Aligning Investments with the Temperature goal of the Paris Agreement

Methodology report: Translating regional scenarios to the country level

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1 Introduction

Assessing how individual investment decisions align with long-term decarbonization goals is not a trivial task. It demands understanding national contexts and factoring in the interlinkages between activities in different sectors. Decarbonization scenarios are available in some countries, and for larger countries and regions as part of international literature. Many countries are working on their long-term low greenhouse gas emission development strategies, however up to the release of this report, only 10 submissions are online[1], and there is no safeguard that those strategies are Paris-aligned. Bottom-up scenarios attempt to model the interlinkages between different sectors and simulate different scenarios to create technology pathways but do not offer resolution for every country in the world.

The proposed approach translates existing decarbonization scenarios of the electricity sector from countries or regions to other countries where no scenario is available. We have created an excel tool that applies this approach and generates scenario pathways[2]. The resulting scenario pathways can be used to determine, for example, whether investments in specific projects are aligned with the Paris temperature goal. They could also provide countries with an overall direction to Paris-aligned development, especially where there are no national decarbonization pathways yet. This paper explains the methodology used,

The methodology aims to combine readily-available, country-specific data with scenario trends to create simplified pathways or strategies for decarbonization. This approach starts with the premise of a fully decarbonized electricity generation sector by mid-century for every country and assesses the path that countries with different electricity mixes would undergo to achieve such goal.

The current methodology is proposed as one of many alternatives to use decarbonization scenarios to develop country specific pathways. These pathways can then be used in combination with other strategies and tools. It can, for example, receive input from national scenarios or be used to help defining technologies that are clearly aligned or misaligned with long-term temperature goals.

The proposed method compares the planned electricity generation increase to the required short to medium-term development of the generation capacities. To that end, the method determines pathways towards 2050 relying on external scenarios and adjusting them to get to zero emissions in 2050. The methodology uses two alternative external scenario sources:

1. Greenpeace's Energy [R]evolution (Teske, Sawyer and Schäfer, 2015): using the *Advanced [R]evolution scenario* as the most ambitious option since it presents a fully decarbonized power sector by 2050 and offers regional level information on decarbonisation pathways for ten regions.
2. IEA's World Energy Outlook (IEA, 2017b): using the *Sustainable Development scenario* as the most ambitious scenario because it simulates emission pathways up to 2040 compatible with scenarios leading to a temperature increase of below 2°C and offers information on decarbonization pathways for eight regions.

These scenarios are sources that provide sufficient level of detail to conduct the desired assessment. These scenarios can be replaced, or others added, so the user can assess how results vary depending on methodological assumptions. The country in question is mapped to one region of the external scenario then the regional pathway is adjusted to reflect country specific information.

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[1] https://unfccc.int/process/the-paris-agreement/long-term-strategies

[2] The excel tool is available upon request to the authors.

2 Assumptions

External scenarios provide information on the evolution of each fuel type group in comparison to the present. They can be used to identify the speed at which technologies need to be deployed or phased out to comply with long-term decarbonization goals. Our approach is based on the scenario trends from the regions, the average lifetime of power plants, and the assumption of full decarbonisation by 2050. The main assumptions to derive country specific Paris -aligned pathways are:

1. Countries with similar electricity generation mix will develop under similar pathways;
2. The overall country emission intensity of electricity generation decreases linearly and reaches zero by 2050;
3. Coal capacity is assumed to follow the same trends as the most ambitious scenario available in each report; (either *Advanced [R]evolution scenario or Sustainable Development scenario,* see Introduction)
4. Gas and oil-fired power plants are phased out considering the average lifetime of that power plant type;
5. New gas-fired power plants are used to balance[3] emissions.
6. Low-carbon sources are used to match total electricity generation from the external scenario used.

Based on user information input, external scenario information and these assumptions, pathways for coal, gas, oil, and low carbon sources are derived.

3 Adjusting external scenarios

The proposed procedure to translate external scenarios to national pathways consists of four steps, as illustrated in Figure 1.

In all steps there is a combination of user and external input. External input, e.g. emissions intensity, is defined and linked to the scenarios mentioned in the Introduction or the WEPP power plant database (S&P Global Platts, 2017) for the calculation of country power plant lifetimes, as described in 3.3. User input data is case dependent and based on readily available information. All external inputs used in the tool is exemplary data, chosen because of data granularity. The users should carefully evaluate the inputs and replace those that do not serve their purpose.

The tool provides electricity generation curves for each fuel type: Coal, Gas, Oil and Low carbon. The following sections describe in more detail the steps outlined above.

[3] The sum of emissions of each fuel type is set to be equal to the total target emissions.

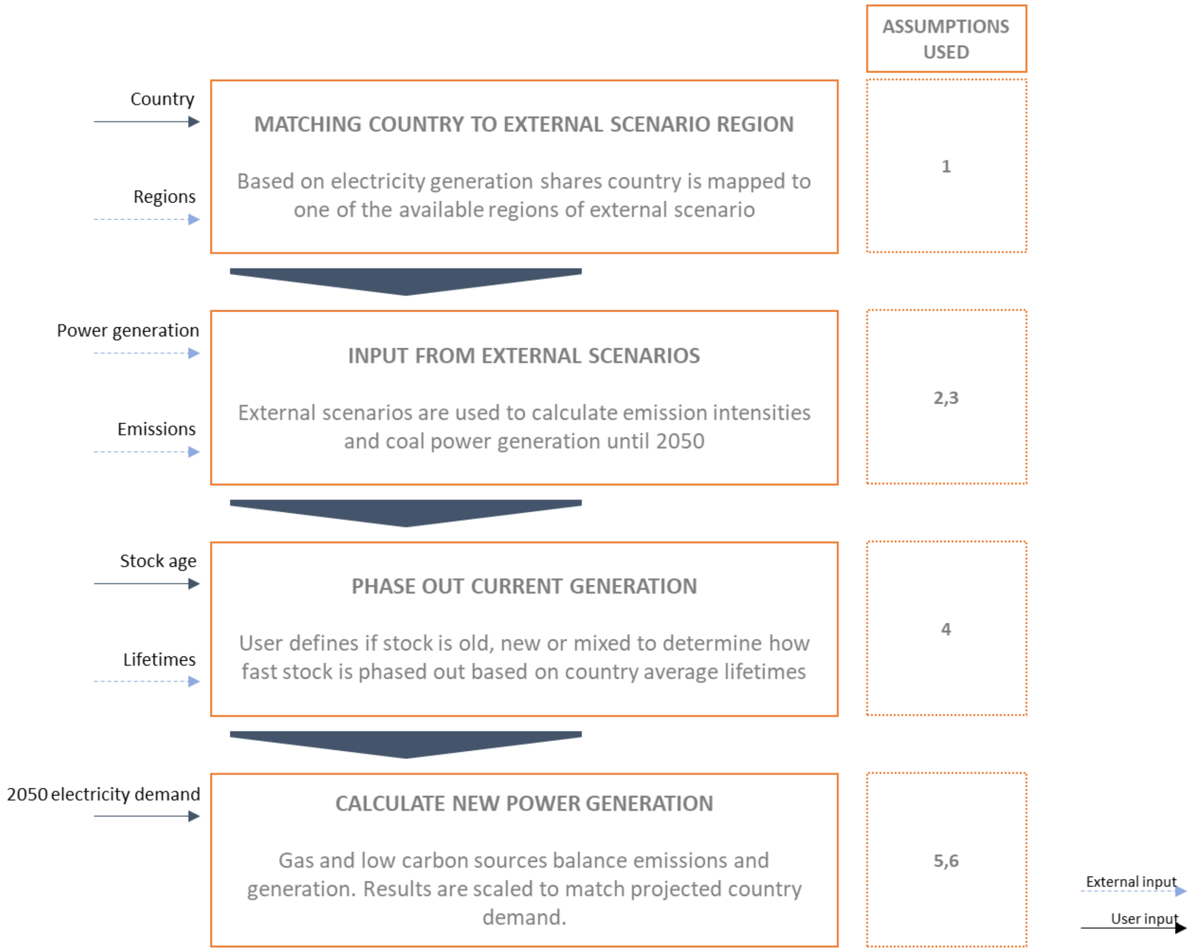

Figure 1 Diagram of methodology to adjust external scenarios

3.1 Matching country to external regional scenario

Based on electricity generation shares the country is mapped to one of the available regions of the external scenario. The indicator that best reflects the electricity sector is electricity generation (in TWh) per year. This indicator englobes both the concept of installed capacity and load factor. Electricity generation shares per fuel type are available for all regions of the scenarios used. With this information, it is possible to calculate the current dependency of each region on the fuel types and create regional profiles which reflect that fuel dependency. The dependency is determined by calculating what is the generation quintile of each electricity generation source.

We define four fuel type groups: Coal, Gas, Oil, and Low Carbon. None of the regions is dominated by oil-fired power plants, so, it is assumed that only the other three groups are needed to define a regional profile. The regions are categorized using the group quintiles as shown in Table 1 for Southeast Asia.

Table 1 Example of regional profile definition (Southeast Asia) using WEO data

ELECTRICITY MIX	TWh	%	QUINTILE
Generation Coal	34.58	19%	Q1
Generation Gas	126.99	71%	Q4
Generation Oil	1.01	1%	Q1
Generation Low carbon	15.18	9%	Q1
Total	**177.76**	**100%**	**Q1411**
Profile without Oil			**Q141**

The same procedure is repeated to determine the regional profile of all regions in the scenarios considered[4]. To determine the country profile the user can both add information about the current electricity mix or choose to use 2015 information from the IEA Energy Balances (IEA, 2017a). In either case, two situations may occur:

1. *The country data matches exactly one of the regional profiles*: the country is mapped to that region.

2. *The country data does not match exactly any of the regions*: the country is mapped to the best available region. The best available match is determined based on two guiding principles:
   i. The country's highest fuel dependency (fuel in highest quintiles) is the main matching criteria.
   ii. Fuel technologies with higher emissions are compared first.

When more than one region has the same profile, e.g. Q222, the geographical location of the country is used as a tiebreaker criterion.

3.2 Input from external scenarios

The external scenarios are then used to calculate emission intensities and coal power generation until 2050.

Emission intensities:
The sum of the total emissions from all sources in 2015 divided by the electricity generation in the same year gives the total emission intensity. This emission intensity is decreased linearly until it reaches zero in 2050 and is taken as the overall target emission intensity (e_{target}). In addition, each fuel type has an emission intensity (e_{fuel}) calculated in intervals of five years from 2015 to 2050 based on external scenario data:

$$e_{fuel}\left[\frac{gCO_2}{kWh}\right] = \frac{Emissions\ [MtCO_2]}{Power\ Generation\ [TWh]} \cdot 10^3$$

Assuming an overall energy intensity – e_{target} – of zero does not imply all technologies will emit 0 gCO_2/kWh by 2050 nor that all emitting sources will have their emission intensities – e_{fuel} – impacted in the same way. Multiplying the emission intensity target by the total electricity generation gives the emission target E_{target}.

[4] Due to regional overlap and different methodological approaches, the user should use one scenario at a time.

Coal trends
Coal electricity generation is another input from external scenarios due to its emission intensities and coal's share in total world electricity generation. But, while emission intensities are taken from reference of current policy scenarios, coal generation is taken from the most ambitious scenario available to consider the fact that current policies are not compatible with coal phase out rate needed to reach decarbonisation by 2050.

3.3 Phasing out current generation

Next, the user of the tool / approach defines if the country's specific fuel stock is "old", "new" or "mixed" to determine how fast the stock has to be phased out based on the country's average lifetime for the specific fuel plant type.

Power plant lifetimes

Technology choice as well as market and environmental conditions may impact the lifetime of power plants in different countries. The following methodology aims to calculate average remaining power plant lifetimes per country that better reflect these characteristics.

The WEPP power plant database (S&P Global Platts, 2017) contains information on over 100,000 power generation units around the world and is used to estimate the impact of national conditions on the operational lifetime of power plants. The database contains information of when the power plant was commissioned and the current status, but not when it was decommissioned. Therefore, all deactivated plants are excluded from the analysis since it is not possible to know for how long they remained active. So, plants included in the analysis are in construction or in operation.

For all power plants that are not yet in operation the remaining lifetime is assumed to be the average lifetime of that fuel type technology. For all the countries where no information was available world averages are assumed.

Phasing out existing generation stock
Existing oil and gas generation infrastructure are assumed to be phased out from the current date until the end of the remaining lifetime. The age distribution of the stock and policy considerations will differ from country to country, and this can impact significantly how fast fossil fuel stock is phased out.

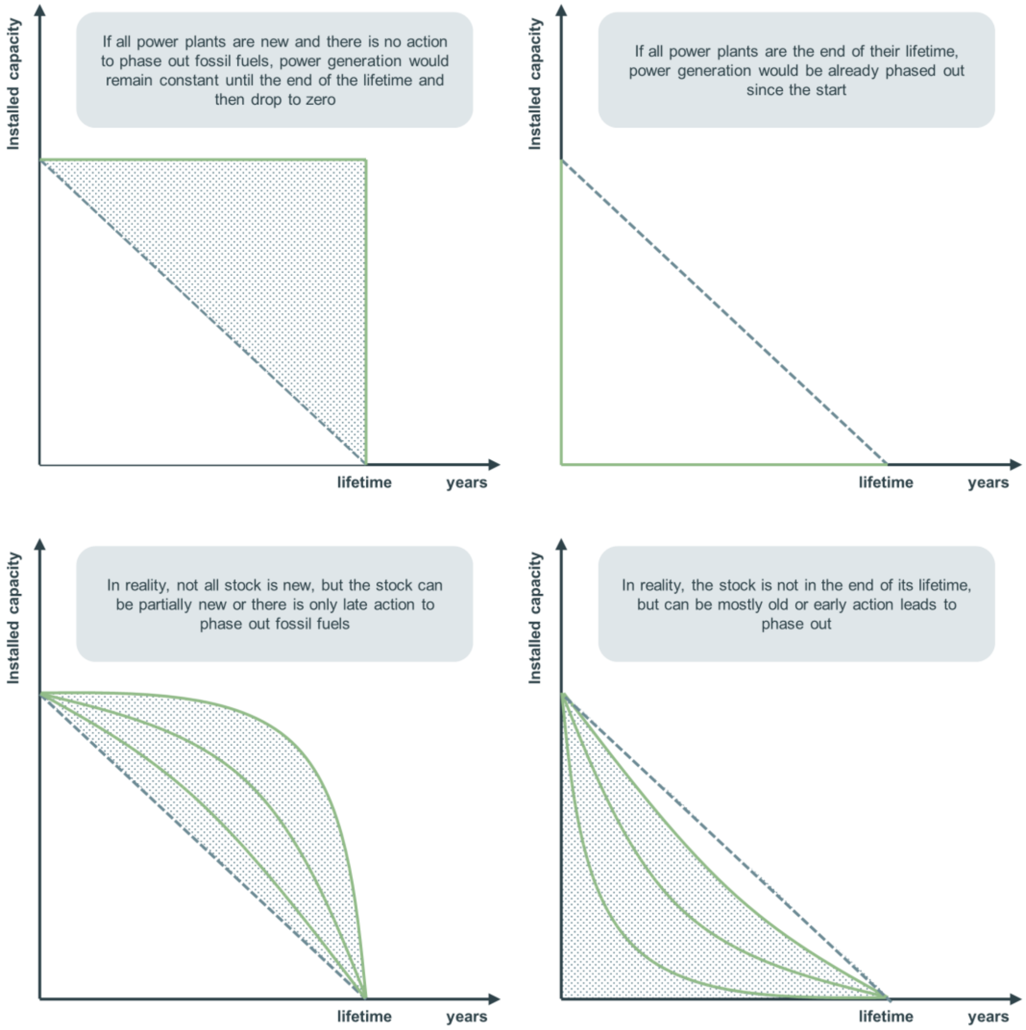

Figure 2 How stock age distribution can impact phasing out speed. Green curve represents examples of phase out curves. The blue dashed line represents a phase out curve under linear phasing out conditions, or average stock age structure.

Due to these differences, three distinct cases are defined to incorporate this effect. The user choses the appropriate case for each country according to the fuel-specific average power plant lifetimes. The cases described below are simplifications aiming to portrait the effects shown in the picture above.

P stands for electricity generation from a specific fuel in the year t. The α_i coefficients determine the degree of convexity or concavity of the curves in Figure 2 and therefore the rate of phase out of a specific technology. The coefficients are all determined by fixing that P_{start} is the current electricity generation and in the end of the lifetime ($t = t_{lifetime}$) the electricity generation is zero.

1. Case 1 – "new stock": Based on the left-hand side of Figure 2, it considers a newer stock or late action to phase out fossil fuels. The following expression is used to phase out the stock in this case:

$$P = \frac{P_{start}}{\alpha_2} \cdot \ln(\alpha_2 - t)$$

2. Case 2 – “old stock”: Based on the right-hand side of Figure 2, it considers an older stock or early action to phase out fossil fuels. The following expression is used to phase out the stock in this case:

$$P = P_{start} \cdot e^{-\alpha_1 \cdot t}$$

3. Case 3 – “mixed stock”: Based on a linear abatement of current fossil fuel capacity, this is an intermediary option in case users don’t know which situation is more likely in their country.

$$P = P_{start} - \alpha_3 \cdot t$$

Electricity generation figures are calculated, for each fuel type, every five years so they can be used with the emission intensities to calculate emissions from the existing stock. This calculation is further described in Section 3.4.

3.4 Calculating new electricity generation

Next, the approach assumes, that gas and low-carbon sources are used to account for the difference in emissions/electricity generation from above calculated generation and projected emissions/electricity generation. Results are scaled to match projected country demand.

While there is no room for new investments in oil and coal, gas-fired power plants might play a role in future electricity systems. Based on existing electricity generation and emission intensities it is possible to calculate the total emissions and compare these to the target emissions (going linearly to zero in 2050). This comparison gives the total gas capacity that could be installed.

Emissions (E_{fuel}) are calculated multiplying the electricity generation (P_{fuel}) by the emission intensities (e_{fuel}). Coal generation is taken directly from the external scenario while oil and gas generation are determined by one of the three cases discussed in Section 3.3:

$$E_{coal} = e_{coal} \cdot P_{coal} \cdot 10^{-3}$$

$$E_{phase\ out\ gas} = e_{\ gas} \cdot P_{phase\ out\ gas} \cdot 10^{-3}$$

$$E_{phase\ out\ oil} = e_{oil} \cdot P_{phase\ out\ oil} \cdot 10^{-3}$$

New electricity generation from gas is used to balance overall emissions: the sum of the emissions calculated above may differ from the emission target (E_{target}). It is assumed that this emission difference is due to new installed gas capacity.

$$E_{new\ gas} = E_{target} - E_{coal} - E_{phase\ out\ gas} - E_{phase\ out\ oil}$$

$$P_{new\ gas} = E_{new\ gas} \cdot e_{gas} \cdot 10^{3}$$

Finally, low carbon capacity is used to balance supply and demand. The sum of the generation is equal to the projected power demand:

$$P_{low\ carbon} = P_{demand} - P_{coal} - P_{oil} - P_{gas} - P_{new\ gas}$$

Two other restrictions are added to the electricity generation:

1. *Low carbon generation is never reduced*: if the calculation above results in Low Carbon electricity generation lower than the previous year, Low Carbon generation is kept constant and gas reduced; while supply and demand are always balanced emissions can be smaller than the emissions target.

2. *Scenario demand is scaled to match country projected electricity demand*: after the electricity generation is calculated it is scaled (but relationship between technologies kept constant) to match the future electricity demand from user input.

New and existing gas curves are combined and four[5] curves are obtained from the generation calculated in the previous steps. Factors, by which the current generation needs to be multiplied to reach the projected generation levels, are also calculated per technology. Figure 3 exemplifies the results.

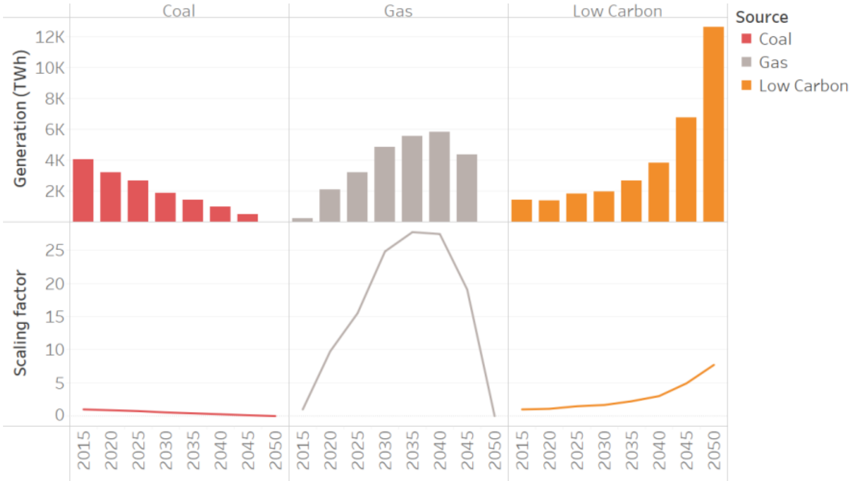

Figure 3 Generation and factor curves

It is important to understand that the suggested curves do not take into account the lifetime of new gas power plants, but still requires the electricity sector to be fully decarbonized by 2050. This means that further criteria need to be considered, to avoid the risk of stranded assets.

[5] The oil curve is omitted due to its scale in comparison to other sources.

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Annex 1: Calculating country average remaining lifetimes of fuel-specific stock

As a starting point, the following global average lifetimes are assumed:

Table 2 Average global operational lifetimes

Fuel Type	Lifetime [years]
Coal	38.6
Gas	35.8
Oil	33.8

For the projects in operation two situations are possible:

The plant is active beyond the average global lifetime

The lifetime is considered to be the current date (fixed in 2015) minus the commissioning date.

Some countries allow for power plants to operate significantly longer than the average global lifetimes. In this case, these power plants overall lifetime is assumed to be the operation time. By taking the operating time into account the average remaining lifetime of that fuel in the country can only be increased.

The plant is within the average global lifetime

The lifetime is the commissioning date plus the average lifetime minus the current date (fixed in 2015).

Power plants that are operational for a period shorter than the global average lifetime per fuel are assessed considering their remaining lifetime. This reflects the age of the stock: more power plants operating for a period close to the lifetime should reduce the projected average remaining power plant lifetime for that country. By taking the remaining lifetime of the country's individual plants into account the average remaining lifetime of that fuel in the country can only be reduced compared to the global average lifetime.

The fuel types from the WEPP database need to be mapped to one of the encompassing fossil fuel groups: Coal, Oil or Gas. The table below shows the classification adopted:

Coal

- Coal
- Coal seam gas (aka coal bed gas or coal bed methane or CBM)
- Coal syngas - fuel for IGCC plants (from gasified coal)
- Coal-water mixture (aka coal-water slurry)

Gas

- Blast-furnace gas also converter gas or LDG or Finex gas (approx 10% of the heat content of pipeline gas)
- Coke oven gas (approximately 50% of the heat content of pipeline natural gas)
- Corex process offgas
- Dimethyl ether
- Flare gas or wellhead gas or associated gas
- Landfill gas
- Liquified natural gas
- Liquified petroleum gas (usually butane or propane)
- Mine gas (methane from active or abandoned coal mines)
- Natural gas
- Natural gas liquids, also natural gas condensate
- Refinery off-gas
- Syngas from gasified refuse
- Top gas
- Waste gas or low calorific gas (LCV from refinery or other industrial processes)

Oil

- Ethanol
- Fuel oil
- Gasified crude oil or refinery bottoms or bitumen
- Jet fuel (typically kerosene, also naphtha-type)
- Kerosene (also see jet fuel)
- Methanol
- Oil shale
- Pulping liquor (black liquor)
- Synthetic gas from petroleum coke

Figure 4 Fossil fuel WEPP database classification

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