatively assesses the evolution of the biosphere for its different scenarios. However, (Association négaWatt, 2017) provides information about the variation direction of the overall impact on biosphere of its "négaWatt" scenario compared to its Reference scenario. (European

Commission, 2011) provides information about the impacts of the energy system on biosphere without explicitly linking those considerations to its different scenarios.

Most likely, computationally modelling biosphere and its integrity is not realistic. However, a qualitative assessment based on demographic evolution, on energy and material extraction, on water use, on land use, on built infrastructure (would it be demand side infrastructure such as roads, or supply-side infrastructure such as hydropower dams) and on the specific environmental practices of the different economic agents may be useful to inform the energy transition debate.

Recommendations to scenario producers

A strategy about biosphere integrity assessment should be defined and substantiated with regards to the driving questions. The following aspects may be considered:

- Impact(s) definition: Drivers of biosphere evolution which are considered in the assessment (habitat transformation, exploitation of living organisms, climate change, pollution, invasive alien species)
- Type of assessment approach which is used (territory, or footprint)
- Inventory: Activities and processes which are considered as sources of the biosphere evolution.
- Modeling methodology. The methodology can be qualitative in order to trigger discussion with stakeholders and to inform the debate about the interactions between the energy transition and biosphere. *For example, for each considered activity in the scenario, does it improve/degrade habitat, does it increase/decrease the exploitation of living organisms and so on.*

D. Land use change

Land use and land use change impacts are by essence local (they happen where the land is used). However, these impacts may be indirect, such as when agricultural production switches from food use to biofuel production use (no direct land use change), triggering in turn deforestation to farm in order to produce the missing food (indirect impact).

As previously mentioned, land use changes have significant impacts on carbon emissions or storage, as different types of soil and vegetation store more or less carbon. They also have impacts on the biosphere. Furthermore, those changes may be more or less desirable by local populations (see section on desirability).

As previously described, the drivers of land use change at the world level is agriculture. However, energy system evolution may also greatly affect land use both through supply-side installations[3] and through demand-side evolutions.

Concerning the former aspect (supply-side), land may be differently occupied by supply-side installations: either land is entirely dedicated to the installation, or it can be used for other purposes (Criqui, 2013). For example, ground PV installations may cover other activities from the Sun, hydropower dams may be used for irrigation and leisure activities (or even for installing floating PV panels), and so on. Some installations may also reduce the number of activities which can be performed on their land, causing land use conflicts (and desirability issues). For example, off-shore installations may cause conflicts with fishery activities. Supply-side evolution may also lead to evolutions in biofuel production, or energy wood production. These productions are actually photosynthesis exploitation through agriculture and forestry. As such, their evolutions may lead to direct or indirect land use changes.

Concerning the latter aspect (demand-side), as explained in the lifestyles and consumption section, urban planning and transportation networks are two key technical and organizational systems which influence energy demand.

A few studies assess the evolution of land uses per say (that is, not only for computing LULUCF GHG emissions) either qualitatively or quantitatively through the area of land used by the energy, or power, system supply-side (ADEME, 2015; ANCRE, 2013; Association négaWatt, 2017).

[3] For a comprehensive assessment of the space required to extract and refine primary energy, see (Smil, 2015).

Recommendations to scenario producers

A strategy about land use change assessment should be defined and substantiated with regards to the driving questions. The following aspects may be considered:

- Impact(s) definition: specificities of lands (area, current land use(s), types of land…). *For example, does the study only assess total surface of land use change, or does it assess land use change along different types of lands (forests, marshlands, croplands…), or does it assess the nature of the changes (e.g. from fishery to electricity production)?*
- Type of assessment approach which is used (territory, or footprint)
- Inventory: Activities and processes which are considered as sources of land use changes.
- Modeling methodology. The methodology can be qualitative in order to trigger discussion with stakeholders and to inform the debate about the land use changes involved by the proposed energy transitions. Desirability aspects such as impacts on human ecology or on employment may be discussed. Such discussions are much more concrete than the sole indication of the total surface of land which changed during the transition.

E. Air pollution

Air pollution may be defined as any atmospheric constituent present as a result of anthropogenic activity or natural processes that causes adverse effects to humans, animals, vegetation, or materials. Air pollution is an impact on the meso-environment (typically, city scale).

The main adverse effects usually considered in the public debate are effects on human health (respiratory and cardio-vascular diseases, cancers) and acid rains. According to the World Health Organization, 1.3 million people die each year for air pollution reasons in the world (« OMS | Effets sur la santé de la pollution de l'air en milieu urbain », 2019).

The main air pollutants which are considered in national legislations and in future studies are the following (IIASA, 2012; Liu, 2015):

- Sulfur dioxide (SO_2). It affects human health and it is a precursor to acid rains and particulate matter. It is produced by the burning of fossil fuels contaminated with sulfur compounds (such as coal or heavy oil) and copper extraction.
- Nitrogen oxides (NOx). It affects human health and it is a precursor to acid rains. It is produced through the combustion of fuels at high temperature such as in ICE vehicles or power plants, and through agricultural fertilization.
- Carbon monoxide. It is a highly toxic gas, inhibiting respiratory functions. Carbon monoxide poisoning is the most common type of fatal air poisoning in many countries (Omaye, 2002). It is mainly produced by ICE vehicles.
- Volatile organic compounds (VOC). They have effects on human health. They can have anthropic sources such as the use of various chemicals such as paints and coatings, ICE vehicles and other sources.
- Particulate matter PM2.5 and PM10. They are particles which can be inhaled and are classified by size. The smaller the particle, the deeper in the lungs it can get. They affect human health. They are produced by industrial combustion, agriculture, ICE vehicles, and construction industry, under the form of dust, soil, soot or smoke.

Some of these pollutants interact with each other and with other atmospheric components (called precursors) to produce secondary air pollutants following complex interactions.

A few studies model air pollution: (IIASA, 2012; OECD/IEA, 2017) use the GAINS model to do so. (ADEME, 2012) uses another model first computing the emissions of primary pollutants and precursors of secondary pollutants, and then assessing air quality in urban areas through a second module.

Recommendations to scenario producers

A strategy about air pollution assessment should be defined and substantiated with regards to the driving questions. The following aspects may be considered:

- Impact(s) definition: air pollutants which are considered in the study
- Type of assessment approach which is used (territory, or footprint)
- Inventory: Activities and processes which are considered as sources, or precursors of the pollutants (both primary and secondary)
- Modeling methodology

F. Water use

Water use may affect sea water and/or freshwater; freshwater can be running water or fossil water (non renewable water, typically groundwater in an aquifer). It may affect water quality and/or water flow. Water quality can be measured along several dimensions (temperature, pH, amount of dissolved oxygen, amount of toxic substances…). Water use has local impacts.

Water use affects the biosphere. For example, thermal power plants (nuclear or fossil fuel power plants) need a cooling source to properly operate. Some of them use water as a cooling source, in turn releasing water that is warmer than the ambient water. Local ecosystems may be sensitive to these releases. Legislations control local water temperatures, sometimes leading to power plants' temporary shutdown in case of heat waves. Hydropower dams also have impacts on the biosphere (other than the direct submersion of the local ecosystems), preventing sediments and species to move freely.

Water use can also directly affect human activities (fishery, irrigation, industrial cooling, leisure activities…), or human direct water consumption, hence rising water use conflicts and desirability questions.

Water is used in nearly all industrial processes within the energy sector (extraction, processing of fossil fuels and uranium, biomass production and conversion, thermal, nuclear, geothermal, hydro- electricity production). As a result, the energy sector represents nearly 50 % of water withdrawal in developed countries[4] (Lemoine, 2016).

No future study about energy transition quantitatively tackles the question of water use to our knowledge. Some studies provide qualitative considerations about this aspect: (Association négaWatt, 2017) qualitatively considers the variation direction of water consumption in its "négaWatt" scenario compared to the Reference scenario. (European Commission, 2011) provides qualitative considerations on this aspect without linking them explicitly to its different scenarios.

Recommendations to scenario producers

A strategy about water use assessment should be defined and substantiated with regards to the driving questions. The following aspects may be considered:

- Impact(s) definition: specificities of the water which is used (sea water, freshwater); specific indicators which are used (volume of consumed water, water temperature…)
- Type of assessment approach which is used (territory, or footprint)
- Inventory: Activities and processes which are considered as sources of water use
- Modeling methodology. As the considered impacts are local, local conditions would have to be known in order to precisely assess and discuss the impacts of water use evolution. As a result, qualitative general considerations can be provided and some case studies could be examined to illustrate specific effects of the proposed energy transition. Important aspects to discuss are impacts on biosphere and desirability aspects (for individuals and businesses).

[4] Water withdrawal is the amount of water withdrawn from a source whereas water consumption is the amount of water which is not released back in the source.

G. Hazardous and nuclear solid wastes

Solid wastes are of various natures. However some of them can be reused, or recycled, or incinerated, biologically or chemically treated. After these options, some wastes remain and are landfilled. Part of these wastes are categorized as "hazardous", other as non-hazardous, with regards to the landfilling practices (Méhu, 2016). Ultimate nuclear wastes[5] are treated, stored and landfilled in separate processes.

These solid wastes have local impacts if properly stored. They may have impacts on the meso-environment in case leachate risks[6] are not properly managed, polluted water then circulating in the environment. However, several practices are applied to avoid leachate being formed and being released in the environment: waste can be vitrified, as is performed for nuclear waste, preventing any contact with water, or landfills can be equipped with leachate collection and treatment systems.

Numerous activities linked with the energy system generate hazardous wastes (SEPA/Environment and heritage service/Environment Agency, 2003): different activities in fossil fuels extraction and transformation/refining; combustion of fossil fuels in power plants and in industrial processes generate ashes and residues which ultimately have to be landfilled; end-of-life vehicles contain different substances considered as hazardous; some end-of-life batteries are hazardous waste… These wastes have various effects on, or pose various risks for, human health and the environment in case of direct exposure (Directive 2008/98/EC on waste, 2008): they can be explosive, highly flammable, irritant, harmful, toxic, carcinogenic, corrosive, infectious, mutagenic, ecotoxic…

Nuclear industry generate nuclear wastes, during and after uranium extraction, uranium treatment and enrichment, residues from nuclear power production, radioactive waste from power plant dismantling. These wastes are categorized according to two criteria: radioactivity level and radioactivity duration. These wastes mainly have long-term carcinogenic effects on humans, and living organisms, in case of direct exposure (« Answers to Frequently Asked Questions (FAQs) by UNSCEAR », 2019).

A few future studies on the energy transition consider solid waste. (Association négaWatt, 2017) estimates the variation direction of the amount of waste (without waste distinction) produced from its Reference scenario to its négaWatt scenario. (European Commission, 2011) assesses the variation direction of the amount of nuclear waste which will have to be managed in its different scenarios, compared to its Reference scenario.

Recommendations to scenario producers

A strategy about hazardous and nuclear waste assessment should be defined and substantiated with regards to the driving questions. The following aspects may be considered:

- Impact(s) definition: specificities of wastes which are considered (hazardous or not, nuclear, type of effect on human health or the environment, radioactivity level, radioactivity duration…). *For example, does the study only assess the total amount of solid waste from the energy sector, or does it assess the amount of nuclear, and hazardous waste?*
- Type of assessment approach which is used (territory, or footprint)
- Inventory: Activities and processes which are considered as sources of the considered wastes.
- Modeling methodology. The methodology can be qualitative in order to trigger discussion with stakeholders and to inform the debate about waste generation and management involved by the proposed energy transitions. Desirability aspects may be discussed. Such discussions are much more concrete than the sole indications of the total amount of generated waste during the studied transitions.

[5] That is, those which are considered as not usable in future industrial processes.
[6] Leachate is water which passed through the waste and extracted soluble or suspended solids within the waste.

H. Noise

Noise can be defined as annoying sound, which is a partly subjective definition. However, above a certain volume level, any sound is annoying for human beings (« Bruit. Définitions - Risques - INRS », 2019). Noise is a local impact, as sound level rapidly decreases with distance to the sound source.

Noise has effects on health, mainly on auditory capacities, and generates stress and sleep problems.

Noise is generated by air movement, hence technically any process involving movement can be a source of noise. However, as noise has a subjective definition, it has to be linked with desirability questions. Most commonly considered sources of noise within the energy system is noise from passenger or freight transportation (ground or air transportation), and from the operation of some power plants (such as wind turbines).

Noise is not considered in the future studies we reviewed.

Recommendations to scenario producers

A strategy about noise assessment should be defined and substantiated with regards to the driving questions. The following aspects may be considered:

- Impact(s) definition: what specific aspects of noise are considered
- Type of assessment approach which is used (territory, or footprint)
- Inventory: Activities and processes which are considered as noise sources
- Modeling methodology. As the considered impacts are local, local conditions would have to be known in order to precisely assess and discuss the impacts of noise. As a result, qualitative general considerations can be provided and some case studies could be examined to illustrate specific effects of the proposed energy transition. An important aspect of noise impact is the desirability for individuals.

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The Shift Project

The Shift Project, a non-profit organization, is a French think-tank dedicated to informing and influencing the debate on energy transition in Europe. The Shift Project is supported by European companies that want to make the energy transition their strategic priority & by French public funding.

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Criticité des métaux et autres matériaux dans les scénarios de transition

Fiche technique – Pour discussion. Version française.

Table des matières

Clés de lecture

Encart explicatif, contenant des informations clés permettant une meilleure compréhension globale du sujet.

Recommandations pour les producteurs de scénarios :

Ces cadres contiennent des recommandations pour les producteurs de scénarios.

Le terme "devrait" (ou "devraient") signifie que les producteurs de scénarios, s'ils veulent suivre les lignes directrices, doivent justifier le point correspondant. Les termes "peut" ou "pourrait" indiquent des suggestions, des idées pour aider le producteur du scénario à répondre à ce point.

Les questions en italique sont des exemples de questions que les producteurs pourraient se poser pour étayer leurs arguments. Elles sont ici dans un but d'illustration.

Les phrases surlignées en jaune font référence à d'autres documents techniques de cette série.

I. La criticité des métaux : un enjeu complexe, potentiellement dimensionnant, et peu traité dans les études prospectives sur la transition énergétique

A. Un enjeu clé sous-estimé malgré un intérêt croissant

Les métaux et matériaux sont, avec les énergies fossiles, une des principales **ressources de stock** que nous utilisons à grande échelle sur la planète. Leur exploitation à l'échelle mondiale a fortement augmenté dans les années 2009-2010. Ainsi, leur possible épuisement pose question, comme cela est résumé dans l'étude (ADEME, 2017) :

« La croissance exponentielle de la demande risque d'être supérieure au rythme de la croissance des capacités d'exploitation. En conséquence des pénuries sur certaines matières minérales pourraient survenir dans un avenir proche (10 ans). Dans une croissance continue de la demande à 2 ou 3% le recyclage ne pourra pas répondre à cet accroissement et restera à moins de 20% des approvisionnements nécessaires.

Par ailleurs les conséquences environnementales locales de l'exploitation de ces gisements en limiteront l'acceptabilité sociale si elles ne sont pas totalement maîtrisées. En outre l'augmentation des consommations énergétiques de ce secteur risque de rentrer en confrontation avec la lutte contre le changement climatique. Ce n'est probablement pas l'épuisement des métaux et minéraux qui est à craindre mais très certainement la fin de l'extraction et de la disponibilité faciles. »

Or, nombreuses sont les études prospectives proposant des scénarios de transition et qui n'étudient pas ces questions de criticité des métaux et matériaux. Certaines proposent parfois des transitions au niveau mondial, en faisant appel souvent à des changements importants incluant une large part d'énergies renouvelables, de grandes capacité de stockage, un fort développement du véhicule électrique et/ou un renforcement du réseau. Comme nous allons le voir, l'analyse de la faisabilité technique de ces scénarios comporte un réel **angle mort** si la question des matériaux n'est pas abordée. Parmi les rares études qui prennent en compte quantitativement ces questions, on peut citer (Association négaWatt, 2018), qui présente un bilan de besoin de certains matériaux de son principal scénario.

Plus généralement, la recherche sur ces contraintes est assez restreinte en comparaison à l'importance manifeste du sujet, mais se développe tout de même : (Bonnet, Carcanague, Hache, Seck, & Simoën, 2019) montre à travers un graphique du nombre annuel de publications l'intérêt croissant de la littérature sur ces questions, mais l'étude conclut par ailleurs qu'il est difficile de faire émerger un consensus sur le risque d'approvisionnement lié à une matière première car il existe une grande sensibilité dans les résultats selon les méthodes et les données.

B. Criticité : une analyse multidimensionnelle de la dépendance aux ressources minérales

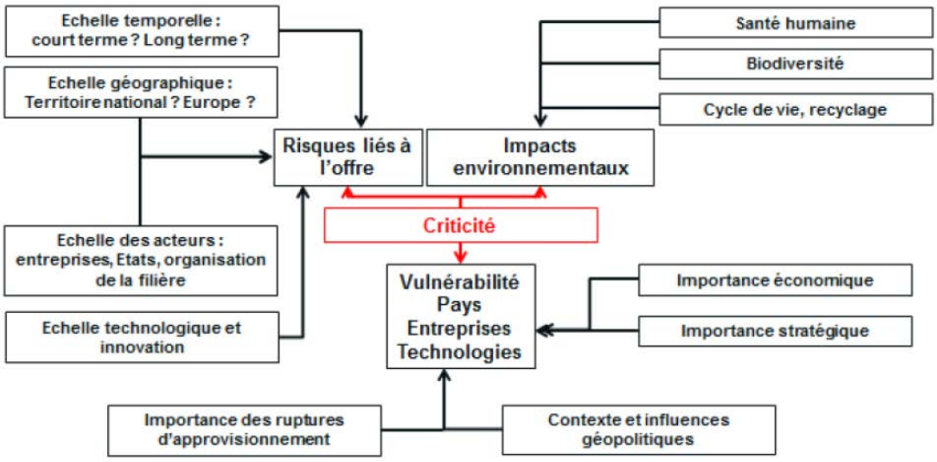
La dépendance aux ressources minérales est communément appelée « criticité ». Le principal élément de complexité dans l'étude des contraintes sur l'approvisionnement en métaux vient de son **caractère multidimensionnel**. En effet, prendre en compte l'aspect technique uniquement ne permet pas d'évaluer correctement le niveau de criticité : il existe des métaux critiques et non rares, tout comme des métaux critiques et recyclables.

Ainsi, comme cela est résumé dans l'étude (Bonnet, Carcanague, Hache, Seck, et al., 2019) :

« La criticité n'est ni universelle, ni intemporelle, ni binaire (Graedel and Reck, 2016). Elle varie en réalité en fonction des intérêts économiques (commerciaux, technologiques, financiers) et politiques (sécurité, défense, politique étrangère) d'un État, dont elle est nécessairement le reflet. Elle constitue également une clé de lecture pour les relations de cet État avec ses partenaires sur la scène internationale. La nécessité de prendre en compte la dimension géopolitique et d'en affiner la mesure quantitative et qualitative, dans les études sur la criticité apparaît ainsi comme un défi essentiel, à la fois pour le chercheur et le décideur. »

La criticité peut être vue comme **un ensemble de risques**, de nature géopolitique, économique, lié à la production, environnemental ou social :

Figure 11: Évaluer la criticité des matières premières



Source : auteurs, tiré de Helbig et al., 2016.

Source : (Bonnet, Carcanague, Hache, Seck, et al., 2019)

C. Les grandes familles de métaux et les incontournables de la transition énergétique

(ADEME, 2017) propose dans ses annexes une taxonomie claire pour catégoriser les métaux (voir la source pour une taxonomie plus complète). Une première distinction importante est relative à leur concentration dans la croûte terrestre :

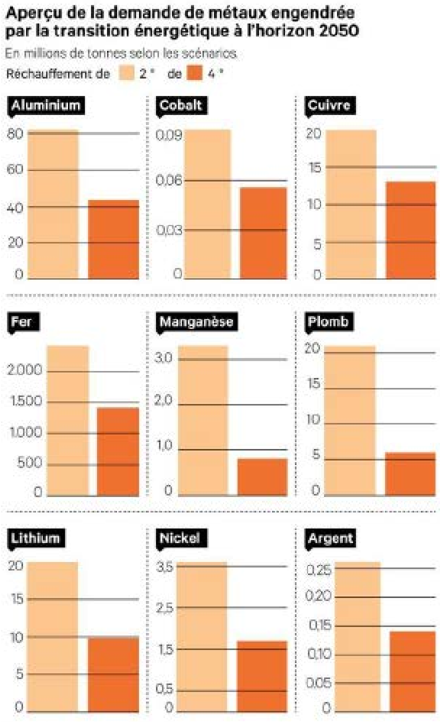
- au-dessus de 1000 ppm, on trouve les **métaux dits « abondants »**, comme le silicium ou l'aluminium.
- entre 1 et 1000 ppm, ce sont les **métaux rares** (ou « peu abondants »). Il en existe de nombreux, dont le plomb, le cuivre, le zinc, le nickel, le cobalt, le molybdène et le tungstène.
- en-dessous de 1 ppm, on trouve les **métaux « très rares »**. Parmi ceux-ci, on compte les métaux « précieux » (or, argent, et les 6 platinoïdes) et 3 autres métaux : l'antimoine, le sélénium et l'indium.

Un second point important est l'appellation **« terres rares »**. Celle-ci désigne un groupe précis de 16 ou 17 éléments qui ne sont en fait pas si rares. Ce groupe comprend les 15 éléments de la famille des Lanthanides (57 à 71) et l'yttrium. Tous ont des propriétés proches et sont pratiquement toujours associés dans leurs gisements. Le scandium est parfois ajouté à la liste. Leur appellation date d'une période où on les pensait vraiment rares, mais ils ont en réalité un niveau de rareté de l'ordre de celle des « métaux rares ». En revanche, leurs gisements ont la particularité d'être très localisés.

Parmi l'ensemble des métaux, certains sont **sollicités plus ou moins fortement** par les nombreuses technologies habituellement mobilisées dans les **scénarios de transition** : les différentes filières de solaire photovoltaïque nécessitent silicium, argent, tellure, galium et indium, les batteries font appel entre autres au lithium, nickel, cobalt, les besoins de renforcement réseau nécessitent du cuivre, certains types d'éoliennes ainsi que les voitures électriques nécessitent des terres rares (néodyme, praséodyme et dysprosium notamment) pour leurs aimants permanents, les véhicules hydrogène nécessitent des platinoïdes, etc.

Voici à titre d'illustration un aperçu de l'augmentation de la demande pour certains métaux dans un contexte de scénarios dits « deux degrés » :

Graphique 1 – Demande médiane en métaux pour les technologies éoliennes à l'horizon 2050



Évolution de la demande en métaux dans l'hypothèse d'un réchauffement de 2° C et de 4° C, en comparaison avec un scénario 6° C.

Source : Les Échos ; la Banque mondiale.

Source : (IFRI, 2018)

Egalement, voici quelques éléments clés concernant la criticité de certains métaux en particulier :

- Pour ce qui est de la situation des **terres rares**, deux chiffres clés sont à retenir. D'une part, environ 90% de la production actuelle se trouve en Chine, et d'autre part environ 80% de la demande vient des besoins en aimants permanents. Ainsi, l'analyse de la criticité passe nécessairement par un volet géopolitique. A ce titre, voir l'étude "Rare Earths and China: A Review of Changing Criticality in the New Economy" (Seaman, 2019).
- Pour le **lithium,** la criticité géologique ne semble pas être trop importante. En revanche, comme pour les terres rares, la criticité géopolitique est bien réelle. En effet, le lithium est produit de façon très concentrée, en grande majorité dans le « triangle du lithium », c'est-à-dire en Bolivie, au Chili et en Argentine par une poignée d'entreprise. De plus, la part de la demande en lithium venant des batteries est importante et devrait augmenter. Sur ce métal, voir, par exemple, l'étude "Critical raw materials and transportation sector electrification: A detailed bottom-up analysis in world transport" (Hache, Seck, Simoen, Bonnet, & Carcanague, 2019).
- Pour le **cuivre** en revanche, une criticité géologique est à prévoir. Comme présenté dans l'étude (Bonnet, Carcanague, Hache, Seck, et al., 2019), une partie importante de la demande de cuivre vient du secteur électrique. Pour une modélisation de la criticité géologique sur le cuivre, entre augmentation de la demande et développement de filières de recyclage, voir le projet SURFER porté par le CNRS, le BRGM et l'ADEME.
- Enfin, au sujet d'**autres matériaux** comme le ciment, voir l'étude "The impact of Future Generation on Cement Demand: An Assessment based on Climate Scenarios" (Bonnet, Carcanague, Hache, Simoen, & Seck, 2019), ou l'étude (United States Department of Energy, 2015) qui fournit des tableaux concernant la

consommation en matériaux de différentes technologies de production d'énergie et différents types de véhicules.

D. Quelques points de départ pour mener une analyse sur la criticité dans les scénarios

Comme on l'a vu, la criticité est un paramètre aux multiples facettes. Voici un ensemble de critères et de questions qui peuvent se poser dans l'analyse de la criticité d'un métal dans un scénario (fonctionne aussi avec d'autres matériaux) :

- **Disponibilité géologique**. *Le métal est-il rare ?*
- **Dépendance entre matériaux au niveau du minerai**. *Le métal est-il le sous-produit d'un autre ?*
- **Temps de développement de la production**. *Combien de temps se passe-t-il entre les premières études sur une exploitation et son plein fonctionnement ?*
- **Filière de recyclage**. *Sait-on recycler ce métal ? A quel taux ? Quelles sont les capacités effectives ?*
- **Possibilités de substitution**. *Peut-on facilement changer de métal pour une même utilisation ? Ou bien changer de technologie pour se passer de ce métal ?*
- **Croissance de la demande**.
- **Concentration de la production**. *Combien de producteurs de ce métal ?*
- **Risque politique**
- **Contraintes environnementales et sociales**, avec notamment la disponibilité en eau pour la production du minerai et la possibilité de refus par la communauté des répercussions de son exploitation (Donella H. Meadows, Randers, & Meadows, 2004). Sur ce dernier point, il peut être important de rappeler que certaines exploitations actuelles de minerai se font dans des conditions environnementales et sociales pour le moins discutables. De plus, la notion de contraintes environnementales permet d'introduire l'**impact du changement climatique** sur ces enjeux. En effet, comme cela est développé dans l'étude (Carbone 4, 2019) : « l'activité minière est par essence particulièrement exposée aux aléas climatiques et notamment aux problématiques de gestion de la ressource en eau. » Cela illustre comment différents problèmes environnementaux peuvent être liés.

Ainsi, pour mener des analyses sur la notion de criticité dans les scénarios, on voit bien qu'une partie importante des risques dépend surtout du **narratif**, c'est-à-dire de choix faits dans la **storyline** de l'étude (voir le dossier Future studies). Ceux-ci peuvent être traités de façon qualitative. D'autres éléments peuvent être modélisés de façon quantitative, comme le développement de filières de recyclage par exemple.

Le tableau des métaux jugés critiques pour l'Union Européenne (Commission européenne, 2017) peut constituer un point de départ pour une analyse qualitative. On y retrouve 27 métaux, avec notamment leurs principaux pays producteurs, leur indice de substitution et leur taux de recyclage.

NB : Une difficulté dans l'étude de ces enjeux vient du fait que ces métaux ne sont pas seulement utilisés dans le cadre de la transition énergétique. Le secteur de la Défense, par exemple, nécessite des terres rares.

Voici un tableau d'indicateurs communément utilisés dans la littérature, parmi lesquels il peut être intéressant de s'inspirer :

Tableau 3 : Indicateurs de mesure de la vulnérabilité ou de risque sur l'offre identifiés dans la littérature selon leur fréquence d'apparition

Indicateurs de vulnérabilité économique	Indicateur de risque sur l'offre
Existence d'un substitut (Qualitatif)	Concentration de la production par pays (HHI)
Valeur des produits affectés (en % du PIB)	Gouvernance (Qualitatif ou Index de gouvernance)
Ratio de demande future sur l'offre (Qualitatif)	Temps de déplétion des ressources (années)
Valeur des matériaux utilisés (en % du PIB)	Dépendance aux coproduits (en %)
Importance de l'utilisation (en % de la population, en % du PIB)	Concentration d'entreprises minières (HHI)
Dépendance aux importations (en %)	Croissance de la demande (Qualitatif ou ratio)
Importance stratégique (Qualitatif)	Dépendance aux importations (en %, en valeur)
Capacité à innover (Qualitatif)	Potentiel de recyclage (en volume)
Variation des importations (en %)	Existence d'un substitut (Qualitatif)
Concentration des entreprises productrices (HHI)	Volatilité des prix des matières premières (en $)
Volume de consommation (en volume)	Dépenses d'exploration (en $)
Variation de la production minière (en %)	Coûts d'extraction (en $)
Recyclabilité du produit (Qualitatif)	Équilibre du marché (en volume)
	Taux d'utilisation de la capacité minière, capacité de raffinage (en %)
	Existence d'un marché financier
	Investissement dans le secteur minier (en $)
	Vulnérabilité au changement climatique (Qualitatif)
	Existence de pénurie temporaire (Qualitatif)
	Risque stratégique (embargo) (Qualitatif)
	Présence dans la croute terrestre

Sources : Tiré de Helbig et al. (2016) et de Frenzel et al. (2017)

Source : (Bonnet, Carcanague, Hache, Seck, et al., 2019)

Pour aller plus loin dans ces analyses, voir les liens vers des études citées précédemment comme le projet SURFER, ou l'étude (Bonnet, Carcanague, Hache, Seck, et al., 2019) qui présente une analyse de la criticité des matériaux de la transition énergétique en général à partir de modèles de l'AIE, puis une analyse sur la criticité du lithium du cuivre à l'aide du modèle TIAM.

NB : Les enjeux d'approvisionnement en métaux sont des sujets qui évoluent rapidement, notamment ces dernières années, et la littérature sur ces questions n'est pas encore fortement développée. Ainsi, il peut arriver que certaines données utilisées soient **obsolètes**. En effet, certaines publications s'appuient sur les données d'autres publications, etc. avec comme source initiale des bases de données trop anciennes pour être à jour.

E. Le recyclage est un levier clé mais ne peut pas tout

Le recyclage est un levier important pour réduire la criticité des métaux et matériaux, une des principales questions étant de savoir jusqu'où il est possible d'utiliser ce levier. Si le recyclage est utilisé dans le scénario, un **narratif** sur la mise en place de filières de recyclage peut être utile :

- Est-ce l'**incitation économique** qui permet le développement des filières, ce qui signifie qu'un métal est recyclé sous condition d'un débouché rentable ? (c'est majoritairement le cas aujourd'hui) Dans ce cas, le prix du métal sur les marchés est un élément important : s'il celui-ci est bas, alors l'incitation à recycler est faible.
- Est-ce qu'**une planification** par l'Etat ou un autre acteur est mise en place ? A ce titre, le marché du recyclage a pour avantage d'être connu à l'avance : le besoin en recyclage de panneaux photovoltaïques par exemple suit le rythme de la production de panneaux avec un décalage qui correspond à la durée de vie moyenne d'un panneau.
- Est-ce que l'incitation est liée à des **contraintes d'acceptabilité** liées au pays ou à la région, qui exercent ainsi une pression sur l'image du constructeur ou de l'exploitant de la technologie à recycler ?

Parmi les outils permettant d'inciter au développement des filières de recyclage on trouve : les garanties financières pour chaque installation permettant de couvrir les coûts de démantèlement en cas de faillite de l'exploitant ; le principe de Responsabilité élargie du producteur (REP) qui oblige l'entreprise qui met la technologie en question sur le marché à payer une participation au moment de cette mise sur le marché pour financer son recyclage par les filières adéquates une fois le produit arrivé en fin de vie ; des réglementations sur le taux de recyclage, etc.

Pour mener à bien une analyse quantitative sur le recyclage, voici pour point de départ deux indicateurs spécifiques :

- le **End-Of-Life Recycling Rate** (EoL RR) est la part de matériaux contenue dans des produits arrivés en fin de vie qui est collectée, prétraitée et finalement recyclée pour être introduite à nouveau dans le cycle. C'est l'indicateur communément appelé « taux de recyclage ».
- le **Recycling Input Rate** (RIR) mesure la part de métal provenant du recyclage dans la totalité de la production de ce métal.

Il convient également de préciser de quelles 'sources' le métal doit être issu pour être considéré comme 'recyclé' : prend-on en compte uniquement les produits en fin de vie, les chutes de métal générées durant les activités de production, etc.

Pour un exemple de modélisation intégrant la notion de recyclage, voir le **projet SURFER** porté par le CNRS, le BRGM et l'ADEME. Cette modélisation permet de mettre en lumière comment le rythme de développement des filières de recyclage peut être un paramètre décisif.

NB : Il est important de noter qu'on ne peut **jamais atteindre un taux de recyclage de 100%**. Cela est dû à des pertes inévitables au moment de la collecte, au niveau des procédés, etc. En effet, une des grandes difficultés du recyclage est qu'un même produit contient de très nombreux éléments chimiques différents (c'est une tendance qui s'accentue). Cette entropie se manifeste également par une perte de qualité progressive du matériau à chaque boucle de recyclage. Le matériau doit être utilisé dans des applications nécessitant un niveau de pureté moindre, et l'application initiale nécessite alors un apport en matériau 'neuf'.

De plus, le recyclage nécessite différents types de procédés (recyclage mécanique, chimique, thermique, …) Cela implique donc une consommation d'énergie et, directement ou indirectement, un rejet de substances dans l'atmosphère ou autre. Ainsi, le recyclage permet dans la grande majorité des cas de réduire l'impact environnemental par rapport à un métal directement extrait de la croûte terrestre, mais **cela ne permet pas de faire disparaitre cet impact pour autant**.

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The Shift Project

The Shift Project, a non-profit organization, is a French think-tank dedicated to informing and influencing the debate on energy transition in Europe. The Shift Project is supported by European companies that want to make the energy transition their strategic priority & by French public funding.

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Employment assessment of energy transition scenarios

Technical file #12 – Draft version

Information and recommendations for scenario producers

This document is part of a set of 12 technical files. These files have been produced by *The Shift Project* after one year and a half of research and experts consultations on the different aspects of energy transition and the future studies around these aspects.

Our project, "Power Systems 2050 – Guidelines for design," started in January 2018, with the participation of 10 experts who defined the key subjects which according to them have to be collectively tackled by future studies about the power transition. *The Shift Project* then investigated each of these subjects, consulting in total 40 experts, organizing 4 workshops, and reviewing a large bibliography, including a dozen of future studies about power (and energy) transition at different geographical scales.

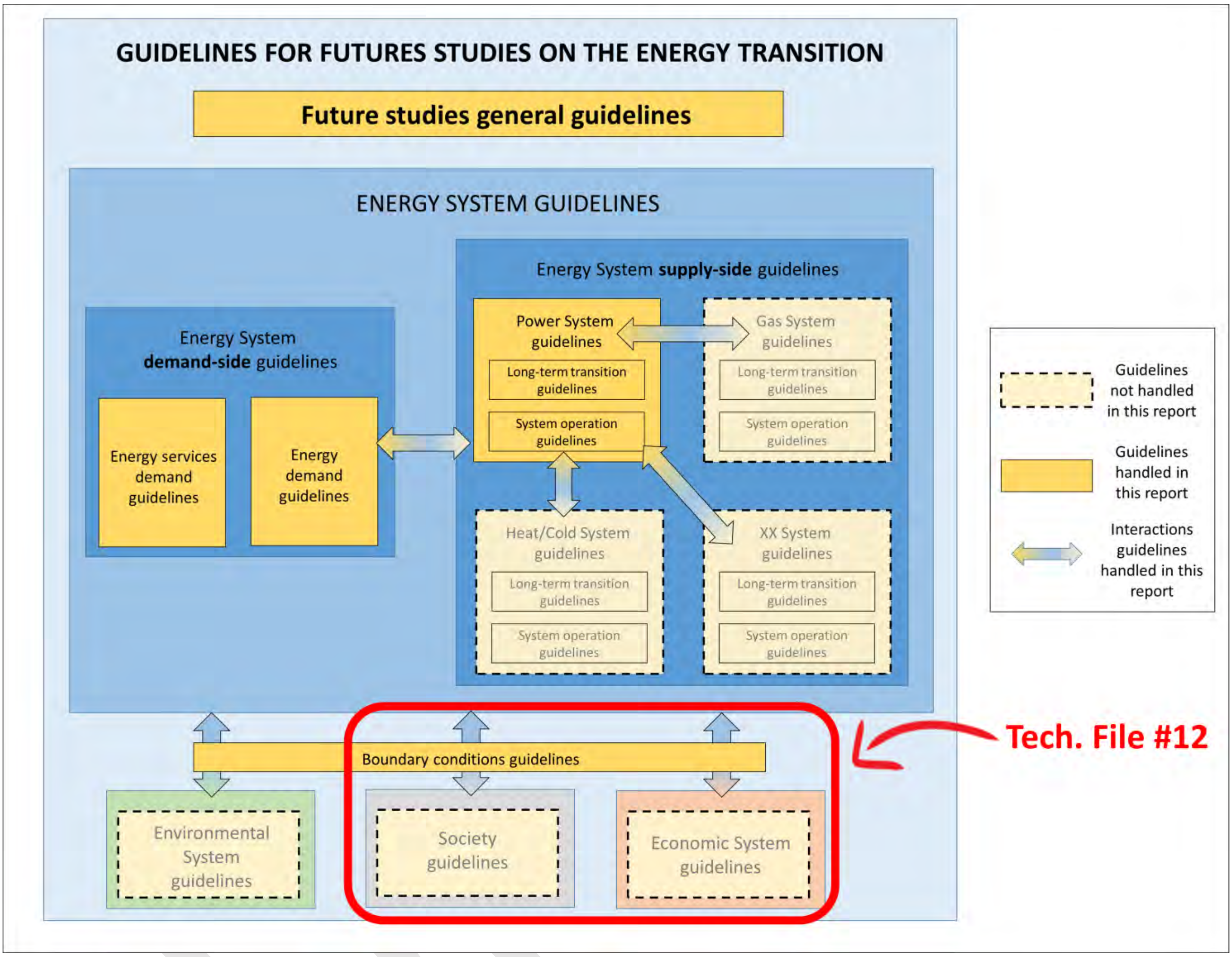
The goal of this project is to produce a set of guidelines addressed to scenario producers. These guidelines seek to foster transparency and consistency *within* future studies and to develop a common language *across* studies. By defining a number of important items which are key to deal with in future studies, we actually propose a study template which enables a better understanding of the location of each proposed scenario on the tree of possible transitions. Once again, the objective is not to *rank* studies, or scenarios, but rather to *compare* them to get a better collective overview of the different aspects of the transition (what are the differences between studies in terms of driving questions, hypotheses, models, methodology, results?).

Several aspects of the energy transition are handled in these technical files. However, on the energy supply-side only the power system has been studied. The main reason for this choice is that we had to start from somewhere with limited resources, and the power system seemed to be a key system to study in the energy transition context, towards a low-carbon economy, as shown by the growing number of future studies focusing on this system. However, the guidelines we propose could be completed by analyzes on the other energy supply-side systems (the gas system, oil system, heat system and so on).

Each technical file tackles several aspects of future studies for the power (and energy) transition. Here is the complete list of the technical files produced during the project:

#	Technical file title
1	Future studies on the energy transition
2	Energy transition models
3	Boundary conditions for energy transition scenarios
4	Long-term evolution of energy consumption in energy transition scenarios
5	Lifestyles and consumption behaviors in energy transition scenarios
6	Long-term evolution of the power system supply-side in energy transition scenarios
7	Power system operation in energy transition scenarios
8	Impact assessment in energy transition scenarios
9	Transition desirability in energy transition scenarios
10	Environmental assessment of energy transition scenarios
11	Economic evaluation of energy transition scenarios
12	Employment assessment of energy transition scenarios

Altogether, these files cover the fields described on the following map of the guidelines for future studies on the energy transition. The document you are reading covers the red-circled topics.



In addition to these technical files, three complementary notes have been produced as specific focuses on the following aspects: material criticality in energy transitions (in French, to be translated and added to technical file #10), levelized cost of electricity (LCOE) in energy transition future studies (in French) and discount rate in energy transition future studies (in French).

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Table of content

List of figures

Reading keys

Explanation box, containing key information for a better overall understanding of the subjects.

Recommendations for scenario producers:

These boxes contain the recommendations for scenario producers.

The word "should" means that scenario producers, if they are to follow the guidelines, must substantiate the corresponding point. The words "may" or "might" relates to suggestions, ideas to help the scenario producer respond to the point.

Questions in italic are examples of questions scenario producers might ask to substantiate the points. They are here in an illustration purpose.

Phrases in italic in the text are words which are being defined and will be subsequently used in the framework.

Phrases which are highlighted in yellow refer to other technical documents of this series.

I. Introduction on employment assessment

A. Employment definition and usefullness for public decision

1. A job is a number of worked hours

The definition of what is a "job" is not universal. A job is usually associated with a "working person". But that person could very well be at work 10 hours a day, 6 days a week since the age of 10, or 35 hours a week for 40 years.

It is therefore necessary to clarify what is considered as a "job". The best way to do this is to associate a job with a total number of hours of work, for example by defining a number of hours worked per year with the corresponding number of years required. Using full-time equivalent (FTE) after defining the corresponding workload can be an appropriate approach.

E.g.: building this new section of cycle path requires 3000 hours of work, i.e. 2 FTEs of 1500h/year for 1 year.

Recommendations for scenario producers:

What is called a "job" in the employment assessment should be defined. It should be ultimately expressed as a total number of hours of work, typically by providing a workload per year and a corresponding number of years.

What is the workload of a full-time equivalent job? How many FTE over how many years are required?

2. Job *need* rather than job *impact*

In future studies, employment assessment usually comes after the definition of a pathway. Therefore the term "job impact" is used very often. However in the real world big changes do not come from nowhere and as a result have an impact on employment. Instead, open job positions and skilled workers are needed before these big changes can actually happen. These are prerequisites. This is why we prefer to use the "job need" designation.

3. Employment is a key indicator for political decision makers

Employment is a key indicator for political decision makers if they want to involve people in a strategic choice. Assessing this aspect enables to better prepare the training for people, the infrastructures, training the instructors, for the right economic sectors. Many future studies already assess employment while some other don't.

As pointed out by (Perrier & Quirion, 2017b), although this indicator is less systematically studied than cost indicators, it may have an equivalent importance in the public debate. A policy with a real or perceived negative impact on employment could be disqualified.

This importance given to the employment assessment of scenarios can partly be explained by the high unemployment rates currently experienced in some countries (sometimes for decades), as unemployment can raise strong desirability issues.

4. When talking about employment, human resource management issues are at least as important as the global net employment need

When assessing employment, several indicators are useful to enlighten public debate.

First, the global net employment need is an important value. It makes it possible to compare two scenarios. *Which trajectory has the highest need for employment? Are the two values close or very different?* Stakeholders can then decide which situation they prefer according to whether they prefer more or fewer jobs in the future.

But this is not the only indicator that matters, and not necessarily the most important one.

Indeed, a transition in employment is above all a need in human resource management. Human resource management is required both to handle the need for skills in the case of job creations and for people management in the case of job destructions.

The sectoral distribution of the creation and destruction of jobs, as well as their geographical distribution are key elements to better inform this human resource management. It is this level of details that enables to build a detailed narrative, making it possible to discuss the desirability of the proposed trajectory with the stakeholders.

These different elements will be discussed in this following parts.

Recommendations for scenario producers:

Scenarios should assess the employment needs in their world.

Global net employment need is an interesting indicator, but it should be completed with insights about human resource management evaluation. This concerns both the need for skills in the case of job creations and people management in the case of job destructions. This can be enlighten thanks to an evaluation of sectoral and geographical distribution of the creation and destruction of jobs.

In the end, all these elements should be used to build a comprehensible narrative for stakeholders so as to discuss the enabling conditions and the overall desirability of the proposed trajectory.

B. Introduction on existing employment assessment methods

1. Two literature reviews

(Quirion, 2013) and (Breitschopf, Nathani, & Resch, 2012) are the two main sources presenting a review of existing employment assessment methods used for writing this employment section.

They both explore pros and cons of the several methods they present. (Breitschopf et al., 2012) provides a "methodological guidelines for estimating the employment impacts of using renewable energies for electricity generation" while (Quirion, 2013) provides a review of existing methods, especially those used in future studies, before evaluating the employment need of the study (NégaWatt, 2011).

2. Gross assessment is useful from a specific actor's perspective whereas net assessment is required to enlighten system perspective

As any public policy, energy policies do create jobs in some sectors and destroy jobs in others. Therefore one should first distinguish two main types of employment assessment: gross assessment and net assessment.

A gross assessment focuses on job creation only or on job destruction only while net assessment takes both effects into account.

Assessing a gross effect can sometimes appear as a caveat but it is not. In fact, all depends on the question that is being answered. (Breitschopf et al., 2012)

Indeed, gross effect can be useful from a specific actor's perspective. (Percebois, s. d.) gives the example of a study from AREVA evaluating the destruction of employment related to a nuclear phase-out, and another example of a study from SER assessing job creation in the renewable energy industry related to an increase of RES in the mix. In both cases, this kind of gross assessment provides insights for one specific industry and is therefore useful from this specific industry point of view, both for work unions and business owners of the sector.

However, gross effect alone is not adapted to inform public decision from a system perspective (see Economic Evaluation section for a detailed *system perspective* definition)

Indeed, when estimating the global employment need of a scenario, net assessment is better adapted. (Criqui, 2013; Quirion, 2013)

Therefore we will focus only on net assessment methods in this employment section (just note that not all the net employment assessment methods enable to enlighten system point of view, as explained in the next part).

> Recommendations for scenario producers:
>
> Scenario producers should explain their choice of assessing only job creation, only job destruction or both job creation and destruction with regard to the question that is being answered and the related chosen point of view of their employment need assessment.
>
> The answered question and the related chosen perspective should be clarified.
>
> Gross assessment (only job creation or only job destruction) is better adapted from a specific actor's perspective. A net assessment (both job creation and destruction) is required to evaluate the global employment need of a scenario from a system perspective so as to fully inform public decision.

3. Four categories of effects on employment: how deep in the value chain to assess employment need for a transition?

Methods to assess employment needs divide those needs into four main categories.

a. Direct and indirect effects

The first two are direct effect and indirect effect.

Direct jobs are those in the primary industry sector that is mobilized for the proposed transition. It can include jobs in fuel production, manufacturing, construction, and operations and maintenance.

Indirect jobs generally include jobs in secondary industries which supply the primary industry sector. This is all the supply chain and may include, for example, catering and accommodation. (Rutovitz, Dominish, & Downes, 2015).

In other words direct jobs are those in the branches directly solicited for the transition while indirect jobs are those appearing (or disappearing) within the suppliers of this branches, and their own suppliers, etc.

Both effects are of a *technical* nature: they occur within the energy sector and do not involve any macroeconomic mechanism.

b. Induced effects

The third category is induced effects.

These effects on employment are of a macroeconomic nature.

From one study to another, the term "induced effect" often takes on different definitions, and may sometimes not even be clearly defined.[1] Therefore we will refer here to induced effects as all the effects on employment of a macroeconomic nature that can be calculated alone, that is independently of other effects.

One calculated, these effects can added up 'manually' to direct and indirect effects without going through the use of a macroeconomic model ("full model" approach), as detailed later.

We will later explore several examples of studies assessing induced effects. From one study to another, these effects are sometimes similar, sometimes different, or they can partially overlap.[2]

One **example of induced effect: the 'expenses-induced' effect**

To give an example, (Quirion, 2013) takes into account an induced effect corresponding to the jobs created or destroyed by the change in expenses of all economic agents (households, private actors, the State ...) To remove any ambiguity we will use the "expenses-induced" designation for this type of induced effect. When comparing a transition scenario to a reference scenario, there are two possibilities for these economic agents:

- They can either benefit from cost reductions (e.g. if they consume less energy for heating after insulating of their houses). In that case all the money that is not saved is reused, which increases consumption in other sectors of the economy. This leads to job creation. These jobs are called here expenses-induced jobs.

---

[1] "Induced effect" designates for example jobs resulting from spending wages earned in the primary energy industries in (Rutovitz, Dominish, & Downes, 2015), while it refers to all the jobs created or destroyed by any macroeconomic mechanism in (Percebois, s. d.), etc.

[2] This is why we indicate 'some induced jobs' in summary equations and tables.

- Or, they can have to pay for additional costs. It causes the opposite effect: consumption reduces in other sectors which has a negative impact on employment.

Thus, this effect is not technical but rather macroeconomic. Expenses-induced effect can be significant.

c. Other macroeconomic effects

The last effects on employment are all other macroeconomic effects, such as merit order effects, multiplier effect, or effects occurring when economy is close to full employment, or when a policy improves the balance of trade, etc. Some of these macroeconomic feedback loops are detailed later in the model-based methods paragraph.

4. Summary equation and table

Now that these four types of effects are defined we can express the total net employment need with the following equation:

Total net employment need **= Δ direct jobs + Δ indirect jobs + Δ** some **induced jobs + Δ jobs due to other** macroeconomic effects

With Δ = job creation – job destruction (otherwise this would be a gross assessment rather than a net assessment).

Not all employment assessment methods take all these effects into account. As we will see, these methods tends to gradually add effects in their assessment which allows to progressively expand the scope of the branches of the economy taken into account.

Here is a table to visualize and categorize employment assessment methods. Every existing study would probably fall into one of those boxes:

	Direct jobs	Direct + indirect jobs	Direct + indirect + some 'induced' jobs	Direct + indirect + some 'induced' + other macro-related jobs
Job creation or destruction	Gross assessment			
Job creation & destruction	Net assessment			

Source: author

Figure 1: Employment assessment methods summary table #1

Note: no matter the type of future study, none of those we reviewed was evaluating job need of their several scenarios in their core modelling. Indeed, all the studies including an employment assessment within our scope were always requiring an extra evaluation to do it: a modelling of the Institute for Sustainable Futures at the University of Technology Sydney for (Greenpeace, 2015), (Quirion, 2013) study for (NégaWatt, 2011), the use of ThreeMe model for (ADEME, 2012), (Cambridge Econometrics, 2011) modelling to evaluate (European Commission, 2011), etc.

Furthermore, there is no direct link *a priori* between the type of future study and the chosen employment assessment method.

Several methods to perform a net employment assessment are presented in the next part.

II. The four main types of net employment assessment methods

In this part, four types of methods for net employment assessment are presented.

	Direct jobs	Direct + indirect jobs	Direct + indirect + some 'induced' jobs	Direct + indirect + some 'induced' + other macro-related jobs
Job creation or destruction				
Job creation & destruction	1	2	3	4

These methods exist along a continuum: the further to the right of the table, the more effects are taken into account, but the more complex the evaluation becomes. The last column for example enables to take all effects into account but requires the use of macroeconomic models which are difficult to grasp.

'Manual' vs Full-model approaches

A first distinction between these methods comes from the way in which the calculations are carried out.

Columns 1, 2 and 3 follow a 'manual' process, where the employment need for each sector is calculated thanks to employment factors and where the effects can be calculated separately (as in column 3 where induced effects are calculated separately from direct and indirect effects).

Column 4 consists in the use of a macroeconomic model. This type of method is called here 'full-model' approach.

There is therefore a trade-off between clarity and completeness. On the one hand, full-model approach takes all macroeconomic effects into account. On the other hand, manual methods have the advantage of being inherently transparent and relatively simple to understand. Main drivers of the results are typically more easily identified with such method. It makes it easier to build a narrative around the transition in employment, and thus facilitate discussion with stakeholders. Manual methods can be grasped more easily and can therefore be transparently reused for more disaggregated evaluations such as employment need assessment of a transition on a local scale for example, as with the tool (« Outil TETE - Transition Ecologique Territoires Emplois », s. d.)

Technical vs Macroeconomic approaches

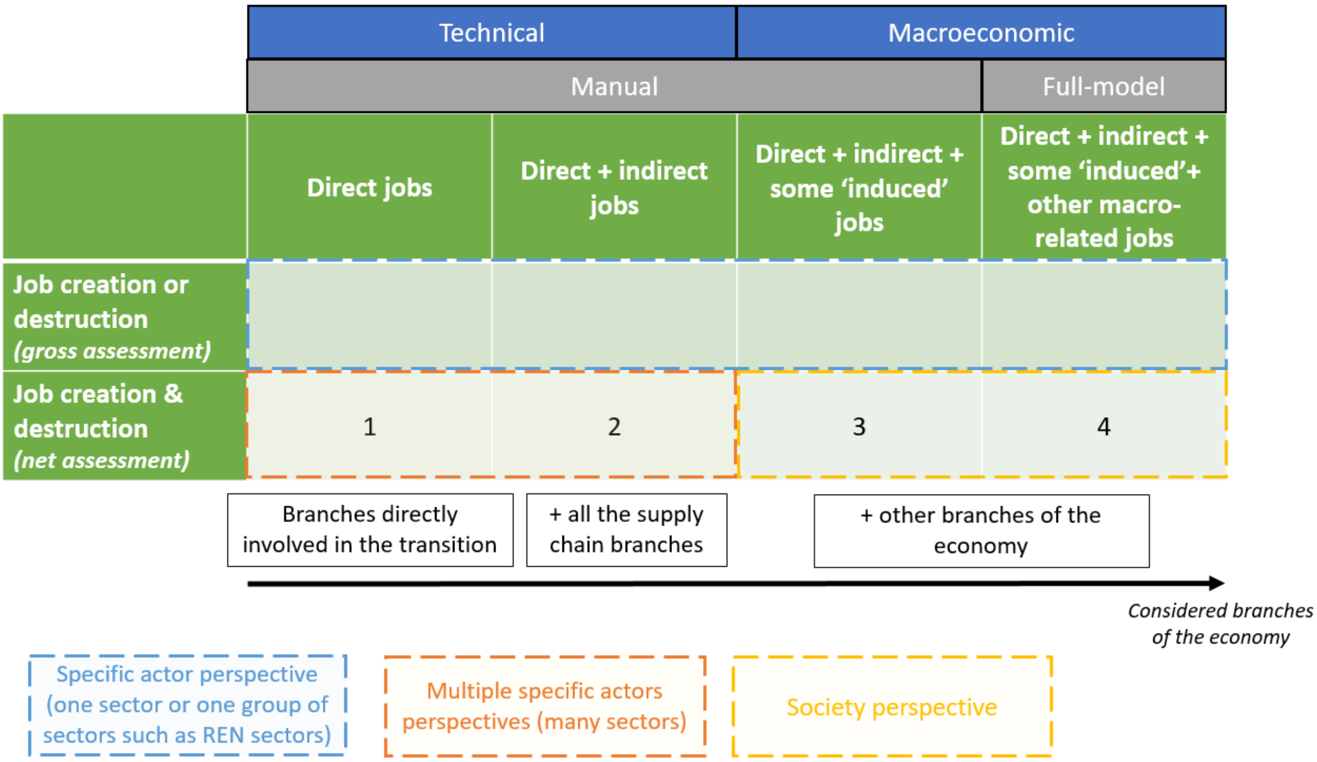
Another distinction between these methods lies in the scope of the considered branches of the economy. Each effect is indeed linked to corresponding branches of the economy.

The first column provides insights on branches directly linked to the transition. The second column takes in addition all the involved supply chain branches into account. These two types of methods are called **'technical'** because they focus on the energy sector only by excluding any macroeconomic effects (as explained in the previous part, direct and indirect effects are of a technical nature). Since macroeconomic effects are often significant, we argue technical methods alone are not suitable for fully informing the debate on total employment need from a system perspective.

Rather, technical methods are useful to provide insights for a set of specific actors. Unlike gross employment assessment, they make it possible to shed light on both the job creation and job destruction, and thus inform more broadly the various specific actors' perspectives. A dedicated narrative can enable to enlighten the related human resource management needs.

Unlike technical methods, the third and fourth columns also assess the employment needs in other branches of the economy. These are so-called '**macroeconomic**' approaches, whether the method is 'manual' (column 3) or 'full-model' (column 4). Since macroeconomic effects are often significant, we argue macroeconomic methods are the only type of approach that can inform the debate on total employment need from a system perspective.

Here is the corresponding summary table:



Source: author

Figure 2: Employment assessment methods summary table #2

Each method also has other specific advantages and caveats, which will be explored in the next section. For example, they all enlighten sectoral distribution of job creation and destruction but not with the same disaggregation level. Sectoral distribution is crucial information with regards to human resource management so as to inform the debate with stakeholders.

A. Two technical types of methods to enlighten multiple specific actors' perspectives

This part provides a description and discussion about the two technical types of employment assessment methods. The first one takes only direct jobs into account while the second one considers both direct and indirect jobs.

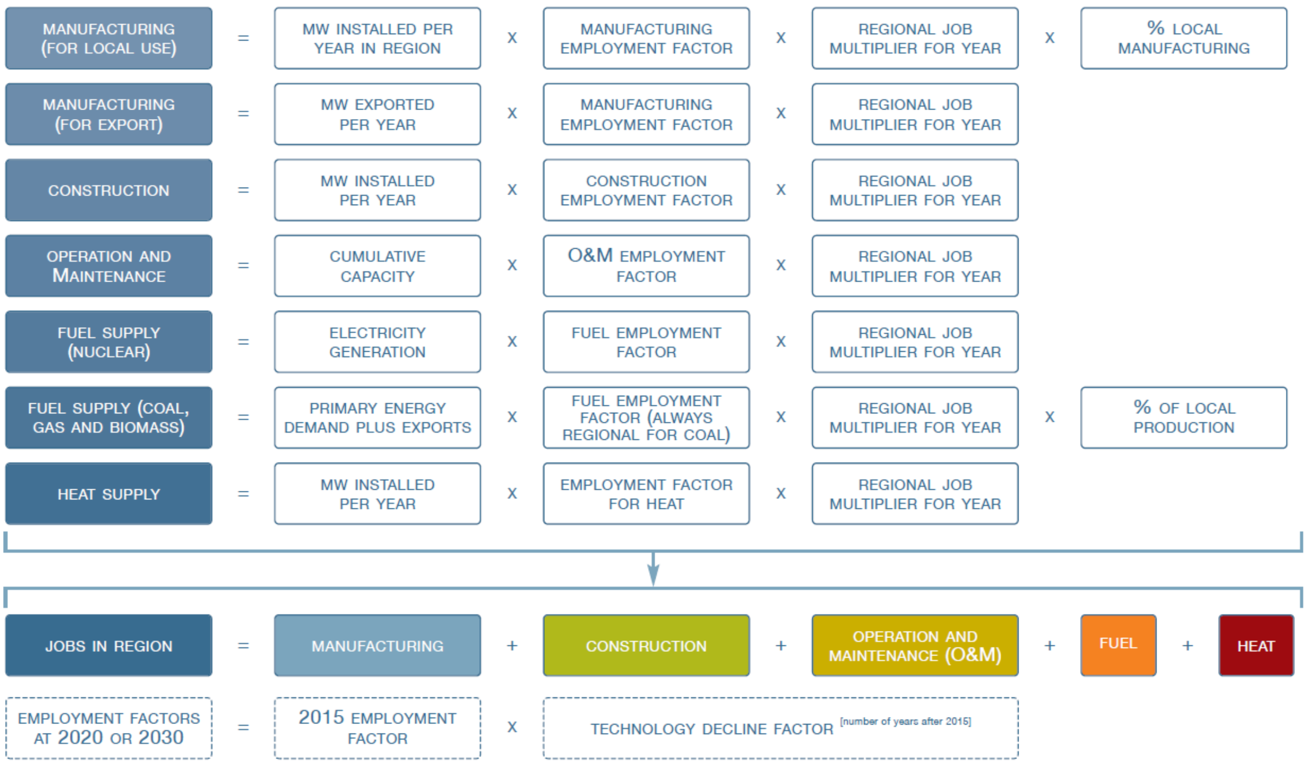
1. Assessing branches directly involved: a type of method to evaluate net direct employment needs

The first method is a technical and manual one, focusing on direct employment only. The related equation would be:

Net employment need **= Δ direct jobs**

a. A method based on 'physical' employment factors

This is an approach used in studies such as (Greenpeace, 2015) and (Lappeenranta University of Technology / Energy Watch Group, 2017). They both explain the several steps of their employment assessment. The method behind these two assessments is described in details in (Rutovitz et al., 2015), and summed up by (Greenpeace, 2015) with the following figure:



Source: (Greenpeace, 2015)

Figure 3: Overview of the net direct employment assessment method from (Rutovitz et al., 2015)

Jobs are divided into seven branches: manufacturing for local use, manufacturing for exports, construction, operation and maintenance, nuclear fuel supply, coal, gas, and biomass fuel supply, and heat supply.

For each branch there is a physical need derived from the scenario: MW installed each year for manufacturing, energy demand each year expressed in PJ for fuel supply, etc.

Each physical quantity is multiplied by a job factor, expressed as jobs/MW or jobs/PJ. In order to distinguish this type of employment factors from those expressed in jobs/€ (see next method), we will call them **'physical'** employment factors.

Since these physical job factors are calculated for OECD countries, a regional adjustment is applied where a local factor is not available thanks to a "regional job multiplier". Furthermore, each physical job factor is also time-adjusted thanks to a "technology decline factor" that reflects the increase in productivity over time. Indeed, as technologies and companies become more efficient and production processes are scaled up, the employment content of an activity progressively decreases.

Finally, the results for the seven branches are added together to obtain the final result.

As explained in (Rutovitz et al., 2015), there are still some significant areas of employment which are not included in the evaluation such as jobs in periodic replacements of the plants, jobs in energy efficiency, and a portion of the jobs related to heat supply. This is a transparent limitation specific to this study.

More generally, most of the work of such methodology lies in estimating the physical employment factors. As explained in the Limitations section, this can be a complicated task.

Note: this method can also be used for gross assessments such as the estimation of direct job creation need only. (Breitschopf et al., 2012) describes how to perform a gross assessment with this method. This is what they call "Employment factor approach". Further information can be found in (Breitschopf et al., 2012).

b. Limitations: no indirect jobs and no clear separation between direct and indirect jobs at the same time

The first obvious limitation of this type of method is that **it doesn't take into account indirect effects**. These are not negligible: as mentioned in (Rutovitz et al., 2015), "The inclusion of indirect jobs would typically increase job numbers by 50 – 100%." It can be noted that the study is transparent on this limitation, which is a good practice.

The second limitation of this approach lies in the way physical employment factors are determined. As (Breitschopf et al., 2012) explains it: "there are only a few basic data sources that are used to derive job factors, and the job factors for the same technologies vary greatly between the sources. In many cases, the employment factors are poorly documented, so that definitions of the system boundaries of technologies are not always transparent." Results could be very different between two studies using different databases.

(Rutovitz et al., 2015) confirms that a large number of assumptions are required to make the calculations. Indeed, "Quantitative data on present employment based on actual surveys is difficult to obtain, so it is not possible to calibrate the methodology against time series data, or even against current data in many regions".

This is related to the fact that there is no clear separation between direct and indirect jobs. This blurred lines result in an uncertainty range for the physical employment factors values for each sector. Therefore, final results could be strongly biased upwards or downwards.

NB: we could also mention as a third limitation the static nature of physical employment factors. This limitation is rather developed for the next type of method.

Recommendations for scenario producers:

When evaluating net direct employment needs only, it should be explicitly mentioned that such assessment only enlightens employment needs of branches directly involved by proposed changes of the scenario. Indeed, all the related supply chain branches are not taken into account.

Such a choice of method should be justified with regards to the driving question.

In addition, scenario producers should provide discussion about the uncertainty around the physical employment factors values, especially about the fact that for each sector the distinction between direct and indirect jobs is often unclear. The static nature of physical employment factors should also be discussed.

2. Assessing both branches directly involved and the related supply chain branches: a type of method to evaluate net direct & indirect employment needs

As the previously presented method, this type of approach is also both technical and manual. It enables to consider both direct and indirect effects. The related equation would be:

Net employment need = Δ direct employment + Δ indirect employment

a. A method based on 'monetary' employment factors determined through an Input-Output analysis

The following steps are described in line with explanations presented in (Quirion, 2013).

As with the previous method, different branches are defined and a physical need is derived from the scenario for each branch (let's take the example of MW of installed wind turbines).

Then, a unit cost is calculated for each branch (these would be the €/MW value of installed wind turbines). This unit cost can vary over the time to reflect changes in costs in each branch during the scenario timeframe. Compared to previously presented method, additional information is required to evaluate these unit costs.

The multiplication of physical need and the corresponding unit cost gives a monetary demand associated with each activity (total amount of € for wind turbine installation).

Each monetary demand is then multiplied by a job factor, expressed as **jobs/€**, which will be called here **'monetary' employment factors** in order to distinguish it from physical employment factors (see previous method). The monetary employment factor of each branch is estimated by an input-output analysis, which makes it possible to count the jobs related to all intermediate consumption. Indeed, cost implicitly integrates the entire value chain and therefore both branches directly involved and the related supply branches. This is the advantage of using monetary employment factors: they enable to take both direct and indirect jobs into account.

This results in the net job needs associated with each branch. All the branches can be added together to obtain the total net result.

This calculation is carried out twice: once for a reference scenario and once for the assessed scenario. Employment need is therefore expressed as the difference between the outcomes for the two scenarios.

This is the method used in (« Outil TETE - Transition Ecologique Territoires Emplois », s. d.) for example.

An advantage of this type of method is the possibility of taking into account a large number of sectors. This enables a wide range of choices in the way results are presented. Indeed, the results for these numerous sectors can be merged in many ways to provide useful information. This sectoral disaggregation thus makes it possible to build very specific narratives so as to better enlighten public debate and the discussion with stakeholders.

Note: as for the previous method, this method can probably also be used for a gross assessment. (Breitschopf et al., 2012) presents a similar method (with a few differences) they call 'Gross Input-Output modelling', for gross assessment. They describe the several assessment steps in detail, with concrete examples. Further information can be found in (Breitschopf et al., 2012).

b. Limitation: the static nature of this method implies additional work and assumptions to make it more dynamic

The main limitation of this approach when applied to future studies is its static nature due to the use of an input-output matrix.[3]

Indeed, this matrix reflects the current functioning of the economy. Thus, keeping the values contained in the input-output matrix fixed would consist in assuming everything goes as if the economy didn't change during the scenario. This remains true as long as the studied system remains relatively similar to today's system; however it is not necessarily the case.

Simulating an evolution of the functioning of the economy in accordance with the changes happening within the studied scenarios requires the integration of several phenomena. However integrating all these elements would represent a considerable amount of work, which naturally leads to simplification assumptions.

Here are three of the main elements that can be made dynamic so as to make the structure of the economy of an input-output matrix evolve[4]:

- Changes in productivity. Indeed, as previously explained, employment content of an activity progressively decreases when productivity increases. This parameter should logically be distinguished for each branch and its evolution should depend on changes occurring in each scenario. However, productivity is a complicated parameter to measure. Therefore, there is often a single value for all branches, which is also not distinguished between reference scenario and assessed scenario. In that case, it means productivity is considered exogenous (indeed no matter the changes occurring within the pathways, productivity would evolve in the same way, which means that "something else" outside the scenarios is responsible for the productivity evolution).

- Intermediary goods prices such as energy and raw material prices. Indeed, if oil price increases, monetary employment factors (jobs/€) of branches related to oil activity decreases. Similarly, if the price of certain raw materials increases, then the employment content related to certain renewable energy branches would decrease for the same reason.

- Imports-exports situation evolution within single branches. If part of a branch is offshored, then its monetary employment factor evolves. This is another type of change within the scenarios timeframes that requires additional work to be integrated into the input-output matrix. Changes in monetary employment factors values typically depend on assumptions about the locality of employment. Indeed, job

[3] The previously presented method is also of a static nature.
[4] The first and the third elements (change in productivity and imports-exports situation evolution) can also make physical employment factors more dynamic.

content varies differently depending on whether the job is created locally or not (see Regional evaluation paragraph).

NB: Integrating these changes without transparency and a narrative to explain the causes of these changes would bring opacity to the results and would be counterproductive.

Recommendations for scenario producers:

When using input-output analysis for employment assessment, the static nature of the simulated economy should be discussed.

Is the input-output matrix modified according to changes in productivity along the scenario? Or changes in imports-exports situation? Or changes in intermediary goods prices?

If such changes are taken into account or if monetary employment factors do not evolve, this should be justified with a corresponding narrative in any case. Assumptions about the locality of employment are also important to that extent since it can impact job content greatly.

Why productivity would increase faster in the assessed scenario compared to the reference scenario? Why value would differ from one branch to another? How is job content affected in my scenario after a change in oil prices depending on the country where job destructions or creations happened?

3. Discussions about technical methods

As previously explained, the two types of methods presented here are both technical (since no macroeconomic effect is taken into account) and manual (since they do not require the use of a macroeconomic model).

Both types of methods first start the calculation with the physical flows of each considered branch and then uses employment factors.

The first approach uses physical employment factors and can be summarized by "jobs = MW(h) * jobs/MW(h)". The second approach uses monetary employment factors and can be summarized by "jobs = MW(h) * €/MW(h) * jobs/€".

Because these are manual methods, they are more transparent by nature, which enables better discussion with stakeholders. However, each method has its own limitations, particularly on the values of employment factors.

Because they are technical methods, only the branches directly involved in the transition (first approach) and the supply-related branches (second approach) are taken into account. Therefore these methods can enlighten multiple specific **actors' perspective**s.

However all other branches of the economy are not included within their scopes. This would be a major limitation for the estimation of the total net job need of a scenario from a system perspective. Several sources (Breitschopf et al., 2012; Criqui, 2013; Quirion, 2013) seem to share this vision. Technical methods have for example a cost bias favoring expensive solutions since they do not assess expenses-induced jobs. Indeed, as explained in (Quirion, 2013): "as Huntington (2009) points out, the most costly technical and organizational options typically create more jobs per unit of energy than the others, but their extra cost will necessarily be paid by economic agents who will consequently reduce other expenses, leading to a drop in activity and to a negative "induced" effect on employment."

In a nutshell, these methods are suitable for enlightening multiple specific actors' perspectives but not system perspective.

Recommendations for scenario producers:

Technical methods provide useful insights about job transition from multiple specific **actors' perspective**s. A dedicated narrative should be provided to that extent to enable discussion with stakeholders, for instance by enlightening the human resource management needs related to the assessed job transition. As technical methods are also manual methods, transparency is more easily achieved.

Furthermore, technical methods are not truly adapted for estimating the total net job need of a scenario from a system perspective. Macroeconomic methods should be preferred for that purpose. If a technical method is however used for that purpose, an explanation of the extent of the limitation with regards to the answered question should be added.

B. Two macroeconomic types of methods to enlighten system perspective

This part provides a description and discussion about the two macroeconomic types of employment assessment methods. The first approach is a manual one and takes direct, indirect and some induced jobs into account while the second one is a full-model approach and considers all effects.

1. Assessing 'technical' branches and some other branches of the economy: a manual type of method to evaluate net direct, indirect and some induced employment needs

This type of approach is macroeconomic and manual: it enables to manually take some macroeconomic effects into account. These are called induced effects. The related equation would be:

Net employment need = Δ direct employment + Δ indirect employment + Δ some induced employment

Recommendations for scenario producers:

Since the meaning of "induced effect" varies from one study to another, a clear explanation of what is actually assessed should be provided whenever an "induced effect" is calculated.

a. Two methods based on input-output analysis

The two methods that will be presented here calculate separately direct and indirect effects on the one hand and one or more types of induced effects on the other hand before adding them together. They also both use input-output analysis.

(Quirion, 2013) method

This first method is described and applied to (NégaWatt, 2011) study in (Quirion, 2013).

Firstly, direct and indirect effects are calculated thanks to the previously presented approach, using monetary employment factors determined with an input-output matrix (see corresponding part).

Secondly, an expenses-induced effect is calculated. As explained in Induced effects paragraph (see 'Four categories of effects on employment' section), expenses-induced jobs are the jobs created or destroyed by the change in expenses of all economic agents: if they benefit from cost reductions, money that is not saved is reused, which increases consumption in other sectors of the economy. This leads to job creation. If they have to pay for additional costs it is opposite and it leads to job destruction. Expenses-induced effect can be significant.

Calculating this effect requires further hypothesis: *which economic actors will support the extra costs, how will they change their savings and consumption in response to these extra costs?* (Quirion, 2013) assumes that cost variation goes to households and that they consequently change their consumption by the same amount and with a distribution similar to their initial consumption.

In this case, calculating expenses-induced effect consists in estimating the variation in the amount of household expenditure on the one hand and the average employment content created by household consumption on the other hand, before multiplying the two values. See (Quirion, 2013) for more insights and for the application of this method to a future study.

(Breitschopf et al., 2012) **"Net** Input-Output **modelling" method**

This corresponds to one of the four methods presented in the (Breitschopf et al., 2012) methodological guidelines. It requires the use of two types of input-output matrix: a *quantity* IO model and a *price* IO model.

After estimating direct and indirect effects with the quantity input-output model, this method estimates two types of induced effects:

- The first one corresponds to the changes in household income due to employment in concerned industries. It is estimated with the same quantity input-output model. This type of induced effect is not taken into account by (Quirion, 2013) method.

- The second one corresponds to the changes in electricity prices caused by the switch to a new electricity mix. The price changes are borne by electricity consumers and affect consumption and other production industries. It is estimated with the price input-output model. This induced effect is a portion of the previously presented expenses-induced effect.

Many more insights (detailed calculation steps, data requirements, discussions, etc.) can be found in (Breitschopf et al., 2012).

As they are based on input-output analysis, an advantage of this type of method is the possibility of taking into account a large number of sectors. As explained previously, this enables to build very specific narratives so as to better enlighten public debate and the discussion with stakeholders (see corresponding paragraph).

b. Limitations: some missing effects and a static nature

A first limitation of such approaches is intrinsic to every non 100% technical method: additional assumptions of a macroeconomic nature has to be added. For example, in (Quirion, 2013): *Which economic actors will support the extra costs, how will they change their savings and consumption in response to these extra costs?*

A second obvious limitation is that other macroeconomic effects are not taken into account, such as feedback loops and interactions between actors, prices, quantities and markets (Breitschopf et al., 2012). Adding them one by one 'manually' would probably be a far too complex exercise. This is why the only way to take all these effects into account is to use a full model-based approach.

Therefore (Quirion, 2013) provides qualitative evaluation and discussion about the magnitude of some neglected macroeconomic effects. It concludes that some of these main missing effects ('full employment' effect and 'elastic' effect on balance of trade balance) should be small given the context of the study (high unemployment and European context), and that the main drivers of the results would remain the same.

Further considerations on the magnitude of these neglected effects are presented in the 'Discussions about macroeconomic' section.

Recommendations for scenario producers:

When using a macroeconomic manual approach, both macroeconomic assumption and magnitude of neglected macroeconomic effects should be discussed.

The third limitation comes from the method used to determine direct and indirect effects. As previously explained methods using input-output matrix are of a static nature and imply additional work and assumptions to make it more dynamic (see corresponding paragraph for more details and corresponding recommendations).

Therefore (Breitschopf et al., 2012) study explains Net Input-Output modelling method loses part of its accuracy when applied to depict future effects, compared to a present effects analysis.

2. Assessing all branches of the economy: full model approaches

This type of approach enables to take all macroeconomic effects into account. The related equation would be:

Net employment need **= Δ direct jobs + Δ indirect jobs + Δ some induced jobs + Δ jobs due** to other macroeconomic effects

a. Three types of model

This kind of assessment is used to evaluate the employment need of future studies such as (ADEME, 2012) though the use of ThreeME model, or (European Commission, 2011) that relies on (Cambridge Econometrics, 2011) to evaluate the net employment effects of the EU's 20-20-20 targets, based on Cambridge Econometrics' E3ME model.

Note: we have not studied this type of method in depth. Other sources such as (Breitschopf et al., 2012) already provide many useful insights. What is presented below is directly based on this source.

There are three main types of model-based methods: macro-econometric models, general equilibrium models, and system dynamics based models. Each type has its own characteristics:

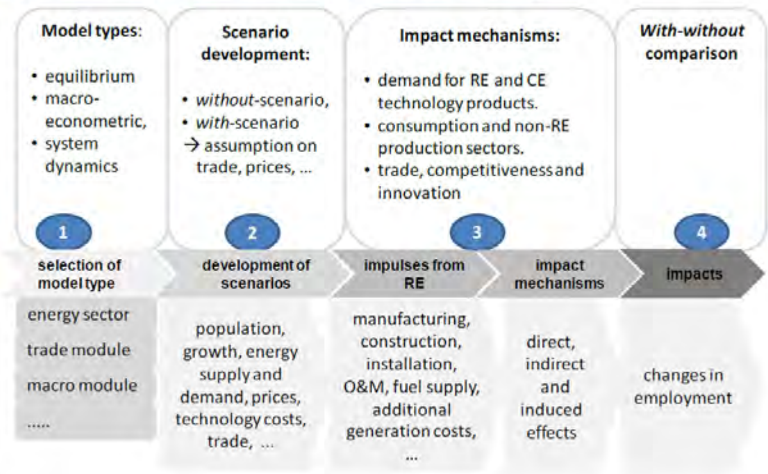
Table 5-4: Overview of model types and their general characteristics

	Macro-econometric model	(Computable) general equilibrium model	System dynamics based model
Use/ Application	Predicts overall level of economic activity (using macroeconomic figures). Analyses transitional impacts e.g. employment, ...	Examines impact of changes in relative prices on economic outcome.	Analyses impacts of price or demand changes on economic activities.
Time horizon	Short- to medium-term predictions	Long-term predictions	Long-term analyses
Drivers	Changes in aggregated quantities, prices	Changes in prices	Changes in prices, quantities
Methods	Considers and solves behavioural and definition equations simultaneously. IO table and national accounting included.	Strong microeconomic foundation with (partial) market equilibriums. Supply and demand functions. CES production and utility function. Contains IO tables.	Consists of non-linear differential equations. Uses positive and negative feedback loops. Includes IO tables and national accounting. Contains attributes of econometric models and applies equilibrium approaches as well.
Parameters	Estimation based on historical data –> fixed relations –> non-optimisation of individual behaviour	Calibrated = replicates data of base year	Estimation and calibration
Crucial issues	Macroeconomic data availability. Time series data. Specification of functional forms.	Exogenous parameters	Complexity
Weaknesses	Great effort involved in model specification. Simplistic functional forms may lead to inconsistencies.	Slightly more emphasis on negative effects since increases in efficiency are hardly taken into account. In some approaches, economic aspects outside the defined field of analysis are kept constant (partial analysis). Assumes optimisation behaviour of economic agents and efficient markets which is not realistic.	Mixed theoretical foundation. Complex structures due to manifold feedback loops
Applicability to net employment impact assessment	Tends to assess effects slightly less pessimistically than equilibrium models. Suited for short-medium term analyses. Depiction of encompassing macroeconomic effects. Depiction of transitional	Depiction of long-term aspects. Depiction of a particular market or a few sectors without including significant spill-overs.	Integration of several sectors and fields of RE use (transportation, heat, power)

Source: (Breitschopf et al., 2012)

(Breitschopf et al., 2012) explores in detail this kind of model-based methods. General procedure of such approach is explained and summed up in this sketch:

Figure 5-2: General procedure in a net impact study



Source: (Breitschopf et al., 2012)

Data requirement is also explored, as a large amount of data is necessary and assumptions need to be made:

Table 5-6: Selection of data required for an economic impact assessment

Data	Unit	Sources
Prices and allocation: Crude oil CO_2 Gas for households, industry, ... Electricity for households, industry, ... Fuel for households, industry, transportation	€ / ... e.g. bbl t kWh kWh l	IEA energy outlook; OECD
Socio-economic data: Population per age group Birth, mortality rate, migration Private households GDP Production value Number of passengers, commercial vehicles, Transportation of goods and persons	 # # € € #; km	National statistics on population, energy, ...
Efficiency indicators: Primary energy consumption (PEC) Share in PEC of each energy source GDP per PEC Final energy consumption (FEC) per household Gross value added per FEC for industry Production value per FEC Transportation per FEC	 GJ/capita % €/GJ GJ/# €/GJ €/GJ km/GJ	National statistics; European Statistics: Eurostat, ...
Emissions: GHG emission factors Substitution factors	 G/kwh %	National statistics, publications of national ministries (environmental, commerce, ...), UNFCCC communications
Policies: Social insurance Tax rates, depreciation rates Operating terms of nuclear power plants, ...		Publications by government ministries; OECD reports
Macroeconomic data: Input-output coefficients National accounting Trade data Labour force data (quantity and qualification)		National and supranational statistics, e.g. Eurostat, UN Comtrade, national energy balance, ...
Statistics on: Housing: real estate prices, existing and new construction, ... Transportation: # of cars, fuel input, average transportation, ... Energy: primary and final energy use, ...		National and supranational statistics, e.g. Eurostat, UN Comtrade, national energy balance, ...

Source: (Breitschopf et al., 2012)

Further insights can be found in (Breitschopf et al., 2012).

b. Some examples of macroeconomic effects

Here are some of the main macroeconomic feedback loops that model-based methods enable to take into account (Breitschopf et al., 2012; Quirion, 2013):

- *Full employment* effect. If the economy is close to full employment, a policy that increases the demand for labor will push up wages. If firms consequently lose market shares and / or substitute capital for work this may reduce the initial positive effect on employment by reducing employment elsewhere in the economy.

- *Elastic* effect on balance of trade. After a policy improving trade balance, some mechanisms - especially though exchange rates - can bring the balance back to equilibrium. This also reduces the initial positive effect on employment.

- *Merit order* effect. If electricity price on wholesale markets is set with a merit order mechanism, a policy increasing the share of renewable energy sources would cause a decrease in the power price due to a higher supply of electricity from sources with low marginal costs (shift of the supply curve to the right). And as any price variation would affect household expenses and industry competitiveness, this would have an impact on employment need.

CO2 price effect, crowding-out effect and multiplier effect are other feedback loops that could be named.

c. Limitations : complexity, less detailed sectoral desaggregation and biases of the chosen economic theory

The first limitation of model-based methods is their complexity.

Using such methods implies a greater need for data and know-how, and therefore a higher budget. This complexity also results in a higher difficulty to identify the main drivers of the results. Indeed, even if a transparent explanation of the model is provided, too many mechanisms are involved to enable a quick comprehension of the overall dynamic. This complicates the debate with the stakeholders.

The second limitation is that these models do not offer the possibility of taking into account a large number of sectors.

In these models, the productive sector is represented by a maximum of about fifteen sectors, compared to 118 in the analysis presented in (Quirion, 2013). Key information can be lost with to aggregated sectors: for example, if jobs in gas and electricity are gathered in the same sector, job evolutions in the case of an evolving share between gas and electricity cannot be properly performed and disclosed. This makes the construction of specific narratives more complicated or impossible and complicates the debate with the stakeholders.

Recommendations for scenario producers:

Due to their complexity and low sectoral disaggregation, full model methods are not naturally adapted to create transparency and clear narratives that stakeholders can grasp so as to create a debate.

Thus, when a full model method is used, scenario producer should put a special effort into building a comprehensive narrative to illustrate the results provided.

What are the main drivers of the results? What do the provided results mean for the different stakeholders?

The third limitation is that the chosen model is subject to the biases of the chosen economic theory. Indeed, there are fundamental differences from one economic theory to another. Results on employment can therefore potentially be significantly impacted by the choice of model.

Recommendations for scenario producers:

When a full model method is used, scenario producer should discuss the extent to which the choice of economic theory can impact the results of the employment assessment.

3. Discussion about macroeconomic methods

The two types of methods presented in this section enable to inform system perspective.

The first type of method is manual, and uses an input-output analysis to calculate direct and indirect effects on the one hand, and then one or more induced effects on the other hand. This type of method offers the possibility of a large sectoral disaggregation, and is naturally transparent. However its static nature implies additional work and assumptions to make it more dynamic and it does not take into account all macroeconomic effects.

The second type of method is composed of full model approaches that make it possible to take into account all the effects dynamically. However it is a complex, prone to ideological biases, approach (difficulties to identify the main drivers of the results) with a relatively low sectoral disaggregation.

There is therefore a trade-off between clarity and completeness.

As already recommended, if the first type of approach is chosen, an effort should be made to explain the assumptions and limitations related to the static nature of input-out matrix and the magnitude of the neglected macroeconomic effects. If it is rather the second type of approach, then the effort should be put into making the results clear, transparent and accessible for stakeholders.

(Perrier & Quirion, 2017a) provides to that extent useful insights by comparing input-output approach and full model approach. Three effects are tested both with an IO model and a computable general equilibrium model (full model approach): labour share, wages and trade. A quantitative employment assessment analysis is then performed with the same data using the two types of model. Some discrepancies do appear even if there is no major inconsistency in the results. Reasons for divergence between the two models are then discussed.

(Breitschopf et al., 2012) provides a table comparing the main characteristics of net Input-Output modelling and full economic model approaches:

Table 2-3: Comparison of the two approaches

Characteristics	Net IO model	Full economic model
Profoundness and accuracy of results	Potentially medium – high. Depending on the level of detail of IO model and update status of IO coefficients	Potentially very high. Depending on the quality of the economic model, update status of IO coefficients and all other relevant data
Direct (RE industry) and indirect effects (RE upstream industry)	Yes	Yes
Induced effects (every sector of the economy)	Type 1 and 2, but limited to consumption (see Annex 1, A 1.3)	Type 1 and 2 Also: could take into account merit order effect, CO_2 prices, crowding-out of investments
Exports, imports	Yes – as a share of sector output or sectoral input	Yes – as share of sector output or input, trade module, etc.
Resource requirements (financial and human)	Medium - high	Very high
Data and model requirements	Medium RE capacity and generation data; technology-specific costs and cost structures; input-output model and coefficients	High RE capacity and generation data; technology-specific costs and cost structures; input-output coefficient, other economic, energy sector-specific and demographic data, macro model with trade module, energy sector module, etc.
Time horizon	Present(– future: simple assessment)	Future[6]
Scenario	Yes (limited baseline or counterfactual)	Yes (baseline)
Dynamic	Limited	Feedback loops, multiplier and accelerator, (endogenous) technical change.
Price and quantity changes	Limited Changes in prices or quantity are completely passed through to total output. Change is based on average coefficients	Yes Price or quantity changes are a result of output and price changes. Changes due to merit-order effect or CO_2 prices can be depicted
Economic relations	--> input-output relations between industry, final demand payment sector (linear - limitational)	--> input-output relations, national accounting, trade, job market, fiscal, climate, energy sector, household consumption, policies, etc.

Source: (Breitschopf et al., 2012)

They also propose to choose between the two types of methods according to budget availability, human resource, know-how and data availability. They recommend the net IO modelling if these are "limited", and the full economic model approach if these are "sufficient".

C. Additional cross-cutting elements to enlighten discussion with stakeholders

1. Geographical repartition of job creation and destruction

As well as sectoral repartition of job creation and destruction, geographical repartition is another key element since all regions do not undergo the same employment transitions, especially in scenarios with high shares of locally produced energy. This enables to better inform human resource management needs and can raise acceptability issues.

a. Several possibilities for a regional evaluation

Unlike sectoral disaggregation, none of the presented methods seem to directly allow a geographical distribution evaluation of job creation and destruction. Therefore such evaluation is less systematically performed. However, there are several possibilities to inform this aspect of an employment transition.

The most obvious one is to apply the chosen employment assessment several times, for every given geographical region. This is for example performed by (Greenpeace, 2015). The study indeed applies their net direct employment assessment method for ten different regions of the world.

Another possibility to illustrate this regional distribution is to define how the main sectors are distributed across the different regions. Thus, by identifying the sectors that will be strongly impacted by the transition to employment, it makes it possible to visualize which regions will be consequently impacted. This is performed for example in (European Commission, 2018).

In all cases, a qualitative narrative can enable to better illustrate this regional distribution aspect of the transition to employment.

b. Relocatable and non-relocatable jobs

Some jobs cannot be outsourced, such as installation jobs. For these non-relocatable jobs, the question is to figure out how to respond to the human resource needs presented in the next section, within the given geographical area.

Other jobs are relocatable. In this case, responding to the human resource need is less restrictive because it becomes possible to call on skilled workers in other regions or outside the studied geographical scope.

However, relocations may raise desirability issues. As described in (IRENA, 2018): "The geographic distribution of energy sector jobs gained and lost are unlikely to be aligned. This could introduce challenges for maintaining employment among fossil fuel workers if the focus is only put on retraining within the energy sector. [...] Additional measures such as social protection programs and adequate transition support are critical." (also see section on desirability)

Furthermore a relocatable job can be effectively outsourced or can stay local.

This depends on several elements:

- The presence or absence of local skills and local industry.

- Competitiveness of the local industry. (Percebois, s. d.) In a globalized world, price has a great influence on relocation choices: if the same good can be produced in a cheaper way elsewhere, relocation is often considered as a consistent option. This depends in particular on the capacity of the given region to take and keep a lead in the concerned sectors. (ECF, 2010). This ultimately requires to correctly manage skills need over time to avoid "bottlenecks" for example. (CEDD, 2013)

- Political choices. Politics can influence the two previous points through subsidies, taxes, bans and obligations and so on, or they can directly decide that no relocations are allowed for example. This depends on the choices made in the scenario.

The fact that a relocatable job is effectively outsourced or stays local has consequences on job content and balance of trade: developing a sector locally leads indeed to local job creations and tends to increase exports while developing it elsewhere does not lead to local job creation and tends to increase imports.

Recommendations for scenario producers:

Scenario producers should substantiate their assessment strategy about the regional distribution of employment needs of their scenarios, with regards to their driving question. If an assessment is performed it should be associated to a specific narrative.

Which regions will be most strongly impacted by the transition to employment? To what extent?

For relocatable jobs, the causes and consequences of offshoring dynamics should be explored.

Are the required skills developing fast enough in the given region so that no imports are necessary? How do relocations impact the employment content of sectors and the trade balance?

2. Job content dynamic

Employment content can vary greatly from one sector to another. This can have a strong overall impact on the employment need of a pathway. Typically, economic activities that come with transition pathways (energy efficiency, RES, etc.) are usually more job intensive than current energy activities (oil, gas and coal, etc.)

In addition, the employment content of each sector also changes over time.

As shown through the description of these several employment assessment methods, the job content of the different sectors vary over time according to many parameters: evolution of productivity, changes in energy and raw material prices, locality of employment, etc.

Recommendations for scenario producers:

The job content of each sector is different, and evolves during the timeframe scenario. Thus, the dynamics of the employment content of the several sectors considered should be explained, with a clear narrative to illustrate discrepancies and evolutions of these values, and their influence on the main results of the employment assessment.

This recommendation has already been formulated for manual methods but also applies for full model methods.

What are the most employment-intensive sectors? How do some changes observed within the scenario timeframe impact the job content values over time? To what extent do these trends influence total employment need?

III. Human ressource management

Transition changes described by scenarios both lead to decline in some sectors and to job creations in other sectors.

Therefore new amounts of skilled labor force are needed for jobs to be created as well as management of people losing their job is required for the change to actually happen without desirability struggles.

As we will see these are key enabling conditions.

A. Skills management for job creation

1. Job need is skills need

We previously explained why 'job need' term could be preferred over 'job impact'. One other added-value of this designation is that it becomes more obvious skills requirement underlies every transition since job need appeals for skills need and more generally for industry experience (which includes the experience in engineering, production or manufacturing).

As (IRENA, 2018) explains it, meeting the human resource requirements of sectors in rapid expansion is an enabling condition for a job transition. It requires to consider education and training policies to meet the demand for the skills needs of these sectors.

Indeed, (CEDD, 2013) supports the fact that paying attention to the supply of work and skills is necessary to avoid "bottlenecks". (European Commission, 2011) also insist on this idea: education and training need to be addressed at an early stage in order to avoid unemployment in some sectors and labour shortages in others. Change rates for each concerned industry in specific country / region is indeed a key element.

Employment needs management also depends on the age pyramid of the concerned population. For example, it is more complicated to mobilize a skilled workforce in a country where a majority of the population is no longer of working age than in a country with a majority of young people.

These questions of taking into account the actual transitions requirement in the labor markets are not only qualitative elements as showed in (Guivarch, 2011): introducing "rigidities" of the labor market in comparison with a "very flexible" situation can have significant impacts on the final results of some studies.

2. Level of professional skills

Another interesting element is the changes that a transition can bring to the level of competence required, and the consequences that these changes can induce.

Indeed, an energy transition can increase investments in new technologies, which can in turn lead to more demand for people in higher skilled jobs. Such a change can have various impacts: higher skilled jobs usually means workers who are better paid, with a higher job quality, but may also lead to a reduced access for women and young people (Cambridge Econometrics, 2011). All these aspects raise desirability issues.

Higher skilled jobs also means higher education time and thus higher inertia for the skills demand to be met.

Recommendations for scenario producers:

The evolution in professional skills and their change rates for each concerned industry in specific country / region should be taken into account.

Scenario producers should provide a narrative around these enabling conditions allowing the transformations to actually be implemented: evolution of skills and its pace should be addressed as well as the underlying need for education and training policies, especially when the proposed scenario includes important variations.

How to train people? What rhythm? How to maintain these skills over time knowing the know-how fades away after years/decades if the skill is not used?

The level of professional skills with regard to job quality and job access should also be qualitatively addressed.

Will the scenario require higher skilled jobs? What are the consequences on job quality? Would some part of the population be more likely to be excluded from these types of employments?

B. Management for job destruction

In the same way job need and skill need are an inseparable duo, job destruction cannot go without human resource management so as to prevent citizens to be left-behind and to avoid long duration unemployment.

Examples in the real world are numerous: when jobs are destroyed, support is needed. Similarly, the expectation of job destruction can generate strong resistance if not well managed. These are again enabling conditions for a job transition.

Thus, putting special effort on workers retraining to enable professional reconversion can be a key element. (IRENA, 2018) underlines that an assessment of the occupational patterns and skill profiles in declining industries is necessary to that extent. They then illustrate what concrete measures professional reconversion may require in terms of job security: "Because reskilling and other adjustments is not always certain to succeed, there is also a need to provide interim support, such as unemployment insurance and other social protection measures."

These are strong desirability issues of a scenario.

Again, management for job destruction can also be linked to the age pyramid of the concerned population. For example, the phase-out of a specific sector is eased when the majority of the workers are old and therefore close to retirement. This has an impact on the 'social cost' of the transition.

Recommendations for scenario producers:

The question of human resource management for job destruction should be addressed.

Scenario producers should provide a narrative around this desirability issue, as significant job destruction could raise strong resistance. They may include considerations on measures for professional reconversion, job security, and age pyramid.

Are some professional reconversions planned? What type of accompanying measures are implemented? In case no accompanying measure is implemented, how are desirability issues handled? How to retrain workers to enable professional reconversion? Are they close to retirement anyway? Which type of support would be needed? Unemployment insurance? Other social protection measures?

C. Stability of employment

Another notion that may be important is the stability of employment. From a total net employment assessment perspective, ten jobs during one year provide the same amount of working hours as one job for ten years. However, this is very different from a job precariousness perspective. Therefore a strong transition on a small timeframe doesn't have the same counterparties as a transition more spread over time.

Recommendations for scenario producers:

Since the different methods of net employment evaluation require to compare an assessed scenario with a reference scenario, all these narrative efforts should also be performed for the reference scenario as well.

The reference scenario may indeed include changes that would require certain elements to be put into perspective.

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The Shift Project

The Shift Project, a non-profit organization, is a French think-tank dedicated to informing and influencing the debate on energy transition in Europe. The Shift Project is supported by European companies that want to make the energy transition their strategic priority & by French public funding.

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