PACTA
2°C Investing Initiative

Methodology Documentation

Company Level Scenario Analysis

PACTA Methodology
2°C Investing Initiative

First draft adapted for Company Reports

Table of contents

1 Climate scenario analysis & portfolio alignment

1.1 How to tackle financial players' climate responsibility

The 2018 IPCC Special Report on the impacts of a global warming of 1.5°C reported that "human activities are estimated to have caused approximately 1.0°C of global warming above pre-industrial levels" and "global warming is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate".[1]

Containing anthropogenic impact on the climate system requires "the upscaling and acceleration of far-reaching, multilevel and cross-sectoral climate mitigation".[2] Managing to stay on a pathway limiting global warming to 1.5°C "would require rapid and far-reaching transitions in energy, land, urban and infrastructure (including transport and buildings), and industrial systems. [...] These systems transitions are unprecedented in terms of scale [...] and imply deep emissions reductions in all sectors."[3]

They are also required to mitigate the existential risk that climate change poses to collective prosperity and ultimately, civilization itself. Failing to mitigate climate change will ultimately threaten habitability on this planet over the next centuries. Collectively, consumers, business, and governments will determine, based on the decisions they make today, that future. Decarbonization is an economic and social imperative.

In response to that reality, a growing number of financial institutions are seeking to understand the contribution their clients and investees are making to this collective decarbonization effort.

These efforts are driven by a combination of business and normative drivers:

- From a **business perspective**, an understanding of clients and investees' contributions to decarbonization efforts can help inform their adaptive capacity and thus act as an input into the assessment of financial risk associated with decarbonization ("transition risk"). It can also help inform on potential reputational risk associated with conducting business with these clients, which in turn can impact the social or political license to operate. Independent of the policy momentum associated with transition risk, financial institutions may also directly face supervisory pressures to address this issue, as evidenced by the EU Sustainable Finance Action Plan and related initiatives in the United States and around the world.

- From a **normative perspective**, a number of financial institutions accept a collective responsibility with regard to the political and social mandate to limit global warming and are seeking for ways to contribute in the context of their business model to that mandate. These institutions are looking for ways to measure the consistency of their investees' and clients' business model and ultimately their own business with climate goals and mechanisms to contribute to achieving these goals.

In this context, the 2° Investing Initiative has developed the Paris Agreement Capital Transition Assessment (PACTA) model, which measures the exposure to and alignment with a series of decarbonization scenarios of companies and financial portfolios.

The model can help inform both on the normative and business objectives of financial institutions. This document provides a comprehensive insight into the methodology and approach underpinning PACTA. It consists of both an introductory section outlining the key concepts, approaches, and methodological

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[1] IPCC (2018) Special Report on the impacts of a global warming of 1.5°C, p. 3

[2] Ibid., p. 5

[3] Ibid., p. 15

choices PACTA takes in a way that is designed to be accessible to non-expert users, as well as a core methodological section outlining the underlying equations in the modelling.

At its heart, PACTA – and all other modelling approaches focusing on the financial sector seeking to answer similar questions – must answer two key questions:

- How do you allocate the global (macro) responsibility associated with decarbonization scenarios to (micro) economic actors (portfolios, companies)?
- How do you allocate the responsibility for the ultimate drivers of climate change – the emissions of real industrial economic assets ("physical assets") – to the instrument that finances the development and operation of these assets ("financial assets")?

Within these two questions, there are of course a range of other 'accounting' and output questions: What is the time horizon over which an alignment with a scenario is measured? What is the unit in which this alignment is measured?

Parallel to these questions is the broader question of the business model underpinning the methodologies and approaches being developed by the market.

Crucially, PACTA is an open-source tool and framework. It enjoys zero protection in terms of intellectual property, the whole of the code designed to implement PACTA is publicly available on GitHub, and the developers of PACTA – the 2° Investing Initiative – have a 100% non-commercial business model. As policymakers and private sector initiatives seek to build standards and common approaches around addressing these questions, such a model will be imperative to avoid commercial biases when designing standards and ensuring a transaction-cost minimizing solution, that allows financial institutions and other users to maximize their resources on action and minimize their resources on measurement.

Users and interested parties reading this document should also be aware that PACTA is a tool that serves two end goals: risk management and having a positive impact in the real economy. While it serves this goal, it does not directly measure either.

PACTA results are not expressed in financial losses or similar outputs, although the PACTA methodology serves as an input to the stress-tests currently being designed by a number of financial supervisors around the world (Bank of England, EIOPA, JFSA).

Similarly, PACTA measures the alignment of financial portfolios and companies with climate goals but does not yet at this stage measure the contribution that financial institutions are making to 'improving' the results in terms of contributing to ultimate emissions reductions in the real economy. Further research and analysis is needed to better understand the relationship between finance and economy on this topic. Nevertheless, even as PACTA – by design – focuses on the first step of alignment, it acts as a critical input and first step towards these ultimate objectives part of the current research programme of the 2° investing Initiative for 2020 and beyond.

The methodology document seeks to answer the following questions:

- What is the scope of PACTA in terms of business activities and financial assets?
- What are the key inputs to the model in terms of climate data and climate scenarios?
- How does the model distribute the global responsibility associated with scenarios to portfolios and companies?
- How does the model allocate the 'responsibility' of financial assets for the economic activity?
- How are the outputs expressed?

This methodology document is intended for readers of the company reports and is an extract from a more comprehensive document designed for users with financial portfolios. Hence there may be some references to investment or lending portfolios throughout. These can be used to understand the context *of how the company level scenario analysis could be used and fits into the bigger picture.*

PACTA at a glance

- has as core objective to **measure the alignment of a financial portfolio with 2°C climate goals**
- to do this: **tracks the forward-looking alignment of the economic activities** financed by the portfolio with macroeconomic decarbonization scenarios
- spans **key climate-related sectors** (fossil fuels extraction, power generation, transport, cement & steel), which account for around **75% of global GHG emissions**, and make up around 20% of a typical lending portfolio
- takes a **sector-specific approach** – providing specific targets for each type of economic activity in different sectors – as opposed to an aggregated portfolio-level target. This allows for portfolio **steering and benchmarking against peers** that provide capital to the same sectors
- **translates 2°C scenarios into portfolio-specific targets** by allocating the macroeconomic trend to the companies and assets in the portfolio based on their market share.
- relies on physical asset-level data, providing for a precise, technology-specific insight into the current and future activities of companies, mapped over a five-year time horizon
- is **adaptable to any to any external scenario** that models the evolution of the economy under a decarbonization pathway

A brief history of the 2° Investing Initiative and PACTA

The 2° Investing Initiative was founded in 2012 with a mission to **align financial markets with climate goals.** Its research aims at integrating long-term climate -risks and -policy objectives into financial markets and regulatory frameworks, and at reversing information asymmetry and market failure on climate risks.

Over the past few years, 2°ii has led **one of the largest global research programmes on long-term risks in financial markets**, working with over 50 research partners. PACTA is the first scenario analysis tool **linking financial portfolios to public policy objectives** – specifically the 2°C climate goal – and is endorsed by the Principles for Responsible Investment and the California Insurance Commissioner. 1,700+ individual users from more than 1,000 institutions (across 70 countries, evenly distributed across developed and developing countries) have used the tool to conduct over 6,700 tests. Nearly 900 financial institutions **have used the tool to analyse over USD 61 trillion in total AuM**.

2°ii **partners with a number of financial supervisory authorities** across Europe, Japan and the US (Bank of England, Dutch Central Bank, European Insurance and Occupational Pensions Authority, Japanese Financial Services Agency, etc.), and was instrumental in the passing of the first legal requirement of climate-risk disclosure (art. 173).
Latest new research streams include **climate stress-tests for insurers** (developed with the Bank of England in 2019) and investment product labelling for **retail investors** (development of a robo-advisor).

1.2 Scope

1.2.1 What does PACTA analyse?

PACTA provides two main types of outputs:

- The diversification of a portfolio at a point in time in terms of exposure to physical assets, benchmarked either to the market, a series of peers, or the diversification of physical assets in scenarios;
- The alignment of the evolution of that exposure over time to climate scenarios.

Further details on the exact configuration and methodological choices with regards to these outputs is provided in section 2.

1.2.2 For which part of the economy is climate alignment analysed?

The scope covered by the model encompasses highly climate-critical sectors (across energy, transport, industry), namely a set of sectors that together concentrate around 80% of all CO_2 emissions and 60% of GHG emissions (IPCC 2014).

All primary energy sources are covered, as well as the main contributors in transport and industry. They make up around 25% of a typical wholesale banking portfolio in terms of lending volume, although of course that share can differ dramatically across banks.

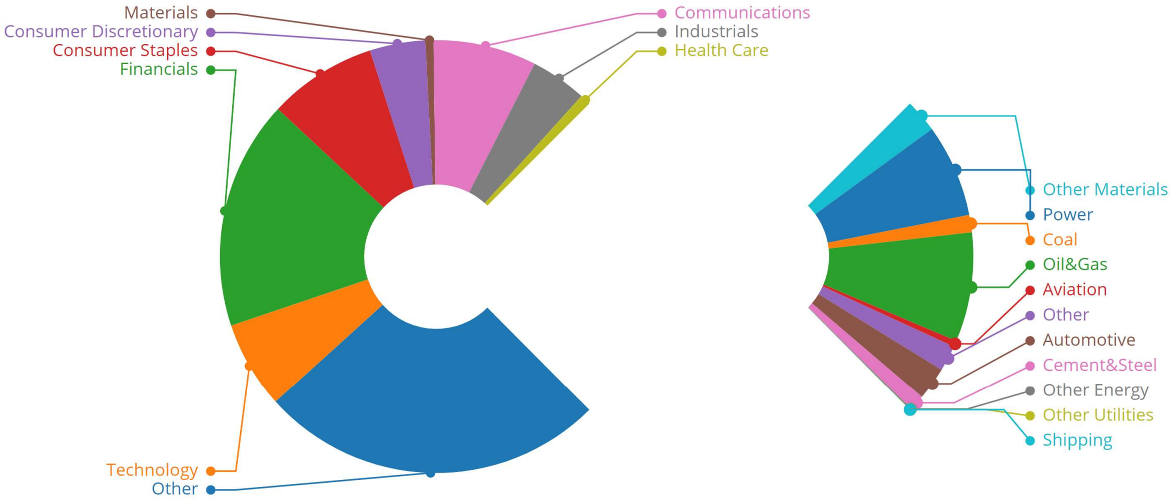


Figure 1 Portfolio distribution across industries

Within these sectors, the scope is circumscribed such as to include the segment of the value chain that holds the bulk of the impact on the climate system, and on which decarbonisation efforts must be concentrated (the blue in the image below):

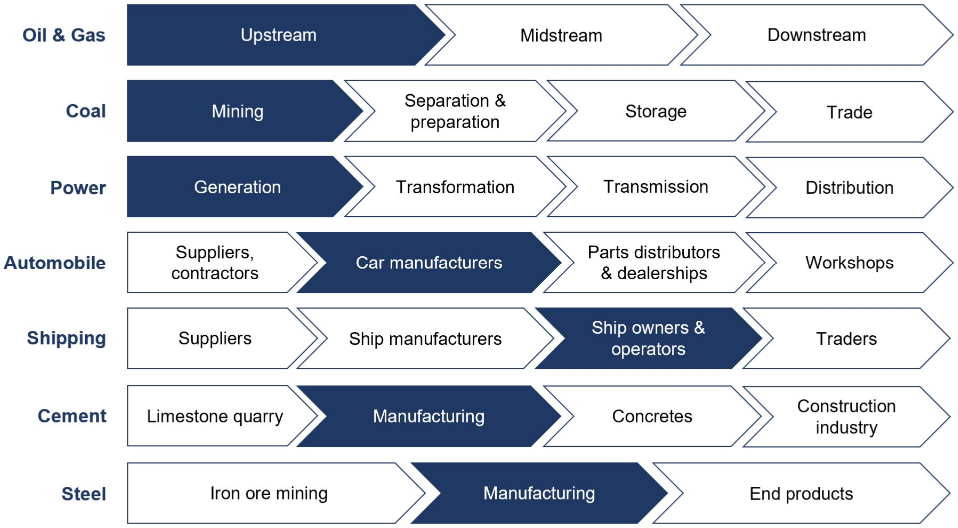


Figure 2 Sectors in scope and climate-critical business segments

1.2.3 "External constraints"

- **We cannot measure alignment in units that are not represented in the scenario. That means that 'financed emissions' are not a viable way to measure alignment.**

Climate scenarios are expressed in almost all cases in real economic units. As a result, the analysis must similarly be expressed in the same units. By extension, financed emissions are disqualified as an indicator to measure warming potential or alignment of portfolios.

Where climate scenarios use investment or financing volume figures, these are absolute figures that would require 'absolute' volume analysis for portfolios. Given the uncertainty of both the actual investment roadmaps, their volatility over time, and data gaps, alignment analysis based on the investment or financing footprints are currently impossible.

- **The analysis must rely on indicators that are not 'polluted' by external factors outside of the scenario (e.g. changes in financial asset prices)**

The analysis should ensure that performance does not improve simply as a result of changes to financial parameters. For example, when analysing companies' emissions intensity related to financial units (revenues, enterprise value), they exhibit high degrees of volatility in response to revenue and enterprise value volatility, independent of the underlying decarbonization of those companies. The figure below highlights the year-on-year volatility of a sample of 1,000 companies in the MSCI World, showing that even for large cap companies, enterprise value can fluctuate dramatically.

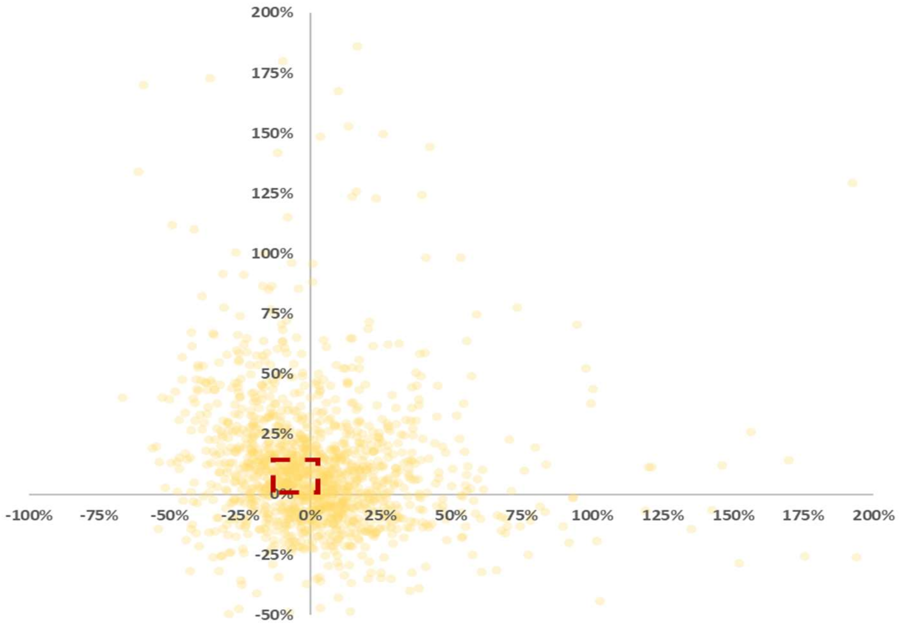


Figure 3 Volatility in market capitalisations

There is currently no scientific way to aggregate ‘alignment’ across different sectors, and thus this is not a feature in the methodology.

There is currently no viable way to measure alignment for economic activities accounting for around ~20% of CO_2 emissions and around 40% of GHG emissions.

1.3 Inputs

1.3.1 Climate data

The PACTA model relies on an assessment of physical assets linked to financial assets and the exposure to and alignment with climate scenarios of these assets.

By extension, the climate data mobilized for PACTA must similarly have at its heart these physical assets, although for various applications, aggregated corporate profiles across these assets can inform the analysis in practice.

Physical assets databases exist for all the sectors covered in the scope of PACTA and are mobilized in the model using third-party databases. While the resorting to asset-level data is here upheld as a necessary pillar of the model, the choice of the source of information can be left up for debate: corporate disclosures, regulatory filings, business intelligence databases, the bank’s internal data (usually highly granular especially for SPVs, but not always aggregated in a standardized way enabling to mobilize it at scale), etc.

The data sources selected record forecasts for future production, enabling a forward-looking analysis. They are updated on a regular basis (from continuously in quickly moving sectors such as automotive, fossil fuels and power to annually for “stable” sectors such as cement) by the data providers, and delivered in batches at regular intervals. 2°II data engineering team obtains the aforementioned extensive asset-level databases from business-intelligence data providers, and further enriches them with financial data, which can be sourced from a range of different data providers. The model thus rests on a network of ultra-precise datapoints.

At each level along corporate structures (subsidiary, parent company, group, etc.), production figures are aggregated as follows. Physical assets' production figures are allocated to the companies that own them using the "equity share approach": if Company A owns x% of Asset 1, it gets attributed x% of its production. Subsidiaries' production figures are allocated to their parent companies are calculated using the "majority ownership approach": if Group α owns the majority of Company A, it gets attributed all its production. This modelling choice was made by default, for lack of ownership data on unlisted companies, and in view of the need for a consistent rule.

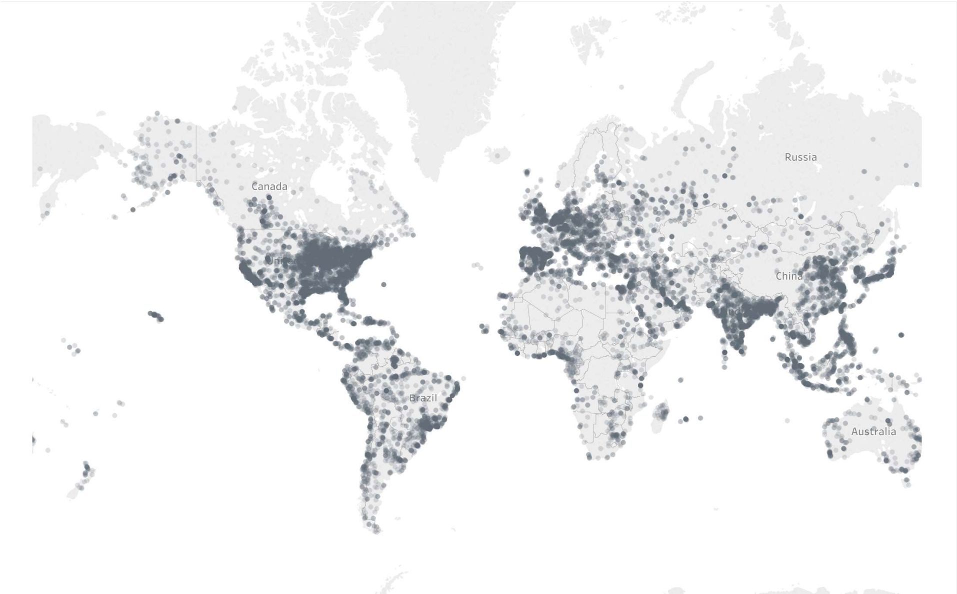


Figure 4 Global distribution of the physical assets in 2II databases

Table 1 Pros and cons of ALD and company reporting

Pros	Cons

Asset level databases	High degree of global coverage of climate relevant sectors (80-100%) Carbon intensive sectors reflect app. 70 – 80 % of the climate impact of a corporate loan book (Exane 2015). Provide forward-looking information in many cases	Generally, not applicable in the context of non-carbon-intensive sectors (e.g. current coverage ~20% of the financial portfolio) Challenge around communicating that the assessment doesn't cover 100% of a corporate lending portfolio Uncertainty in corporate ownership trees may lead to some errors in the data aggregation process Data is not audited and verified independently
Company reporting	Audited, verified data Can capture company strategy (e.g. company targets, etc.)	Limited reporting on listed companies, hardly any reporting on non-listed companies, the latter is the far majority of a bank's clients. Aggregates imply limited usability for scenario analysis Inconsistent accounting rules across reporting

1.3.2 Scenario data

The model stays clear of prescribing the use of any specific scenario and allows for any climate scenario to be used, providing it lays out targets in production-capacity at technology level or – for the relevant sectors – emission-intensity units. The choice of scenario dramatically influences results and thus **the study of each scenario's assumptions and the use of several scenarios is encouraged.**

Different scenarios differ in the main following ways: they

- lay out decarbonisation paths that occur at **different speeds** (rapid ramp-up or long-term adjustment)
- make different assumptions around innovation and thus around **technologies' availability, scalability and cost**
- (as a result) favour or rule out different technologies (e.g. phase-out of nuclear in the Energy Revolution scenario, prominent use of CCS in the B2DS scenario)
- implement decarbonisation paths of **different levels of ambition** (resulting in varying likelihoods of limiting global average rise in temperature to 2°C)
- are **varyingly granular**, e.g. expressed at different time and geographic scales

In the road-test, the International Energy Agency scenarios were used, namely those laid out in the Energy Technology Perspectives (ETP) for the transport and industrial sectors, and those laid out in the World Energy Outlook (WEO) for the fossil fuel and electric power sectors.

Wherever available, scenario data is used at regional rather than global level. This is done only for regional markets such as the power market. Where regional scenarios exist even though the market is global - e.g. for oil - the global scenario is used.

When expressed at global level, targets can be either the world's actual global targets, or a custom global target re-built from regional targets, aggregating them using the same regional distribution as the portfolio.

Wherever required (e.g. for year 2022 to estimate targets for that horizon - IEA data being typically presented in 5-year intervals), data is linearly interpolated using the most recent observed figures (e.g. interpolation for year 2022 using 2019 observations and 2025 projections).

Sectoral Decarbonization Approach

The Sectoral Decarbonization Approach (SDA) is the method used to set carbon-intensity reduction targets based on sectoral carbon budgets. It was designed for homogenous sectors. In the model, it is applied to the cement and steel sectors, and can also be applied to the power and automotive sectors for reporting purposes (production capacity metrics being better suited for steering purposes, for the reasons discussed above).

The SDA was developed by the Science-Based Targets Initiative (SBTI), an international initiative on science-based target setting for companies initiated by CDP, the United Nations Global Compact, the World Resources Institute (WRI), and the Worldwide Fund for Nature (WWF). The SDA is adapted such as to fit the modelling underpinning the PACTA methodology.

These alterations allow to account for a different data universe than the original one of the SDA, and to preserve consistency in market share over time. In the model, the SDA is used to measure alignment between portfolios in the cement and steel sectors and climate scenarios. The reduction target at 5 years from present will differ from one portfolio to the next in relation to the portfolio's initial carbon intensity.

The difference between the portfolio's actual projected intensity and the target set under the SDA can be used as approximation of the portfolio's current degree of alignment with the climate scenario. A key tenet of the SDA is that all portfolio targets will converge to equal the sector intensity target at the end date prescribed by the scenario. The entire formalisation of the application of the SDA in the model is laid out in section 2.3.2.

This methodology will be rolled out in 2020 for the cement and steel sectors.

1.4 Outputs

1.4.1 Two alignment concepts

There are two "alignment concepts" that can be applied in the portfolio analysis under PACTA

1) **The market approach** suggests measuring the 2°C alignment of a financial portfolio at some future point relative to what is called here a '2°C benchmark'. The portfolio mix needs to be consistent with the required mix in a future point of time, independent of the technology mix in t = 0. The market exposure under a 2°C transition here represents the expected evolution of the defined market, which can be scoped in various ways (economy, regional market, asset class, a set of peer portfolios) under a 2°C transition. It is relevant to highlight here that this approach

can obviously also be applied at t=0. The benchmark can be scoped in various ways: all players in the industry or a subset, regionally or globally, or even a set of comparable portfolios. It is defined differently depending on asset classes. Section 1.6.5 discusses the benchmarks used in the application of PACTA to credit portfolios.

2) **The trajectory approach** focusses on the necessary rate of change under a 2°C transition, and takes into account the technologies financed after t= 0 , where the measurement does not compare absolute exposure at a future point to the absolute exposure of a market benchmark, but rather seeks to compare two rates of change, namely the rate of change in the portfolio with respect to the climate unit, and the necessary rate of change under a 2°C transition. In other words, in the trajectory approach, the starting point of the portfolio is identical to the benchmark (e.g. even if the portfolio is 100% coal-fired power exposed today, this starting point is applied despite the fact that in the economy the share of coal power is lower). While the starting point is not directly considered in the trajectory approach, it is needed in order to calculate the market share and thus the allocation of the macroeconomic scenario to the specific company.

1.4.2 Time horizon of analysis

For all regions, companies, and scenarios, several projections are generated:

- a **current-day** estimate
- a **5-year forecast**, which reflects the known CAPEX plans
- a **scenario-aligned target** profile, at a 5-year horizon or any further horizon within the scenario's timeframe

5 years is the furthest horizon for which CAPEX forecasts were considered (i) to be meaningful and (ii) to possibly be reliably tracked.

Acknowledging that the furthest meaningful horizon varies across sectors, this 5-year horizon is adopted as best common denominator. The expected alignment of the portfolio is thus only assessed at a 5-year horizon, but the companys target future profile, and future aligned benchmarks can also be calculated at further time horizons - depending on climate scenarios.

When a company projects future activities or revenues, it does this based on the current fixed asset base and commitments as to the evolution of that asset base based on investments and mergers and acquisitions.

1.4.3 Geography

The model is global in terms of assets coverage and analysis. The scenarios and regional splits are currently either weighted based on regions (OECD, non-OECD, Europe, etc.) or at the global level. At the global level, the target is calculated from aggregating regional targets, weighting them using the same regional distribution as the company's production.

Where markets and scenarios are highly regionally fragmented (as is the case for the power sector), and the scenario provides sufficient regional granularity, the benchmark starting point as well as the slope should be adjusted by the regional scope of the portfolio (in terms of production exposure) per sector. This is notably the case for the power sector, where regional trends for example for coal power differ significantly (see figure below).

The targets laid out in climate scenarios vary by region: some are on more ambitious decarbonisation paths than others. This is not always true for all sectors, essentially depending on how globalised the production process and market are in each sector (e.g. the automotive sector - whose production is concentrated in Asia, but whose market is global - is generally only attributed a global target, whereas the power sector is attributed country-specific targets in some scenarios).

The alignment of the sectoral subsets of the portfolio are assessed via results generated either at the global or at the regional scale (i.e. for fractions of the portfolio once split by geographical region, and using as variable the geolocation of the assets owned by the bank's borrowers).

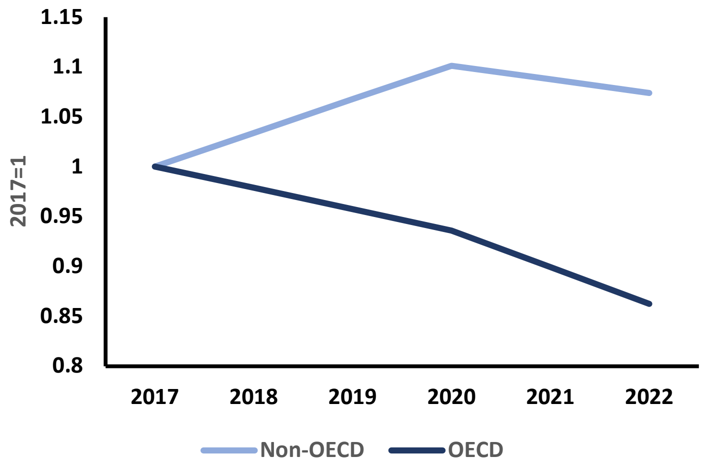


Figure 5 Relative evolution of coal-fired power capacity in the IEA 450 scenario in the OECD and Non-OECD by 2022

1.4.4 Benchmarks

When developing an alignment benchmark / target, one question is the 'universe' against which you are being benchmarked. To address this challenge, the alignment assessment can take various subsets against which the economic trend is compared. The different levels to which the starting point of the benchmark can be mapped are notably: the economy, companies, companies issuing debt, or the portfolio itself (the equivalent of the trajectory approach). Regionality can also be filtered in the starting point, in terms of location of companies and the scenario itself.

1.4.5 Unit of outputs

The unit of measure is arguably the most basic element when it comes to accounting principles, and indeed the one that has received the most attention in the academic and practitioners' literature. The accounting units are generally classified in three categories:

- GHG / CO_2 emissions accounting
- Technology profile
- Qualitative metrics

As outlined above, for *2°C* scenario alignment analysis, the climate units need to be expressed in the same unit as the scenario itself for comparability. Thus, the data point may either be expressed in production capacity, production, investment / financing, and / or CO_2 / GHG emissions). Given the balance of pros and cons (see table on next page, the model developed here relies on the technology mix capacity. The reason for this is that it:

- minimizes the data uncertainty in the economic activity data
- can be linked to equivalent units in the scenario

- reflect the 'supply decisions' that companies control

The caveat to this choice is that for some sectors, a technology profile may not be intuitive. For example, in the cement sector a myriad of adjustments to the fuel, production process, etc. determine the climate impact of a ton of cement. Both from a data availability perspective and the ease of use (navigating 20 indicators), a technology profile at this stage may not be intuitively applicable. Here, CO2-intensity indicators thus may represent a 'proxy' for the technology profile of the product and production process. Similarly, a technology profile is a translation of a global carbon target into investment and economic activity profiles.

For the sake of completeness, while qualitative metrics exist, they can speak to climate strategies, but cannot extend to quantitative scenario and alignment analysis, although of course quantitative indicators can form one of the inputs into qualitative metrics.

Normalization of production capacity logic is a critical part of climate accounting in financial markets as it is required to derive performance benchmarks related to climate. The absolute carbon emissions of a company for example or absolute installed coal power capacity may not be meaningful without understanding the size of the company itself and the scope of their activities. A large electric utility would be expected to have more installed coal power capacity than a smaller utility ceteris paribus, and of course more coal power capacity than a non-utility. Some climate strategies related to climate accounting do not require normalization e.g. an investor that does not want to invest in companies that own any coal-fired power plants does not need to know any more information other than whether the company owns coal-fired power.

Table 2 Pros and cons of different types of metrics

	Pros	**Cons**
Production capacity (categorized by technology or CO_2 intensity input)	In most sectors data point with highest degree of accessibility and quality; Requires limited to no additional estimates around utilization rates Directly relates to 'supply' investment decisions of companies	Not directly related to financial indicators; May over- or understate climate impact given that capacity may not be fully utilized; For some sectors (e.g. cement), lack of technology alternatives does not allow for a discrimination of production processes
Production	Directly related to financial indicators (revenues, sales) More closely related to climate impact	Requires uncertain estimates around utilization rates Since production relates to 'demand' profile, doesn't necessarily reflect the investment decisions of companies
CO_2 / GHG emissions	Indicator most directly related to climate impact; easy to understand by the wider pubic Can mathematically be aggregated across sectors if normalized by financial indicator (e.g. revenue, market capitalization) and applied across all sectors	Uncertainty in GHG emissions estimates May not be linked directly to company decisions, since GHG emissions estimates are sometimes determined by external factors (e.g. supply chain); Normalizing by financial indicator, needs the same indicator by sector, which always gives advantages / dis advantages to certain sectors. => policy setting directly points to

	exclusion of GHG intensive sectors (cement, oil) which does not necessarily help the economy by align to the below -2degree goals of Paris. May hide technology diversification and thus exposure to low-carbon / zero-carbon alternatives (e.g. renewables)

PACTA metrics monitor the following mixes, trajectories and emission intensities:

Sector	**Production mix/Production processes (across the whole sector)**	**Production volume (per technology and across the whole sector)**
Oil & Gas	Distribution of converted energy (PJ) across fossil fuels in the primary energy mix (studied along with coal)	Change in planned production (BOE/day and bcm/day)
Coal	Distribution of production across metallurgical v. coking coal	Change in planned production (MT/day)
Power	Distribution of installed capacity (MW) across power-generation technologies	Change in installed capacity (MW)
Automotive	Distribution of production across powertrain types	Change in production capacity (cars)

Sector	Emission-intensity of production
Cement	TCO_2/TCement
Steel	TCO_2/TSteel
Automotive	gCO2/km
Shipping	AER (Annual Efficiency Ratio)

1.5 Limitations of the model

As is a central caveat of modern portfolio theory, in this work's attempt at adapting the modeling of financial markets to include feedback loops with climate risks, a truly diversified market portfolio cannot be accurately observed not replicated. Not all relevant assets can be satisfactorily mapped and their main variables measured. While a limitation, the modelling work outlined in this document still arguably goes some way in offering a clearer view of climate-related risk as channelled from economic assets to financial institutions.

Companies' relative extents of climate alignment are approximated using production capacity-based figures, and do not encapsulate R&D investment, historical record, lobbying expenditures, etc.

Another limitation in the approach resides in the necessary choice of climate scenarios: while there exists an endless number of combinations of technology-specific pathways, the model relies on a small number of scenarios and accepts their uncertainty and margins of error.

Beyond the model's reliance on the quality of climate-scenario data, it also relies on that of the asset-level data, and crucially, on that of the financial data fed into it, provided by the bank. The road-testing phase has attracted attention to the need for accurate and faithful financial-data inputs.

Last, and while less of limitation than a feature that deliberately falls out of the scope of this model, the approach is not a risk quantification approach. The analytics presented here address relative exposure to climate-relevant economic activities, and impact, but do not aim at providing quantitative insight into credit risk. While model outputs can be used as input into existing risk models to calculate sectoral or company-specific financial risks, their aim is not to comprehensively map all sources of financial risk (e.g. pipelines, distribution networks, upstream supply chain, etc. are not covered).

2 Formalisation of the model

2 Formalisation of the model

Section 2 first lays out the mathematical formalisation of the model, whose economic rationale and assumptions were discussed in section 1.

In a second step, sector-specific methodological choices are described and discussed.

2.1 Notations

2.1.1 Indices

$$\mathbf{P}_{\mathbf{s}[\mathbf{j}],\ \mathbf{t},\ \mathrm{p},\ \mathrm{r}}^{\mathbf{u}[\mathbf{i}],\ \mathrm{d}}$$

- **Universe** index: $\mathrm{u} \in \{\mathrm{pf}, \mathrm{co}, \mathrm{sc}, \mathrm{in}\}$, where:
u = ‘sc’ refers to production figures as obtained from climate scenarios
u = ‘pf’ refers to the production allocated to a portfolio
u = ‘co’ refers to a company’s production
u = ‘in’ refers to the whole industry’s production, also referred to as the market

- **Elements** index: $\mathrm{i} \in \{1, \dots, \mathrm{n}\}$, where n is the total number of elements in the specified universe, e.g. total number of companies in a portfolio, scenarios, portfolios

- **Sector** index: $\mathrm{s} \in \{1, \dots, \mathrm{k}\}$, where k is the total number of sectors

- **Technology** index: $\mathrm{j} \in \{1, \dots, \mathrm{m}\}$, where m is the total number of technologies in a given sector

- **Time** index: $\mathrm{t} \in \{\mathrm{t}_0, \mathrm{t}_1, \mathrm{t}_\alpha, \mathrm{t}_\beta, \dots, \mathrm{t}_\infty\}$, where:
t_0 is the start year of the analysis (current year)
α is the number of years between the nearest date for which a scenario prescription is available and the current date: e.g. $\alpha = 2025 - 2019 = 6$
β is the horizon (in years) at which the portfolio target is calculated. In this model, we set $\beta = 5$

- **Projection** index: $\mathrm{p} \in \{\mathrm{actual}, \mathrm{target}\}$, where
p = ‘actual’ refers to production figures and forward-looking figures
p = ‘target’ refers to the production level computed by applying climate scenarios to the metric
Target function $\mathrm{g}: \mathrm{P}_{\mathrm{actual}}^{\mathrm{u[i]}} \mapsto \mathrm{P}_{\mathrm{target}}^{\mathrm{u[i]}}$

- **Definition** index: $\mathrm{d} \in \{\mathrm{SBTI}, \mathrm{PACTA}\}$, where d refers to different definitions of a same variable

- **Region** index: $\mathrm{r} \in \{1, \dots, \mathrm{x}\}$, where x is the total number of regions

2.1.2 Variables

- P : **Production**
Variable $\mathrm{P}^{\mathrm{sc[i]}}$ corresponds to climate-scenario production figures at the global scale for scenario i.
For all $\mathrm{t} \in]0; \alpha[$, $\mathrm{P}_{\mathrm{t}}^{\mathrm{sc[i]}}$ is obtained by linear interpolation between $\mathrm{P}_{\mathrm{t}_0}^{\mathrm{sc[i]}}$ and $\mathrm{P}_{\mathrm{t}_\alpha}^{\mathrm{sc[i]}}$.

- I : **Intensity:** carbon intensity of an economic activity

- A: **Asset**, financial asset (loan, stock)

- X: **Scaled proxy**, the production volume proxy scaled such as to equal 1 in t_0

2.2 Metrics

Section 2.2 describes the modelling choices that underpin the following metrics: (i) technology-exposure, (ii) volume-trajectory, (iii) carbon-intensity, and in each of these, (iv) company-level scoring.

In each sector, and for each metric type, the overarching rationale consists in
- approximating the company's current profile
- approximating the company's projected profile – based on CAPEX plans
- benchmarking the company's profile against the market, and the 2°C-aligned market
- studying the extent of the alignment between the company's projected profile and its target profile under a 2°C scenario (or any other scenario of choice)

2.2.1 General parameters of the model

2.2.1.1 Sector-specific results

The model adopts a **sector-specific approach** – no trans-sector, aggregate results are produced.

The scope was designed with climate-scenario analysis in mind. It tackles the activities that are most critical to shift in alignment with climate scenarios, rather all activities finding themselves at some risk to the low-carbon transition. Within these sectors, the scope is circumscribed such as to include the segment of the value chain that holds the bulk of the impact on the climate system, and on which decarbonisation efforts must be concentrated.

The model adopts **an economic-activity -based approach** – assessing technology-based production profiles against climate scenarios - **rather than a financed-emissions** - or carbon footprint – approach. This economic-activity-based approach requires outputs to be quantified in units that: (i) can be compared and aggregated across companies, and (ii) allow to assess climate alignment.

In view of this, the approach can allow for several units of measurement – of those, production capacity units are preferred wherever available.

2.2.1.2 Production capacity units

In each sector, the model is underpinned by a technology-specific, production capacity logic, and capacity figures are compared to targets equally expressed in capacity units in climate scenarios.
This avoids having to resort to uncertain investment-size targets (biased by variations in capital intensiveness), or to emission estimates.

Furthermore, having the model operate on capacity puts it at the closest it can be to what companies control and decide upon when they plan future investment. It aims at not favouring decarbonization actions that could be simple shifts in investment towards less carbon-intensive sectors.

In sectors for which climate targets do not distinguish between technologies, and that are homogenous, the analysis focuses on emission intensity, i.e. not aiming at approximating total emissions but rather emissions per economic unit of output (cf section 2.2.3).

Furthermore, there is considerable uncertainty that comes with emission estimates (e.g. for the power sector: on load factors, efficiency factors, emission factors), which detracts from what is at the heart of the analysis. The model therefore focuses on what can be acted upon rather than on an estimation of the CO_2 emissions associated with the physical assets financed by a portfolio.

A financed-emissions approach would suggest using metrics denominated in CO2/$, which are highly liable to becoming vastly disconnected from the effectively released emissions.

2.2.2 Technology exposure

First, the analysis focuses on the **changes in the processes by which outputs are produced** (e.g. shift from renewable-fuelled to coal-fuelled power generation), and on **changes in the nature of the output** itself (e.g. shift from combustion engines to electric vehicles). Results take the form of a distribution across technologies (i.e. fuel mix or production).

As outlined in section 1, the mixes studied are:

- for the fossil fuel sector: the distribution of total energy content (physical units converted into GJ/d) across fossil primary energies (oil, gas and coal), based on production capacity
- for the power generation sector: the distribution of installed capacity (in GW) across primary-energy sources (oil, gas, coal, hydropower, nuclear energy and renewable energies as defined by the IEA, namely: bioenergy, geothermal, hydropower, solar photovoltaic (PV), concentrating solar power (CSP), wind and marine (tide and wave) energy for electricity and heat generation)
- for the automotive sector: the distribution of production capacity (in number of vehicles) across powertrain types (Internal Combustion Engine (ICE), hybrid and EV)

2.2.3 Emission intensity metrics

For the cement, steel manufacturing, and shipping sectors – for which no technology roadmap is available – and for the automotive sector – for which it can be done with much higher certainty than e.g. for the power sector –, the **emission-intensity** of production is analysed.

Emission-intensity metrics are addressed in each sector's section and climate-scenario alignment modelling is addressed in the SDA section.

Below is a rapid overview of the data sources used to produce emission metrics for the automotive, cement and steel sectors. The modelling for each of these sectors is laid out in section 2.4.

- **Automotive**
  - **Emission factors**: gCO_2/km (no life-cycle emissions)
    - based on test-cycle results collected by 5 regulatory agencies (EU, USA, UK, Japan, Mexico)
    - specific to each car manufacturer, car model (available for over 20k car models), each existing fuel type for each car model, production year, and country of production
    - biases in results due to different test-cycle regime procedures are harmonized to fit the WLTP standard (Worldwide harmonized light vehicles test cycles)
    - emission factors are first assigned to the assets in 2dii's ALD using all 5 criteria above, then fewer criteria if no emission factor exists that meets all 5
  - **ALD** provider: AFS (>370 car manufacturers; data purchased at production-country level for each car model, distinguishing by fuel type; forecasts to 2026

- **Cement**
    - Emission factors: tCO_2/t cement
        - based on national emission factors from the GNR database of the Cement Sustainability Initiative (WBCSD & industry)
        - 3 sources of emissions to model: calcination, thermal, power (same source)
            - regional clinker:cement ratios, global calcination factors
            - national/regional energy intensity factors and fuel emission factors
            - national/regional power intensity factors and power emission factors
    - ALD source: Global Cement Directory (production units at plant-level, for >2k active integrated facilities)

- **Steel**
    - Emission factors: tCO_2/t steel
        - based on IEA data (GHG R&D, 2000)
        - specific to each process type, and allow to account for the share of electricity
    - 2dii derived technology-specific emission factors using these EFs and:
        - regional plant utilization factors sourced from the World Steel Association (2018)
        - energy intensity factors by process type (IEA, 2000)
        - power emission factors sourced from the IEA (2011)
    - ALD provider: VDEH PlantFacts (‘Stahl’) (production units at technology-specific facility level (e.g. blast furnace) (not plant level))
        - 2dii’s methodology covers the steel manufacturing process by assessing production at the end of the supply chain, namely when hot-metal (pig iron) is purified into raw steel output (using open-hearth, electric arc, and basic oxygen furnaces)

2.2.4 Company-level climate-alignment scores

N.B. The following section outlines the modelling for climate-alignment scores under its current development – not definitive – version. This has not currently been implemented but could be in future.

2.2.4.1 Synthesizing value sets and time series in singe-unit company-level alignment scores

- **Pros and cons of single-figure indicators: enable a rapid overview, at the risk of critical information loss**

While company-level metrics warrant close attention (e.g. careful study of the deviation between each individual technology’s share and its share in 2°C pathways, study of the slope of the production volume proxy over the period, etc.), in view of the large number of metrics produced by the model – as numerous as there are counterparties, scenarios and regions –, there is a case to produce indicators that summarise the alignment of a company in a single figure.

The balance between too much and too little information is a hard one to strike because it largely depends on the use case. A single-figure indicator should mainly be used as entry-point into a large quantity of data, and as a means to summarize metrics – because they over-simplify reality, after this full-fledged metrics should be favoured.

These climate-alignment scores are a step in distinguishing best-in-class from worst-offenders companies. As such they can inform initial reflection on the selection of clients for steering strategies (e.g. strong engagement, mobilization of clients' stakeholders (suppliers, clients), or divestment from most-misaligned clients). However, the more granular indicators are better suited to all further strategy design

These scores enable the user to appreciate the discrepancy in climate alignment across a set of counterparties at a glance. However, it should not detract attention from the larger quantity of information that can be derived from the main company-level metrics, that are particularly relevant for steering purposes and to engage with clients on decarbonization actions.

- **Aggregation of technology results, distinguishing by technologies' climate criticality**

The alignment extent that is observable in a set of values for the technology-exposure metric and in a time series of the volume-trajectory metric is synthesised in a single-unit alignment score. For trans-technology metrics, the deviation in each technology is weighted in accordance with that technology's climate criticality.

This facilitates the study of the climate alignment of a wide set of counterparties and provides a simple way to rank them amongst each other.

Scores are generated at company level. For each company, they are generated at both:
- technology level for the volume-trajectory metric
- sector level for the technology mix metric

2.2.4.2 Technology-mix climate-alignment scores

The climate-alignment score – as applied to the technology mix metric – summarises in a single figure the deviation between the value set that makes up a company's technology mix and the value set of the scenario mix. The score essentially encapsulates the difference between the company's mix and the aligned mix.

The goal here is to score a company's technology mix against the mixes prescribed in climate scenarios. On a short horizon, **we compare the company's mix against that of the 2°C-aligned market**. Peer companies and the current-day market benchmark are scored as well, to allow for comparison.

This score can be applied to companies in sectors with low-carbon alternatives such as the power and automotive sector.

- **Synthesising a value set in a single figure**

A company's (weighted) deviation from the target, for technology j in sector s, is computed as:

$$\mathrm{deviation}_{s[j]}^{co[i]} = (\mathrm{tech\_share}_{s[j],actual}^{co[i]} - \mathrm{tech\_share}_{s[j],target}^{in}) \times \mathrm{dummy}_j$$

$$\mathrm{weighted\_deviation}_{s[j]}^{co[i]} = \mathrm{deviation}_{s[j]}^{co[i]} \times \mathrm{weight}_j$$

This deviation can be calculated for different points in time.

The different deviations of the elements of the mix from the respective elements of the aligned market mix are then aggregated in a weighted sum. The company's score for sector s is computed as:

$$\mathrm{score}_s^{co[i]} = \sum_{j=1}^{m} \mathrm{weighted\_deviation}_{s[j]}^{co[i]}$$

- **Low- and high-carbon technologies**

The target must be overshot in opposite ways for high- and low-carbon technologies - therefore deviations are recorded in opposite ways: upwards deviations are retributed for low-carbon technologies (i.e. a technology share that is higher than the target technology share); whereas downwards deviations are retributed for high-carbon technologies (i.e. a technology share that is lower than the target technology share).

$$\mathrm{dummy_j} = \left(\begin{array}{ll} 1, & \text{if j is low} - \text{carbon} \\ \\ -1, & \text{if j is high} - \text{carbon} \end{array} \right.$$

- **Weighting technologies according to climate criticality**

The weights attributed to technology-specific deviations are the changes in the amount of power generated via each technology, over the total power generated across all technologies in the start year. Change in generation (TWh) rather than capacity (GW) is used, so as to best reflect the relative climate criticality of each power-generation technology, eliminating here the bias that could be introduced by contrasting load factors.

$$\mathrm{weight_j} = \left(\frac{\left| \mathrm{P}^{\mathrm{sc}}_{\mathrm{s[j]},\ \mathbf{t_\beta}} - \mathrm{P}^{\mathrm{sc}}_{\mathrm{s[j]},\ \mathbf{t_0}} \right|}{\sum_{\mathrm{j=1}}^{\mathrm{m}} \mathrm{P}^{\mathrm{sc}}_{\mathrm{s[j]},\ \mathbf{t_0}}} \right)$$

These weights are then re-tallied over 1, i.e. such that their sum is equal to 1, so that the unit remain percentage-point deviation.

Aligned market mixes as defined according to different scenarios are also scored against the reference scenario (defined as the most ambitious scenario for the sector), so that companies' scores can be situated in scenario intervals.

So that all scores (companies and scenarios) are comparable, a same set of weighting coefficients is used for all (i.e. weighting coefficients are not scenario-specific). This is consistent as long as the set of scenarios used broadly use the same assumptions, such that they each rate the climate criticality of each technology similarly. If a scenario with a vastly different take on a technology's criticality (e.g. the E[R] scenario with respect to nuclear) is included, a specific set of weighting coefficients should be applied.

- **Ranking companies on a single scale, with scenario intervals**

Companies' scores are then ranked; the company with the highest score is the best aligned with respect to the reference. The score of the reference scenario is equal to 0. Other scenarios are also scored against the reference scenario so that companies can be likened different scenarios.

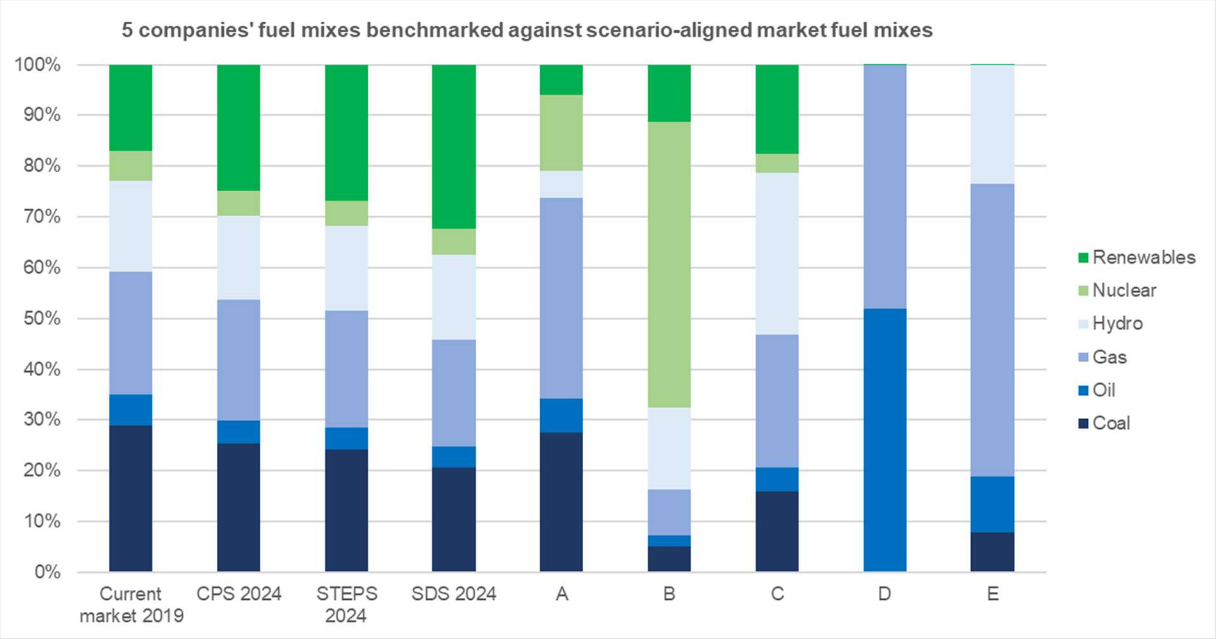
Lastly, each company is "shaded" relatively to the best-performing scenario amongst those it is aligned with (i.e. scenarios whose own score against the reference scenario is lower than that of the company).

- **Fictional case study**: **technology-mix climate-alignment scores**

In this example, we will be benchmarking the power-sector fuel mixes of five power generators against (i) the current market mix and (ii) aligned market mixes as prescribed by different climate scenarios.

Below are represented: (i) the current installed capacity across the entire power industry (the ‘market’), (i) the market mix modelled as aligned with three different scenarios: Current Policies scenario (CPS), Stated Policies scenario (STEPS), and Sustainable Development scenario (SDS), (iii) the fuel mixes of five large power producers, based upon actual companies.

It is not straightforward to appreciate at first glance which of these five companies is most aligned, hence the single-figure indicator. These five mixes and those of the market and the scenarios (using the SDS as reference scenario) will be synthesised into an alignment score calculated as indicated above.



- **Technology-specific weighting coefficients**

The coefficients used to weight the deviations in each technology are calculated in proportion with the relative changes in the power generated through each, expressed as a share of the total.

Table 3 Weighted deviations used to calculate single indicator

Weighting: based on the power-generation trends over the 2040-2018	**Nuclear**	**Hydro**	**Renewables**	**Gas**	**Coal**	**Oil**
Power generation 2018 (TWh)	2718	4203	2596	6118	10123	808
Power generation under the SDS 2040	4409	6934	19131	5584	2428	197
Technology weight	0.06	0.09	0.55	0.02	0.26	0.02

In this example, coal and renewables are the technologies that are weighted most heavily – as they are those whose shifts are the most significant out of the total.

- **Alignment scores & scenario shading**

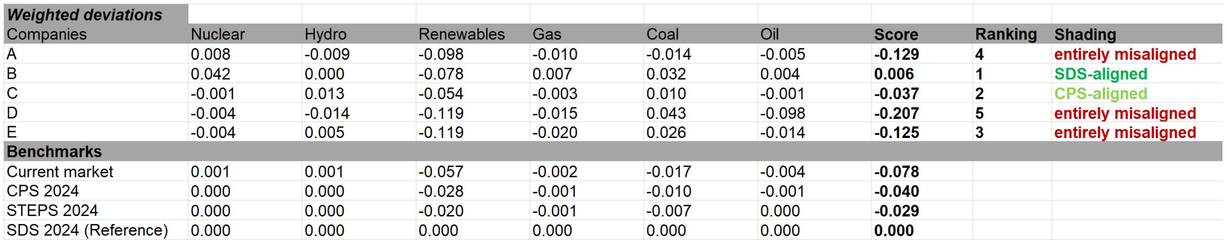
Alignment scores for companies and benchmarks are calculated using the modelling described above.

The table below displays:

- weighted technology-specific deviations
- alignment scores (sum of the weighted deviations)
- ranking of alignment scores
- shading: each company is likened to the best among the climate scenario that it is aligned

to

Table 4 Comparative results of single indicator calculations



Weighted deviations									
Companies	Nuclear	Hydro	Renewables	Gas	Coal	Oil	**Score**	**Ranking**	**Shading**
A	0.008	-0.009	-0.098	-0.010	-0.014	-0.005	**-0.129**	**4**	**entirely misaligned**
B	0.042	0.000	-0.078	0.007	0.032	0.004	**0.006**	**1**	**SDS-aligned**
C	-0.001	0.013	-0.054	-0.003	0.010	-0.001	**-0.037**	**2**	**CPS-aligned**
D	-0.004	-0.014	-0.119	-0.015	0.043	-0.098	**-0.207**	**5**	**entirely misaligned**
E	-0.004	0.005	-0.119	-0.020	0.026	-0.014	**-0.125**	**3**	**entirely misaligned**
Benchmarks									
Current market	0.001	0.001	-0.057	-0.002	-0.017	-0.004	**-0.078**		
CPS 2024	0.000	0.000	-0.028	-0.001	-0.010	-0.001	**-0.040**		
STEPS 2024	0.000	0.000	-0.020	-0.001	-0.007	0.000	**-0.029**		
SDS 2024 (Reference)	0.000	0.000	0.000	0.000	0.000	0.000	**0.000**		

- Only B is SDS-aligned; it obtains the highest score of the five companies, and thus ranks first
- A, D and E have too high shares of fossil fuel-powered capacity to be aligned with any scenario
- D – devoid of any low-carbon capacity – scores the lowest total climate-alignment
- C is closer to the CPS scenario

- **Limitations**

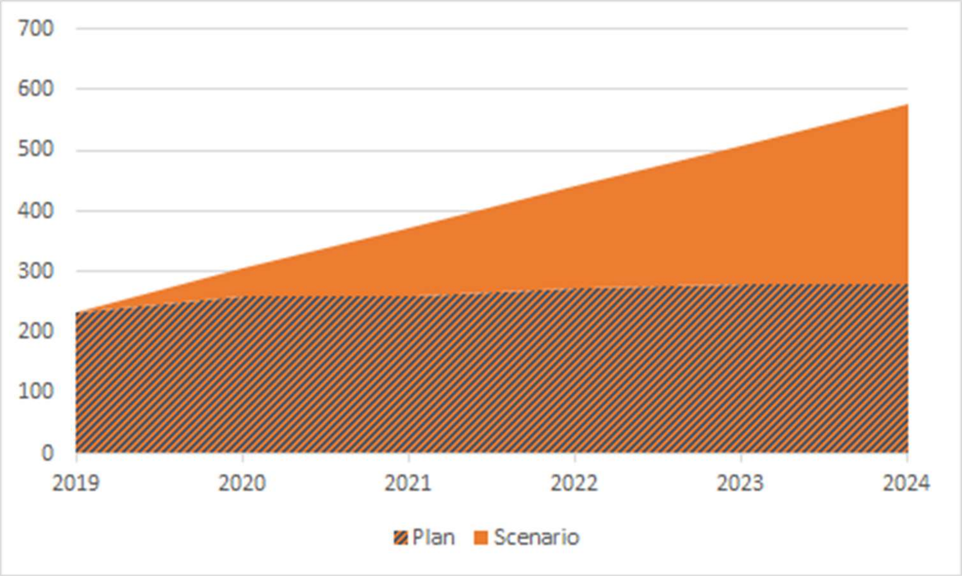
It should be noted that this single-figure indicator is a simplification of the observations that can be made from studying the full-fledged technology mix of a company. It is provided solely as an entryway into the vast amounts of metrics generated when this model is applied to a large portfolio.

Furthermore, this very modelling of the single-figure indicator is mainly suited to large companies that have a diversified fuel mix, e.g. national leaders of developed countries.

In order to benchmark the fuel mix of a smaller company with a narrower range of assets, or that of a company present in a region from which some technologies are near-absent, the benchmark mixes and weighting coefficients should be recalculated such as to make abstraction of the technologies that are absent from that company’s fuel mix.

Besides, single-figure indicators are not fit for target-setting, as they are not liable to be acted upon by companies when they undertake efforts to align. The score is also more disconnected from emissions and thus emission reductions than production capacity figures.

2.2.4.3 Volume-trajectory climate-alignment scores at technology level



The climate-alignment score – as applied to the volume trajectory metric – summarises in a single figure the deviation between the trajectory of a company's production volume and the trajectory prescribed by climate scenarios.

The goal of this rating is to assess a company's projected change in production volume against climate scenarios. Peer companies and the market benchmark are scored as well, to allow for comparison. This score is applied to companies and benchmarks in the power, automotive, and fossil-fuel sectors.

So that they can be situated on a same scale, companies, market benchmarks and scenarios are all scored against a same benchmark scenario (whose score is equal to zero).

- **Synthesising a production function in a single figure**

A company's score, for technology j in sector s, over 5 years, is the difference in two definite integrals: the integral of the company's production function, and the integral of the scenario-prescribed production function over the same period:

$$\mathrm{score}_{s[j]}^{co[i]} = \int_{t_0}^{t_5} \mathrm{production\_function}_{s[j]}^{co[i]} - \int_{t_0}^{t_5} \mathrm{target\_function}_{s[j]}^{sc}$$

Integrals are used instead of simple rates of change across the whole period, given that the timely alignment of production is instrumental in determining the scale of final climate impact.

A company is aligned with the reference scenario if its $\mathrm{score}_{s[j]}^{co[i]}$ is greater than zero.

So that both terms in the difference are comparable, we take the integral of the scaled proxies (variable X) as defined in section 2.2.2.

Furthermore, in this work, companies' production functions are approximated as time series obtained from data providers.
Therefore the approximation of production functions' integrals used here is the sum of the time series of the scaled proxy:

$$\int_{t_0}^{t_5} \mathrm{production\_function}_{s[j]}^{co[i]} = \sum_{t=0}^{5} X_{s[j],\ t}^{co[i]}$$

As explained in section 2.2.2 the volume proxy $X_{s[j]}$ is calculated identically for companies and scenarios. The approximation of production functions' integrals used here is therefore a sum of the time series of the scaled proxy.

As explained in section 2.2.2 the proxy is scaled in two distinct ways for low-carbon and high-carbon technologies. Therefore the approximation of the integral takes two definitions (N.B. no new modelling choice is being introduced here, the complete equations are only included for comprehensiveness):

- For high carbon technologies

The scaled proxy corresponds to the ratio of its value in t over its value in t_0:

$$\int_{t_0}^{t_5} \mathrm{production\_function}_{s[j]} = \sum_{t=0}^{5} \left(\frac{\mathrm{Proxy}_{s[j],\ t}}{\mathrm{Proxy}_{s[j],\ t_0}} \right)$$

- For low-carbon technologies

The scaled proxy corresponds to the additions in production in technology j, expressed as percentage points of the initial total production across all technologies.

$$\int_{t_0}^{t_5} \mathrm{production\_function}_{s[j]} = \sum_{t=0}^{5} \left(\frac{\mathrm{Proxy}_{s[j],t} - \mathrm{Proxy}_{s[j],t_0}}{\sum_{j=1}^{m} (\mathrm{Proxy}_{s[j],\ t_0})} \times 100 \right)$$

2.2.4.3 Volume-trajectory climate-alignment scores at sector level

The same modelling is then applied at sector level, i.e. encompassing production in all technologies, such that the relative trends in each are put into perspective with the overall trend in the sector.

This metric is produced so that it is duly reflected that in parallel to the different rates of change of technology-specific production volumes – which result in a re-shuffling in technology mixes –, each sector is no less crucially prescribed a sector-wide trajectory of production, namely a decrease in the fossil fuel and automotive sectors, and an increase in the power sector.

Lastly, it should be noted that while single-unit climate-alignment scores provide a convenient way to appreciate at a glance how a great number of companies fare in these metrics, they should be looked at in conjunction with the full-fledged metrics in order to gauge an idea of how that company is performing.

Furthermore, climate-alignment scores are a mere synthesis of these metrics and therefore have the same limitations (e.g. they do not encapsulate companies' R&D investments, lobbying, etc.).

2.3 Scenario allocation: formalisation

2.3.1 Fair-share approach modelling (main sectors)

2.3.1.1 Economic rationale

The rationale is the following: the targets laid out in a climate scenario are applied to the portfolio's current profile in such a way as to ensure that the portfolio-specific pathway fosters alignment. Each technology-specific element (technology share, production volume) is set to change at a rate consistent with the climate scenario.

The rational is the following: The decarbonization efforts are equally distributed from sector level to companies depending on the market share of the company within the sector. Thus, if you have a market share of 10% you need to contribute 10% of the decarbonization effort.

There are two ways of defining the market depending on whether a technology is high or low carbon:

- Low-carbon: how much of the sector total production capacity you own decides on how much you need to build-out.
- High carbon: how much of the technology production or capacity you own decides on how much you need to retire - this is done as otherwise the decarbonization effort would be distributed to companies (or other universes) that cannot contribute to the carbonization and thus the macro target would not be reached.

By limiting the market for high-carbon technologies to the technology rather than the sector, the decarbonization effort is only distributed between companies that can contribute to it.

- **A same rate of efforts for all regardless of size or initial alignment**

In the model, companies are prescribed custom targets that are calculated using the same rate of change, regardless of each company's initial performance (positing that a relatively greener initial profile should not warrant a lesser contribution to global efforts).

Having companies be assigned targets under the form of industry-wide rates of change guarantees that the model keeps market shares constant.

The rates of change applied to companies' technology-specific production figures are calculated using the pathways laid out in climate scenarios, expressed in absolute values.

Companies are expected to provide the same proportion of efforts relative to their size, and regardless of their technology mix.

- **Accounting for the current global lag in low-carbon technologies**

As addressed and justified several times above, and as illustrated in section 2.2.2.4, targets are applied differently for high-carbon and low-carbon technologies:

- For high-carbon-technologies,[4] the rate of change used is simply the rate by which the climate scenario prescribes that the global production volume should decrease
- For low-carbon-technologies, the required additional production is expressed as a share of intial total production within the sector

The initial distribution of the portfolio does not come into play in the application of the low-carbon pathway to the portfolio, which is performed to calculate the portfolio's future aligned profile.
Portfolios are being prescribed identical changes: **a same rate of reduction of their financing to high-carbon activities**, and **a same additional volume** (expressed as a share of the portfolio's total activities) by which to increase their financing **to low-carbon activities**.

In other words, depending on a portfolio's initial distribution, this low-carbon increase prescribed under the form of an addition of percentage points of the initial total is such that a 'laggard' portfolio (i.e. one

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[4] And for all technologies for the fossil fuel sector

that initially displays a exposure to a low-carbon technology that is smaller than that technology's prominence in the market) will see its share of that technology -when studied in isolation- grow faster than a 'leader' portfolio (refer to section 2.2.2 for a detailed case study illustrating this economic rationale, and 2.3.1 for the mathematical formalisation of this modelling).

Two portfolios of identical size – i.e. deemed to both finance a same-size market share – will be required to add a same volume (expressed as share of their total) of low-carbon capacity to the activities they finance. Only when we look at the internal shift that undertaking this addition amounts to, does this same target represent varying levels of effort.

Indeed, if a portfolio finances no renewable power capacity, applying any rate of change to it will leave that capacity at zero in the portfolio's custom pathway. Therefore, laggards would not be expected to build out renewable power capacity; would fall behind in terms of market share as the sector shifts towards in increasing volume of renewable power, and the bulk of the necessary build-out would fall upon historical leaders in the field. This is why the target is set in the form of a percentage-point increase that is expressed in relation to the initial distribution. A portfolio is not required to increase its low-carbon capacity by x%, but rather to increase it by a volume equivalent to y% of its total production.

Conversely, for decreasing (high-carbon) technologies, the pace at which production has to decline is set in isolation from initial distribution across technologies.

Overall both calculation rules yield the same result, wherein all decarbonisation efforts are distributed to micro-economic actors. However, the combination of the two generates a different distribution than if either had been exclusively used.

2.3.1.2 High-carbon technologies

gs[j] $g^{\mathbf{HC}}_{s[j]}$ is the rate of change implicitly required by the scenario for technology j, such that we have:

$$P^{sc[i]}_{s[j],\,t_\alpha} = \alpha \times g^{\mathbf{HC}}_{s[j]} \times P^{sc[i]}_{s[j],\,t_0}$$

$$g^{\mathbf{HC}}_{s[j]} = \frac{P^{sc[i]}_{s[j],\,t_\alpha}}{P^{sc[i]}_{s[j],\,t_0}} \times \frac{1}{\alpha}$$

We then compute $P^{pf[i]}_{s[j],\,\mathrm{target},\;t_\beta}$ by applying this rate of change accordingly:

$$P^{pf[i]}_{s[j],\,\mathrm{target},\;t_\beta} = P^{pf[i]}_{s[j],\,\mathrm{actual},\;t_0} \times \beta \times (g_{s[j]})$$

2.3.1.3 Low-carbon technologies

We define $g^{\mathbf{LC}}_{s[j]}$ as the annual required additional production for technology j expressed as a share of $\sum_{j=1}^{m} P^{sc[i]}_{s[j],\,t_0}$ such that we have:

$$P^{sc[i]}_{s[j],\,t_\alpha} = P^{sc[i]}_{s[j],\,t_0} + \left(g^{\mathbf{LC}}_{s[j]} \times \alpha \times \sum_{j\prime=1}^{m} P^{sc[i]}_{s[j\prime],\,t_0}\right)$$

$$\mathrm{g}^{\mathbf{LC}}_{\mathrm{s[j]}} \times = \left(\frac{\mathrm{P}^{\mathrm{sc[i]}}_{\mathrm{s[j]},\,\mathrm{t}_\alpha} - \mathrm{P}^{\mathrm{sc[i]}}_{\mathrm{s[j]},\,\mathrm{t}_0}}{\sum_{\mathrm{j}'=1}^{\mathrm{m}} \mathrm{P}^{\mathrm{sc[i]}}_{\mathrm{s[j']},\,\mathrm{t}_0}} \right) \times \frac{1}{\alpha}$$

We then compute $\mathrm{P}^{\mathrm{pf[i]}}_{\mathrm{s[j]},\,\mathrm{target},\ \mathrm{t}_\beta}$ accordingly:

$$\mathrm{P}^{\mathrm{pf[i]}}_{\mathrm{s[j]},\,\mathrm{target},\ \mathrm{t}_\beta} = \mathrm{P}^{\mathrm{pf[i]}}_{\mathrm{s[j]},\,\mathrm{actual},\ \mathrm{t}_0} + \left(\sum_{\mathrm{j}'=1}^{\mathrm{m}} \mathrm{P}^{\mathrm{pf[i]}}_{\mathrm{s[j]},\,\mathrm{actual},\ \mathrm{t}_0} \right) \times \mathrm{g}^{\mathbf{LC}}_{\mathrm{s[j]}} \times \beta$$

$\mathrm{g}_{\mathrm{j[LC]}}$ is applied to all portfolios regardless of initial profile. As laid out above, the way it is used in the calculation aims to account for the relative lag for these technologies at the global scale.

2.3.2 The Sectoral Decarbonisation Approach (SDA)

The Sectoral Decarbonisation Approach (SDA) is a method for setting corporate emission reduction targets in line with climate science. This method was developed by the Science-Based Targets Initiative (SBTI), an international initiative on science-based target setting for companies initiated by CDP, the United Nations Global Compact, the World Resources Institute (WRI), and the Worldwide Fund for Nature (WWF).[5]

The following section explains the SDA; A description of how the approach is applied in the SBTI framework is given, followed by an explanation of the amendments made to the SDA as applied in the PACTA tool.

2.3.2.1 Overarching modelling applied by the SBTI

Company intensity targets pathways are derived from the company's base year intensity and the sectoral intensity pathway based on decarbonization scenarios, in particular the B2DS scenario from the IEA (while the model is in principle scenario open, the B2DS is the standard scenario being used).

- **Distance to target (d)**

First, the distance between the company's carbon intensity *I* at a given base year t_0 and the target for the average market intensity in 2050 is calculated, named d. The sectoral intensity in 2050 is taken from the IEA's B2DS scenario.
d is defined as:

$$d^{co} = I^{co}_{t_0} - I^{in}_{t_{2050}}$$

- **Company market share parameter (m_y)**

Second, the company's market share parameter, m_y is calculated. The company's expected future activity is divided by the sector's future activity to reflect the expected forward-looking market share of the company. This is given as a ratio to the company's base year market share, derived from its activity

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[5] Sciencebasedtargets.org. (2019). Science Based Targets. [online] Available at: https://sciencebasedtargets.org/ [Accessed 11 Nov. 2019].

divided by the sector's activity in the same year. In both cases, the former is provided by the company and the latter is derived from the B2DS scenario.[6]

This parameter is summarised in the following equation:

$$m_y = {(P_{t_0}^{co}/P_{t_0}^{in})}\Big/{(P_t^{co}/P_t^{in})}$$

It should be noted that this parameter does not capture the change in the market share of the company but rather the inverse. This is useful as it equates to a decreasing parameter when the company's market share is increasing. This equates to larger reduction efforts when the companies market share is increasing over time.

- **Sector decarbonization variable (p_y)**

Third, the sector decarbonization variable, p_y is calculated. This variable captures the remaining effort needed from the market to meet the target in 2050 in a given year t. Under the SDA assumptions the CO_2-intensity for all companies in a sector converge in 2050. Thus, 100% of the expected decarbonization efforts are still to be met at the base year and 0% should be left at 2050. Essentially, the percentage of efforts still needing to be met at any given year is given by:

$$p_y = \frac{I_t^{in} - I_{t_{2050}}^{sc}}{I_{t_0}^{in} - I_{t_{2050}}^{sc}}$$

where $I_{t_{2050}}^{sc}$ is the intensity of the sector in 2050 as prescribed by the IEA. Using these three parameters we can calculate a carbon intensity target for the company at any year between the base year and the target value in 2050.

- **Carbon intensity target ($I_{t,target}^{co,SBTI}$)**

Company intensity reduction per year is given by:

$$I_{t,target}^{co,SBTI} = d^{co} * p_y * m_y * I_{t_{2050}}^{sc}$$

2.3.2.2 The SDA in PACTA

The SDA applied in PACTA differs slightly from the way it is applied by SBTI to align the approach with the bottom-up asset-level data being used in PACTA compared to the top-down approach applied by SBTI through their interpretation of the IEA scenario. One assumption and one adjustment are made. This reflects the difference in data scope and emission intensity calculation.

- **Assumption:** setting market share changes (m_y) to 1

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[6] The scenario data used in both versions of the SDA is taken from the publicly available Energy Technology Perspective 2017 report from the International Energy Agency (IEA). Data is provided on a 5-yearly basis, gaps between these data points are filled in via a linear interpolation.

Due to the lack of quantitative data on the expected market share changes throughout the entire time horizon up to 2050. m_y is set to 1 for all years. Under the SBTI method for calculating m_y, there will be a higher intensity reduction target in cases where the absolute pathway of the sector exceeds the scenario target. However, applying this at company level is counter-intuitive:

As companies that decrease their market share would be allowed to have a higher CO_2-Intensity than the average market actor. While companies that are increasing their market share are forced to do more in terms of CO_2-Intensity than ones whose market share remains constant. It follows that if a company reaches the targeted CO_2-Intensity it would not be allowed to increase its share in the market.

Despite this, given that m_y is currently not available, it is set to 1, which simplifies the equation to

$$I_{t,target}^{co} = d^{co} * p_y + I_{t_{2050}}^{sc}$$

- **Adjustment:** adjusting sector intensity (SI) in the base year and thus in year 2050 to ensure consistent scope and methodology applied to company and benchmark

In both the SBTI and the PACTA methodology the target emissions for the sector are taken from climate scenarios. This is a global economy top-down approach which applies an absolute emissions value in the year 2050 and then coverts this to yearly emission intensities.

However, a discrepancy arises between the SBTI and PACTA's approach to calculating the global base year and start year of analysis. This is caused by PACTA using bottom-up intensity data from asset-level data. Hence to reflect this difference, a rate of change, g in a specific year t is taken from the average sector CO_2-intensity per unit of production in a specific year, t, compared to the base year, t_0. This ensures consistency in calculating CO_2 intensity targets at any given time as the average sector intensity is calculated on a rolling basis based of real asset data. So, any changes in sector intensity on a year to year basis will be reflected in the company intensity reduction target.

$$g_t = \frac{I_t^{sc}}{I_{t_0}^{sc}}$$

This rate of change in 2050 is then multiplied to the sector intensity in the base year based on the bottom-up asset-level data from 2°II database. Given the following equation:

$$I_{t_{2050}}^{in,PACTA} = g_{t_{2050}} * I_{t_0}^{in,ALD}$$

Hence the SDA equation as amended by the adjustment above and including the assumption here is given as:

$$I_{t,target}^{co,PACTA} = d^{co} * p_y + I_{t_{2050}}^{in,PACTA}$$

The difference in data universes between 2dII's data base and the IEA's would make it unfair to compare portfolios to scenarios on the basis that there may be assets missing in the 2DII database. So, by using

2DII's asset level data base to calculate a new portfolio sector intensity target then comparability is restored with the scenario.

The portfolio's carbon intensity target is obtained by the weighted sum of all of the companies' intensities at the base year. The weight is applied as the financial exposure the bank has to those companies.

This alters the d variable which is calculated as follows:

$$d^{pf} = \sum \left(I_{t_0}^{co} - I_{t_{2050}}^{in} \right) * weight$$

The equation for the portfolios carbon intensity target is thus:

$$I_{t,target}^{pf,PACTA} = d^{pf} * p_y * I_{t_{2050}}^{in,PACTA}$$

- **Case study:** different changes in market share and different starting intensities.

Figure 1 shows 3 different intensity reduction targets for 3 different companies. They all start with the same market share, represented by the red point.
Then over time the market share of the company represented by the orange line increases the blue one decreases and the black one remains constant. All three intensity reduction targets converge at the green point.
This graph demonstrates that under the SDA regardless of changes in market share all company's reduction targets will converge to equal the sectors intensity reduction target at the furthers date given by the climate scenario. Under the PACTA assumption that m_y (change in market share parameter) is set to 1. All portfolios will be required to reduce their intensities at the rate of the black line (i.e. when the market share remains constant). This is due to a lack of forward-looking data in terms of portfolios' changes in market shares.

Figure 2 then shows two portfolio's reduction intensity targets. The sector wide intensity target is show in black. In this case the starting point of the different portfolios are different. The orange line represents a laggard portfolio or one with a higher than average intensity.
The blue line represents a leading portfolio or one with a lower initial intensity that the market. Again, both lines will converge to equal the sector wide intensity target in the year 2050. Here there are no changes in market share and hence the curves mirror that of the sector target. However, taking into account the initial starting point we can see that the orange line is steeper and therefor higher reduction targets will be needed to be aligned with the climate scenario.
It follows that the target per year is proportionate to the initial starting point of the portfolio. So an initially poor portfolio will have to reduce its intensity to a target that is higher than an initially good portfolio in the next 5 years in order to be deemed aligned. However, the rate of reduction required will be faster for the laggard portfolio.

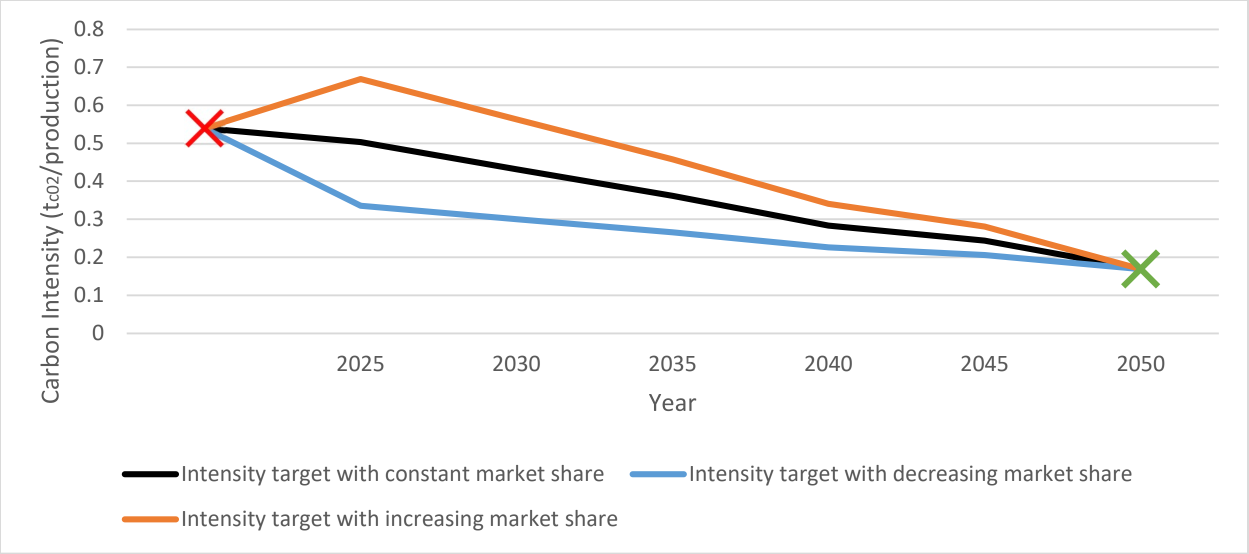

Figure 6 Intensity Reduction Targets for 3 Companies with Different Changes in Market Share

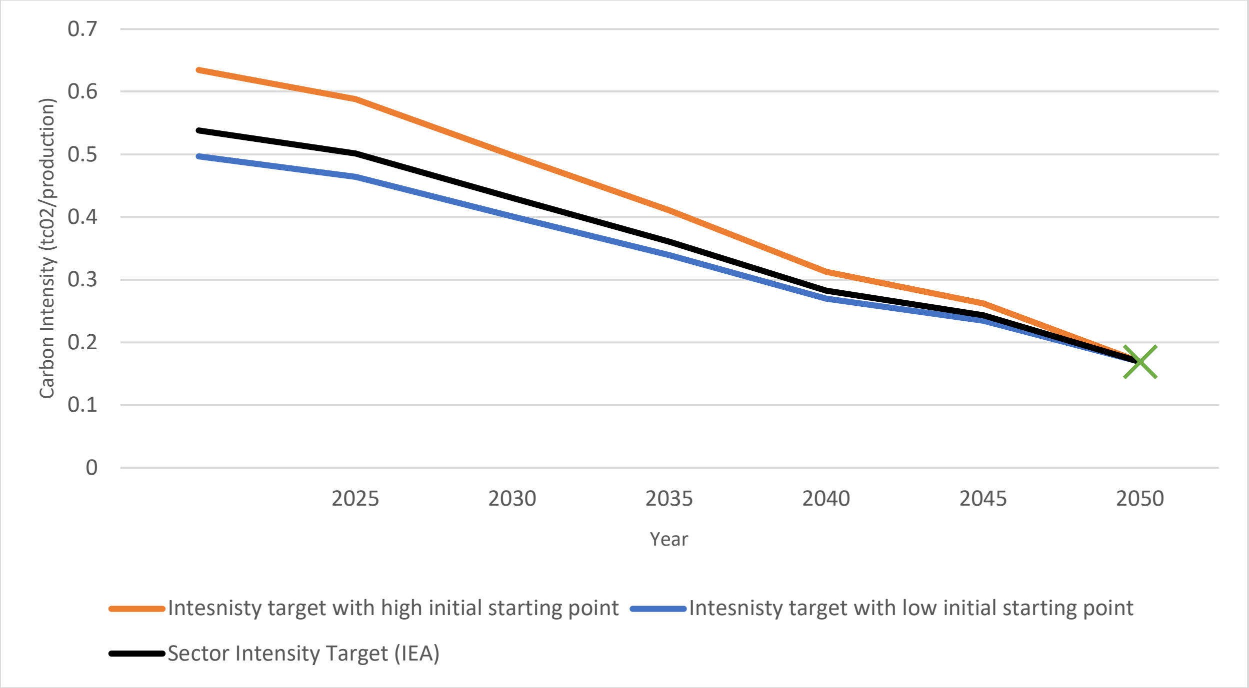

Figure 7 Intensity Reduction Targets for two Companies with Different Initial Starting Points and the Sector Intensity Reduction Target

- **Case Study:** market failure

An issue arises in the SDA methodology in the case when absolute emissions of the sector are higher than what they need to be to achieve the scenario’s target. The issue stems from the fact that the target sector intensity at the end point of the scenario is fixed.

An absolute production increase in the sector over time will lead to missing the emission target in the case when the sector's CO_2-intensity is not adjusted for the target year. This is a result of the way the market share changes are applied (multiplying with the distance d, which declines to 0 in the target year). This leads to the macro target not being solved.

Hence, it is necessary to account for "market failure" (i.e. higher expected absolute production of the sector than prescribed in the scenario) within the SDA methodology. We suggest that this is done by distributing the effort equally across all companies then adjusting the targeted CO_2-intensity in the given year accordingly. That way, all companies must decrease their CO_2-intensity to align at the sector level and in a way that the micro solves the macro emission target. This is essential if production and the associated emissions exceed that prescribed in the scenario by 2-fold then the sector intensity target would have to be half of what is set by the scenario in the end year.

Figure 14 shows the sector's production increasing in the real economy (Blue line) and the production increasing as prescribed by a scenario (red line). Figure 15 shows the sector intensity targets that need to be met per year in order to solve the macro emissions target in line with figure 14. (i.e. The blue line corresponds to the reduction targets that must be made when the sectors production increases in the real economy. The red line shows the intensity target if the sector's production is increase at the rate predicted in the scenario). The failure is what is being solved by adopting the blue line in figure 15.

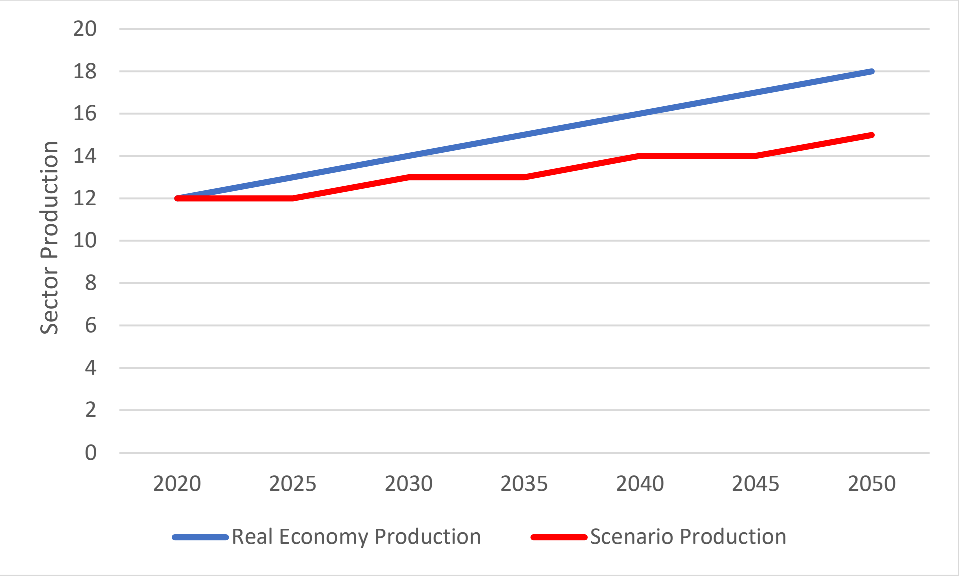

Figure 8 Real v Scenario Production

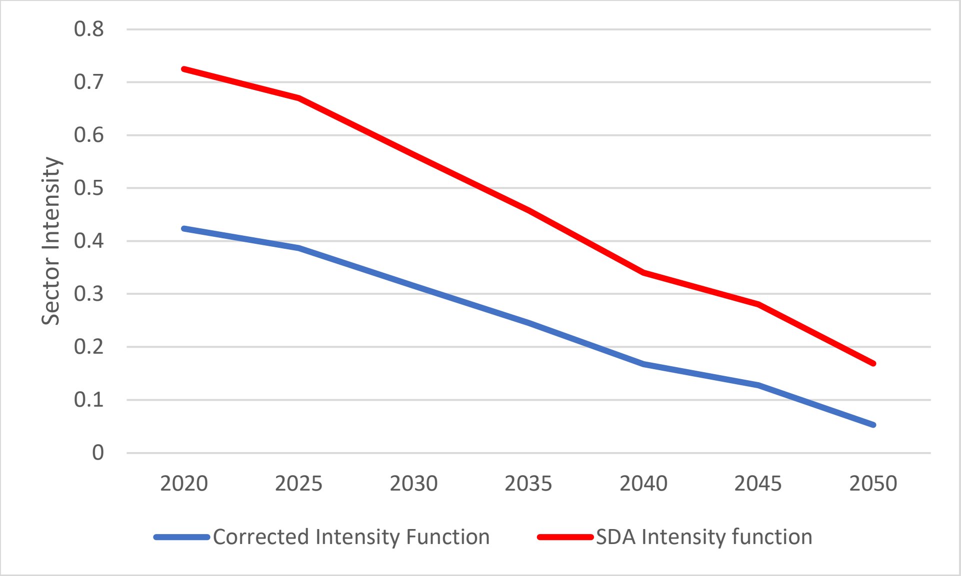

Figure 9 Sector Intensity Targets

2.4 Sectors

2.4.1 Physical asset-level data

Assessing a financial player's alignment with climate scenarios requires precise information on the nature and size of the underlying economic activities. In the absence of precise micro-economic data, the allocation of the macro-economic scenario to micro actors cannot be performed reliably.

In the model, the mapping of economic activities (size, technologies used, future production plans, geolocation, size within a regional market, etc.) is therefore performed at the level of the physical asset, i.e. where it is most precise and allows for the most use cases (e.g. regional split in scenario allocation).

While the resorting to asset-level data is here upheld as a necessary pillar of the model, the choice of the source of information can be left up for debate: corporate disclosures, regulatory filings, business intelligence databases, the bank's internal data (usually highly granular especially for SPVs, but not always aggregated in a standardized way enabling to mobilize it at scale), etc.

The model currently resorts to business intelligence databases, as they minimize the challenges that come with limits and inconsistencies in corporate reporting. Furthermore, it allows for a worldwide coverage (>80% of global capacity or production in each sector) and does not limit data availability to what companies disclose.

The data sources selected record forecasts for future production, enabling a forward-looking analysis. They are updated on a regular basis (from continuously in quickly moving sectors such as automotive, fossil fuels and power to annually for "stable" sectors such as cement) by the data providers, and delivered in batches at regular intervals.

2°II data engineering team obtains the aforementioned extensive asset-level databases from business-intelligence data providers, and further enriches them with financial data obtained from Bloomberg. The model thus rests on a network of ultra-precise datapoints.

Having developed an expertise (for the application of the PACTA methodology to equity and corporates bonds) in linking physical assets to the companies that own them and further to the financial securities they issue, 2°II has subsequently developed its capacity in mapping the unlisted financial world, in view of tackling corporate lending portfolios.

2.4.2 Power

In 2018, the power sector accounted for 42% of global carbon dioxide emissions. The majority of these came from coal fired electricity generation, which alone accounted for 30% of global CO2 emissions. In addition, the IEA has found that coal combustion has been responsible for 0.3°C of the 1°C increase in global temperature above pre-industrial levels and thus represents the single largest source of temperature increase.[7]

Accordingly, the power sector is crucial to meeting the Paris Agreement's goal of limiting the global average temperature rise to well below 2°C above pre-industrial levels and will play a central role in the transition to a low carbon economy.

2.4.2.1 Power generation at the heart of the sector's transition

The power sector traditionally covers generation, distribution, transmission and sale of electricity. In the model, the power sector is tackled via electricity generation. The bulk of carbon emissions associated with the power sector is due to electricity generation in fossil fuel—especially coal—fired power plants. Any emissions associated with distribution, transmission and sale of electricity are negligible in comparison.

The power sector can be broken down into up, mid and downstream:

- The upstream segment covers actual **power generation** and is dominated by electric utilities. This is the segment accountable for the vast majority of emissions in the value chain. The majority of decarbonization efforts will come from a shift in technology mix with additional efforts coming from improved efficiencies in the process.

- The midstream segment refers to the **distribution and transmission of power**. This segment is often but not necessarily owned by different entities than the power generating utilities in the upstream (e.g. the national grid in the UK. The main decarbonization efforts in this segment will come from improved efficiencies via minimizing energy leakage, and further investments in grids.

- The downstream segment relates to the consumption of electricity. Here, decarbonization efforts are related to demand side changes, in part coming from improved efficiency (e.g. more efficient household appliances). Utilities may still play a role with the development of smart grids. Yet, additional innovations around decentralized energy production in the form of small-scale solar panels and other such innovations are allowing households to generate their own electricity. This shift is opening the sector to new players and innovative business plans.

In the model, the alignment of the sector is studied via an analysis of the **upstream segment**, as (i) it is by far the most carbon intensive segment of the sector, (ii) supply-side emissions are the most relevant in terms of steering capital, (iii) asset level data in this sector generally covers individual power plants. Comparable datasets on transmission or distribution assets have not yet been developed.

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[7] https://www.iea.org/geco/emissions/

2.4.2.2 Installed capacity

2°ii's analysis of the upstream segment of the power sector is based on one key metric: the **installed capacity of power generating** assets. Capacity was chosen over generation and emissions metrics as data is more widely publicly available. Forward-looking information on installed capacity is also more reliable, as it is tied to the physical asset itself; whereas capacity-, efficiency- and emissions factors vary. Notably metrics like load factors are often affected by factors out of a company's control. Considering the steering of capital cannot affect how hard the wind blows but it can affect the technology mix that a company decides to build out capacity in.

The following technologies are covered in the model's analysis of the power sector: coal, oil, gas hydropower, nuclear and renewables. The first two are considered high-carbon technologies and in almost all scenarios are required to decrease in capacity.
Gas is still considered as a high-carbon technology, i.e. one that must ultimately be phased out. However, it is considered as a transition fuel and thus is given more leniency in most climate scenarios. The remaining three technologies are considered as low-carbon technologies and are required to increase in the majority of climate scenarios. It should be noted that all scenarios differ in their requirements from each technology. The following is a brief description of each technology and how they are dealt with in the PACTA methodology.

Coal is both still the first global source of generated power, and the most carbon-intensive one. It is prescribed the steepest reduction rates in climate scenarios.

Oil is highly carbon intensive as well as onerous - yet still plays a sizeable role as a backup technology. It is often used in places with limited electricity infrastructure. Oil-fueled power generation is also prescribed ambitious reduction rates in climate scenarios.

Gas is generally considered as a transition fuel and hence in different scenarios and different regions it is treated differently. It most scenarios it is required to decrease in the long term but is allowed a steady increase in the short to medium term. The regional distribution is also highly variable.

Renewable technologies are massively relied upon by most climate scenarios in order to deliver a significant reduction of the emission intensiveness of power generation globally. The main renewable technologies are: hydropower, onshore wind, bioenergy, solar PV, offshore wind, geothermal, CSP and ocean tidal. All are at different stages of development and different levels of deployment, and will require significant R&D investments to further develop scale these technologies to the extent that is required by climate scenarios.

For the most part nuclear – a very low-carbon, baseload technology - is given increasing targets in climate scenarios. An exception to this is found the Greenpeace New Energy Revolution scenario.

Hydropower currently still accounts for a larger share of global installed capacity than all other renewables combined. Large-scale global potential has however largely been tapped already, and environmental issues surrounding the technology are rife. Potential and therefore targets vary widely regionally.

2.4.2.3 Asset level data

2°ii's analysis of holdings in the power sector is based on forward-looking data on individual power generating assets sourced from commercial data provider GlobalData. The following table highlights the most relevant data points included in the power database. Each is associated with a single power plant.

Table 5 Description of power data points

Data point	Description	Options
Installed capacity	The installed capacity of the power plant, in megawatt	
Fuel category	The primary fuel used to generate electricity at the power plant	Coal; gas; hydro; nuclear; renewable (incl. biogas, biomass, geothermal, ocean thermal, wave technology, tidal technology, solar CPV, solar PV, solar thermal, onshore wind, offshore wind); oil.
Country	The country where the power plant is located	
Status	The current status of the power plant	Active (incl. active, partially active); pipeline (incl. announced, dormant, financed, permitting, under construction, under rehabilitation and modernization); discontinued (incl. cancelled, decommissioned, suspended, temporarily shutdown)
Year online	The year in which the plant either came online in the past or is expected to come online in the future	
Decommissioning year	The year in which the plant either was decommissioned or is expected to be decommissioned	
Owner name	The name(s) of the owner(s) of the power plant	
Owner stake	The stake of the power plant that is owned by the corresponding owner, in percent	

GlobalData sources its data using a variety of research capabilities, including web scraping, desk research, and direct engagement with industry representatives. All source material is publicly available in the form of news releases, company websites, company reporting, deals, and contracts. Forward-looking information (see data points “year online” and “decommissioning year”) is based on build out and retirement plans that have been announced publicly by companies that own the relevant power assets.

GlobalData updates its database using two different processes: dynamic updates and scheduled updates. Dynamic updates are performed continuously, on a daily basis, using web scraping techniques. Scheduled updates occur for each power plant every five months and may be performed manually.

For the power sector, assets represent the smallest unit of analysis covered by 2°ii. Capacity is allocated to each company based on direct ownership of power generating assets and based on majority ownership of subsidiary companies that own power generating assets. Using the asset-level power database, each company’s current energy mix is calculated by aggregating capacities across active plants where the company is listed as owner, weighted by an ownership stake. 5-year investment plans are calculated by adding capacities from plants with years online and subtracting capacities from plants with decommissioning years between 2020 and 2024.

Then capacity from subsidiaries is allocated to parent companies according to the following rules: If a subsidiary company is private/unlisted, 100% of its capacity is allocated to the parent company holding the controlling stake. If a subsidiary is public/listed, the non-free float portion of its capacity is allocated to the parent company holding the controlling stake. No power capacity is allocated to parent companies holding non-controlling stakes.

The result is a forward-looking energy mix for each company that serves as starting point and basis for comparison for scenario analysis.

2.4.3 Oil & Gas

2.4.3.1 The lion's share of primary energy demand

Perhaps more than any other industry, oil and gas has been both the catalyst of the unprecedented economic growth over the past century and responsible for the principle share of global emissions (Smil, 2019). Global demand continues to grow year on year for gas and oil, accounting for 54% of global primary energy (IEA, 2019). Under the current policies, the IEA (2019) projects oil and gas demand to continue to increase till 2040 with transportation sector driving demand for oil and increased use of gas for power generation.

Current PACTA metrics for oil & gas and coal focus on the necessary trajectories for volumes extracted of each fossil fuel, and on the relative preponderance of each across primary energy mixes.

*2.4.3.2 **Lifecycle emission profiles of oil and gas***

In recent years with the introduction of hydraulic fracking technology, huge reserves of shale gas in North America, previously unexploited, have filled an ever-growing share of global demand. Per unit of energy, emissions from gas compared to coal and oil are respectively 40% to 20% lower. In this regard, gas is viewed as marginally better alternative to coal in electricity generation. However, when factoring in the full lifecycle emissions of gas, the environmental burden is significantly higher (IEA, 2019).

The lifecycle emissions intensity between oil and gas are significantly different. along the oil and gas supply-chain, downstream oil extraction only accounts for 0.3% lifecycle emissions versus gas at 19%. In comparison, upstream emissions for gas are average 37% of lifecycle emissions (IEA, 2019).

As a byproduct of oil and gas production, methane (the primary constitutes of natural gas) — a potent greenhouse with four times the warming effect of CO2 — is the main driving of emissions from oil and gas production which accounts for 15% of anthropogenic GHG emissions (IEA, 2019). Globally, the emissions from flaring and leaks rose to 140 bcm of gas in 2017, the equivalent to total gas demand in Africa (IEA, 2019).

2.4.3.3 Production cost curves

Compared to other industries oil and gas, production is extremely capital intensive (Smil, 2019). Production costs vary significantly across resource types and companies. Saudi Arabian oil resources are extracted at a fraction the cost of rival producers, roughly $3 a barrel. At the opposite end of the spectrum, Canada produces heavy, high-sulfur content crude like the Canadian Oil Sands at twelve times the price (WSJ, 2019).

CAPEX is primary driver and proxy for emissions intensity. Unconventional oil and gas resources requiring intensive post-processing are both the most indirect and direct emitting resources (Smil, 2019). The most emitting-sources of oil and gas production produce four times the indirect emissions as the least-emitting (IEA, 2019). With the imperative to limit global heating to well below 2°C to mitigate the most catastrophic effects of climate change, a significant proportion of oil and gas CAPEX will need to be stranded.

A proxy for at risk capital is the cost curve of production, a metric pioneered by Carbon Tracker Initiative (2019). With the need to maximize financial flows towards energy efficiency and renewable projects, the cost curve illustrates which oil and gas assets are least viable under 2°C scenario in terms of both emissions' intensity and economic efficiency.

2.4.3.4 Sourcing oil and gas data

The production data used in 2°ii's oil and gas models are sourced from GlobalData (2019). GlobalData (2019) provides a global set of asset-level oil and gas resources with ownership details and 5-year production forecasts. The production data also includes total CAPEX figures and breakeven statistics.

2.4.4 Automotive

PACTA metrics for the automotive sector are technology mixes across powertrain technologies, production volumes (in number of cars) for each, and extremely granular emission intensity estimates, based on car-model specific emission factors.

2.4.4.1 Rising emissions in the transport sector

The transportation sector accounts for 14% of global emissions with the majority of emissions produced by light-duty vehicles such as vars and vans (EIA, 2019).[8] Over the previous decade, automotive emissions have continually risen, offsetting the declines in other sectors like power. Emerging markets are increasingly a significant source of demand growth, but developed markets are still responsible for the largest proportion of vehicle miles (IEA, 2019).[9]

2.4.4.2 Powertrain types and fleet evolution

Emissions factors vary significantly by vehicle segment and powertrain. While most internal combustion vehicles operate around 20-25% efficiency, there is potential to improve by up to 20%. Yet, considering the suite of ever stricter emission standards and some long-term combustion vehicle bans by 2040, it seems unlikely that auto manufacturers will make the necessary investments to fully capitalize on these efficiency gains. Internal combustion engines (ICE) still account for over 95% of the 1.1 billion light-duty vehicles globally. More concerning, ICE sport utility vehicles (SUV) are the fastest growing vehicle segment representing 45% of new vehicle sales in the US, 34% in the EU, and 42% in China (Felipe, 2019).[10]

In comparison, electric vehicles have a conversion efficiency of 59-62% and hybrids, depending on the configurations somewhere between 20-40% (Alexander and Simon, 2019). And in recent years, auto manufacturers have shifted significant amounts of capital towards R&D into battery technology and hybrid systems (Nava, 2017).[11] Still most models remain in the development or pre-market stage. By the end of 2019, there is expected to be 7 to 8 million electric vehicles (EV) on the road, but these only account for 0.1% of the global vehicle stock. By 2025, the IEA (2019) projects electric vehicles will account for 4% of the global stock. In comparison hybrids makeup 3% of light-duty vehicles, but according to the EIA (2019), this share will increase to 6% by 2025.

As an alternative, to electric or hybrid vehicles, fuel-cells have also been considered by policymakers

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[8] Energy Information Agency (EIA). (2019) *Annual Energy Outlook 2019: Reference Case Projections Tables*

[9] International Energy Agency (IEA). (2019) "Global EV Outlook 2019". *International Energy Agency*

[10] Felipe, M. (2019). *Global SUV boom continues in 2018 but growth moderates*

[11] Nava, M. (2017) "The road ahead for electric vehicles". In *BBVA Research*, pp.1-8.

and business as a viable option to gas or diesel combustion engines. Fuel-cells use compressed hydrogen and oxygen to produce electricity to power the vehicle's drivetrain with only water vapor emitted from the tailpipe. Yet, most hydrogen is produced via fossil fuel combustion and current capital flows do not support the technology's long-term development (Zohuri, 2019).[12] Reflecting these facts, fuel cell vehicles account for 0.01% of the global stock and the IEA projects limited growth over the next decade (IEA, 2019).[13]

2.4.4.3 Data & emissions test cycles

Vehicle production data was purchased from Auto Forecast Solutions (AFS, 2019). The AFS covers 60 countries and over 370 different vehicle manufactures. AFS provides production information dating back till 2005 and production forecasts out until 2025. In addition, AFS does regular ex-post analysis of its forecast error and retroactive modifications.

Table 6 provides an overview of production figures and test cycles by segment for 2019. The test-cycle data was sourced from five different super-national and national data sources. While the aggregated test-cycle data does not represent every potential regulatory regime, it provides comprehensive coverage for most major manufacturing markets. In future, 2°ii will expand its test-cycle data.

Table 6 Different Test-cycle Datasets

Segments	Country/Regions	Coverage Periods	Test-Cycle
Cars, Vans	European Union	2010-2019	NEDC/WLTC
Cars, Vans	United States	1984-2019	FTP
Cars, Vans	Mexico	2011-2019	FTP
Cars, Vans	Japan	2014	JC08
Cars, Vans	United Kingdom	2002-2017	NDEC

Across the different test-cycles regimes, there are number of different procedures. This can create slight positive or negative bias depending on the compared data sources. However, the United Nations Economic Commission for Europe has developed the Worldwide harmonized light vehicles test cycles (WLTP), which creates standardized global procedure for light-duty vehicles (UNECE Transport Division, 2019).[14]

2°ii converted all the different test-cycle datasets to the WLTP standard to enable accurate comparison across manufactures and countries. The conversion factors and applied model were developed by the International Council on Clean Transportation (Kühlwein, German, and Bandivadekar, 2014). Lastly, all the different test-cycle data sources are upended together to create a global repository to map to production data.

Lastly, the granularity and definition of segments classifications vary between different test-cycle data sources, so 2°ii harmonized these segments with AFS segments.

2.4.4.4 Regulatory test cycles

Compared to other sectors, automotive has the least complicated emissions models. Since in most major markets, regulatory agencies collect test-cycle results for new vehicles, 2°ii simply connects the test-cycle data to production data.

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[12] Zohuri, B. (2019) Hydrogen-Powered Fuel Cell and Hybrid Automobiles of the Near Future. In *Hydrogen Energy* (pp. 37-59). Springer, Cham.

[13] International Energy Agency (IEA). (2019) "Global EV Outlook 2019". *International Energy Agency*

[14] UNECE Transport Division. (2019). *Worldwide harmonized Light vehicles Test Procedure (WLTP)*

Model outputs are simply expressed in grams of CO_2 per km under normal operating conditions but does not capture the life-cycle emissions. However, test-cycle data offers a number of advantages. First, it is standardized with a consistent testing methodology. Second, in the regulatory context, test-cycle data is the primary indicator used to set emissions intensity targets for vehicle manufactures. And lastly, the data is collected by an independent government organization and therefore, in most case, reliable.

2.4.4.5 Model assigning emission factors to production

The primary challenge of estimating emissions factors for the automotive sector is mapping emissions data to production data. Because the data is aggregated from a variety of sources, manufacture and vehicles names are not standardized.

With over 20,000 different vehicles names, 2°ii relies on Jaro Winkler scoring algorithm to ensure the two different data sources are correctly interfaced (Li, et al., 2014).

With vehicle and manufacture name matches, 2°ii merges on the following criteria:.

i. Manufacturer
ii. Model
iii. Fuel type
iv. Hybrid (hybrid, plug-in hybrid or NA)
v. Production year
vi. Country of production

Vehicles efficiency is determined by the location of production and not the location of sale/operation due to the lack of model level import/export statistics.

The procedure is explained in steps:

1. **String matching on manufacturers name**
   Done by applying 2dii's string matching algorithms

2. **String matching model names**
   AFS' model string is lacking detail compared to the various emissions data sources. Consequently, specific versions of a model from the emissions data could match the general model from the AFS database (i.e. multiple versions of a VW Golf, which in reality have different emission and mileage characteristics, are listed as VW Golf in AFS). Thus, the emissions data model strings are cleaned as a first step, by removing all strings/patterns that did not match any of the strings present in the AFS' Model column by a match value of larger than 0.85% using the Jaro Winkler scoring algorithm (i.e. VW Golf Trendline would be converted to just VW Golf). After cleaning the emissions data's Model string, mean emissions intensity and mileage are calculated per Manufacturer, Model, Fuel type, Production year and Country of production.

3. Joining emissions and AFS data by manufacturer, model, fuel type, hybrid, production year and country of production — 9% of global production.

4. Joining emissions and remaining AFS data by manufacturer, model, fuel type, hybrid and production year criterion (no location criterion) — cumulative 15% of global production.

5. Joining emissions and remaining AFS data by manufacturer, model, fuel type, hybrid and <u>nearest</u> production year (no location criterion) — 40% of global production.

6. Joining emissions and remaining AFS data by manufacturer, model, fuel type, hybrid and country (no production year criterion) — 55% of global production.

7. Joining emissions and remaining AFS data by manufacturer, model, fuel type and hybrid (no location and no production year criteria) — 67% of global production.

To further increase coverage, segment information in used. The most detailed emissions source concerning segment information is the EPA emissions data from the US. The US data segments need to be mapped with the corresponding segment from AFS, for this classification see.

After mapping the different segments consistent with AFS, the coverage is increased by joining the US emissions data and the remaining AFS data (i.e. the rows in AFS that were not already joined with emissions data) by:

8. Segment, manufacturer, fuel type, hybrid and year — 81% of global production.
9. Segment, fuel type, hybrid and year — 82% of global production.
10. Segment, fuel type, hybrid — 99% of global production.
11. Segment — 100% of global production.

Each step, the emissions and ASF production data are joined on less restrictive criteria and therefore the error on the emissions factor is expected to grow. To get an indication of the emission factor error in the different stages of the procedure, we compare the emissions factors of models that joined on the most restrictive criteria (see step 3), to those of the same models but now joined on less restrictive criteria (the emission factors averages are calculated over less restrictive criteria, hence the errors are expected to be bigger).

The mean absolute percentage error (MAPE) and mean absolute error (MAE) can then be calculated to quantify the error.

The mean absolute percentage error is calculated by:

$$\mathrm{MAPE}\ (\%) = \frac{100\%}{\mathrm{nrow}(\mathrm{EF}_{\mathrm{step\ 3}})} \left| \frac{(\mathrm{EF}_{\mathrm{step\ 3}} - \mathrm{EF}_{\mathrm{step\ x}})}{\mathrm{EF}_{\mathrm{step\ 3}}} \right|$$

After completing the procedure, we have a full global production coverage, i.e. the total number of produced cars from AFS that we now have emission factors equals the total number of cars present in AFS. The quality of this coverage can be further increased by including more emissions data sources, (for example for Brazil, Germany and France), since more vehicles will join under more restrictive criteria.

2.4.5 Steel

2.4.5.1 The first industrial source of GHG emissions, and growing

As an essential material to industrialized economies, global annual steel production has doubled over the past two decades from 850 to 1,850 tones. Most of the increased steel output has been driven by the rapid expansion of emerging economies, in particular China which now accounts for 51% of global crude steel production.[15]

According to the IEA[16] steel now accounts for 8% of global carbon emissions and is the largest consumer of energy in the manufacturing sector. While the emission intensity has declined by an

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[15] World Steel Association (2018) Steel Statistical Yearbook 2018

[16] IEA (2019) Tiffany, V., Araceli F-P., and Peter L. (2019). IEA Tracking Clean Energy Progress

average of 0.7% from 2010 to 2016, under the IEA's Sustainable Development Scenario this curtailment must rise to an annual rate of 1% until 2030. With 75% of steel production's primary energy consumption derived from coal, simple fuel switching will only achieve marginal emissions reductions. In the long-term, deep carbonization will require more ambitious technologies and production methods.

2.4.5.2 Steel plant types

Steel manufactures forge steel via four primary routes: primary integrated steel mill, scrap-based mini-mills, direct reduction — electric melting mill, and blast furnace — open hearth plant. Globally integrated steel plants and scrap-based mini-mills account for 70% and 29% of global production respectively.[17] Scrapped based production employs electric arc furnace in the reduction process. With electricity as the primary energy inputs (45% of emissions), the carbon intensity of the local electricity grid plays a critical role in reducing the emissions intensity of mini mills.[18]

Scrap can also be utilized in integrated plants, but primarily acts as a cooling agent for the hot pig iron produced in blast furnaces which, emit a disproportionate share (70%) of the emissions.[19] In the final stage, the gasses from the reduction of pig iron to steel in basic oxygen furnaces can be captured and reutilized through top-gas recovery systems. In integrated facilities, the sintering of iron (12%) and coking of coal (12%) also contribute to facilities' carbon intensity which range from 1.6 to 2.2 tonnes of CO_2 per ton of steel, but oxygen and power production only account for 7% of emissions.[20]

The finishing and rolling of the raw steel accounts for only a marginal share of emissions and therefore is not included in the PACTA methodology.[21]

2.4.5.3 Data used to model the steel sector

The emissions factors employed in the 2°ii steel emissions methodology are taken from the IEA (2000) GHG R&D Program (see Appendix1). The IEA (2000) provides emissions factors for each process type and the share of electricity. With this information, 2°ii is able to process technology specific emissions factors. Similarly, the carbon intensity of electricity data is also sourced from the IEA (2011). The units are expressed as grams of CO_2 per kWh.

Annual plant utilization rates were sourced from the World Steel Association (2018), which reports these figures at a regional level. At the moment, country level utilization rates were not publicly accessible, and the asset level data does not include this indicator.

The data provider for the asset level steel is VEDH (2019).[22] Finding high quality and granular data for technology specific assets remains are persistent problem across climate relevant sectors. To the best of 2°ii knowledge, Stahl is the only one global database of steel production assets.

Stahl provides the unit of observation at the technology specific asset (i.e. Blast Furnace, Sinter), which presents a major methodological challenge. Summing production across technologies would cause egregious case of double counting in total production counts, as the different types of technology-specific assets are present at different points along the value chain.

Additionally, technologies are not linked to specific plants, so it is not possible to simply adjust for the net-production in integrated steel plants. To sum company level production, PACTA considers only one point along the supply chain, the output of raw steel (Open-Hearth, Electric Arc, and Basic Oxygen) furnaces.

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[17] IEA (2000) Greenhouse Gas Emissions From Major Industrial Sources - III Iron and steel Production
[18] IEA (2019) Tiffany, V., Araceli F-P., and Peter L. (2019). IEA Tracking Clean Energy Progress
[19] IEA (2019) Tiffany, V., Araceli F-P., and Peter L. (2019). IEA Tracking Clean Energy Progress
[20] IEA (2000) Greenhouse Gas Emissions From Major Industrial Sources - III Iron and steel Production
[21] IEA (2000) Greenhouse Gas Emissions From Major Industrial Sources - III Iron and steel Production
[22] Stahl, https://en.stahl-online.de/index.php/about-us/vdeh/

Similar problems arise when attributing emissions. Since the dataset does not contain plant level information, when estimating emissions for the three key technologies, (Open-Hearth, Electric Arc, and Basic Oxygen furnaces) emissions must be compounded from the proceeding processes. This entails adjusting for things like the amount of scrap used in the process and mass conversions.

So, in effect, the entire supply chain of emissions is allocated to the raw steel production. In an integrated facility, this would not cause any methodological issues, but if inputs are provided by multiple companies in different locations, it may be considered unfair to allocate all emissions to one plant in the final stage.

However, there are unlikely many companies that focus solely on one production. If this adjustment was not made, Basic Oxygen Furnaces (~60% of global steel production) would appear a net-zero technology (when utilizing waste gas capturing systems). Yet, this would be misleading because Basic Oxygen Furnaces' are always preceded by emission-intensive Blast Furnaces.

2.4.5.4 Model

The PACTA methodology for steel emissions relies on emissions factors are obtained from a report on GHG emissions from major industrial sources, published by the IEA (2000). Combining the process emission factors and electricity generation emissions factors gives the total process specific emissions factors.

Emissions factors for electricity consumption are calculated as the following;

$$\textbf{Electricity Consumption Factor} \left[\frac{\text{GJ}}{\text{t Steel}}\right] = \text{Share of electricity in energy consumption } [\%] * \text{Energy consumption } \left[\frac{\text{GJ}}{\text{t Steel}}\right]$$

$$\textbf{Emissions Factor Electricity} \left[\frac{\text{t CO}_2}{\text{t Steel}}\right] = \text{Emission factor electricity } \left[\frac{\text{t CO}_2}{\text{MWh}}\right] * (\text{Electricity Consumption Factor } \left[\frac{\text{GJ}}{\text{t Steel}}\right] * \left[\frac{1}{3.6}\right])$$

Emissions factors for process are calculated as the following;

$$\textbf{Energy Consumption Factor} \left[\frac{\text{GJ}}{\text{t Steel}}\right] = (1 - \text{Share of electricity in energy consumption } [\%]) * \text{Energy consumption } \left[\frac{\text{GJ}}{\text{t Steel}}\right]$$

$$\textbf{Emissions Factor Process} \left[\frac{\text{t CO}_2}{\text{t Steel}}\right] = \text{Emission factor process} \left[\frac{\text{t CO}_2}{\text{GJ}}\right] * \text{Energy Consumption Factor } \left[\frac{\text{GJ}}{\text{t Steel}}\right]$$

Emissions factors for both process and electricity consumption are calculated as the following;

$$\textbf{Process Emissions Factor} \left[\frac{\text{t CO}_2}{\text{t Steel}}\right] = \text{Emissions Factor Electricity}_{\text{technology}} \left[\frac{\text{t CO}_2}{\text{t Steel}}\right] + \text{Emissions Factor Process}_{\text{technology}} \left[\frac{\text{t CO}_2}{\text{t Steel}}\right]$$

Calculating the direct and indirect emission factors for the Open-Hearth, Electric Arc, and Basic Oxygen furnaces would be the following formulas. The PACTA methodology does not provide emissions for secondary refining operations (vacuum degassing and ladle) and coating operations, as they are assumed to be negligible.

$$\textbf{Direct Process Emissions Factor}\left[\frac{\text{t CO}_2}{\text{t Steel}}\right] = \text{Process Emissions Factor}_{\text{technology}}\left[\frac{\text{t CO}_2}{\text{t Steel}}\right]$$

$$\textbf{Indirect Furnace Emissions Factor}\left[\frac{\text{t CO}_2}{\text{t Steel}}\right] \\ = \text{Furnace Emissions Factor}_{\text{technology}}\left[\frac{\text{t CO}_2}{\text{t Steel}}\right] * \text{Scrap Proportion }[\%] * \text{Mass Adjustment}[\%]$$

$$\textbf{Indirect Coking Emissions Factor}\left[\frac{\text{t CO}_2}{\text{t Steel}}\right] \\ = \text{Coking Emissions Factor}\left[\frac{\text{t CO}_2}{\text{t Steel}}\right] * \text{Scrap Proportion }[\%] * \text{Mass Adjustment}[\%]$$

$$\textbf{Indirect Pelletizing Emissions Factor}\left[\frac{\text{t CO}_2}{\text{t Steel}}\right] \\ = \text{Pelletizing Emissions Factor}\left[\frac{\text{t CO}_2}{\text{t Steel}}\right] * \text{Scrap Proportion }[\%] * \text{Mass Adjustment}[\%]$$

Finally, the following formula for the technologies Open-Hearth, Electric Arc, and Basic Oxygen would calculate the total emissions factor.

$$\textbf{Total Process Emissions Factor} \\ = \sum \text{Indirect Emissions Factors}_{\text{technology}}\left[\frac{\text{t CO}_2}{\text{t Steel}}\right] \\ + \text{Direct Process Emissions Factor}_{\text{technology}}\left[\frac{\text{t CO}_2}{\text{t Steel}}\right]$$

As with any modelling exercising, the asset level emissions from 2°ii’s steel data are certain to have some level of error. These errors are driven by the fact that the model inputs are generalized by technology and regions. On aggregate or at the company level, the margin error maybe reasonable, but at the asset-level, the uncertainty of the emissions estimates is quite high. The model itself has been extensively validated by internal and external steel and modelling experts, therefore limitations of emissions for the steel sectors are best understood from the accuracy of the inputs.

2.4.6 Cement

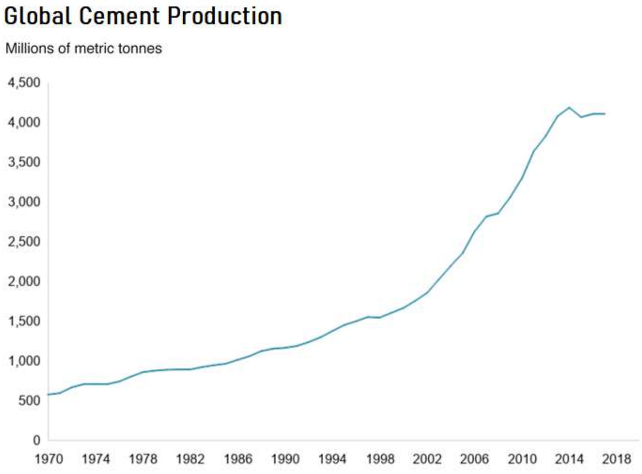
2.4.6.1 A highly energy- and emission-intensive sector

Cement is used to bind together the elements that make up concrete (sand, gravel), which is the world’s widest-used manufactured material. Cement is produced by decomposing and calcinating limestone in a rotating kiln heated up to 1,450°C (where limestone is sintered with other materials, in a very emission-intensive process), thereby creating clinker, which is finally grinded with other components.

As outlined by the IEA in its 2018 Cement Technology Roadmap developed with the Cement Sustainability Initiative, the cement sector is both extremely energy-intensive (requiring both electricity and thermal energy), as “the third-largest industrial energy consumer, comprising 7% of the global industrial energy use [...].” and emission-intensive, accounting for “the second-largest share of total direct industrial CO2 emissions, at 27% (2.2 gigatonnes per year) in 2014.”[23] Process emissions (that arise when limestone is turned into calcium oxide) account for 60%-70% of total emissions. Remaining emissions come from fossil-fuel combustion.[24]

As raw materials are available globally and transportation is costly, cement production is spread across the globe. Global cement production was estimated at 4.1 billion tonnes in 2017 by the United States Geological Survey[25], of which 52% is produced in China, ahead of India (6.2%), the European Union (5.3%) and the USA (1.9%).[26]

Even though figure 1 reflects the fact that Chinese consumption has stagnated, macroeconomic factors and internal market forces will drive future growth of cement production in emerging markets[27].



Source: Unites States Geological Survey

3.2.2 Steep sector growth and corresponding decarbonisation pathways

According to IEA estimates, the emissions caused by cement production accounted for 7% of anthropogenic carbon dioxide emissions in 2017, and global cement production is set to grow by 12 to 23% by 2050 in comparison with 2018 levels.[28]

The cement industry has already reduced CO$_2$ emissions by 18.4% per tonne since 1990.[29] Achieving the ambitions of the 2DS scenario will require reducing cement manufacture emissions by a further 24% by 2050 compared to 2018 levels, which is made harder by the abovementioned increase in global cement production.[30]

“Improving energy efficiency, switching to alternative fuels (fuels that are less carbon intensive), reducing the clinker to cement ratio and integrating carbon capture into cement production are the main carbon mitigation levers supporting the sustainable transition of the cement sector.”[31]

As in other sectors, in the B2DS scenario carbon capture and storage features much more prominently than in the 2DS: by 2050 63% of the cement sector’s total direct generated CO$_2$ emissions are stored,

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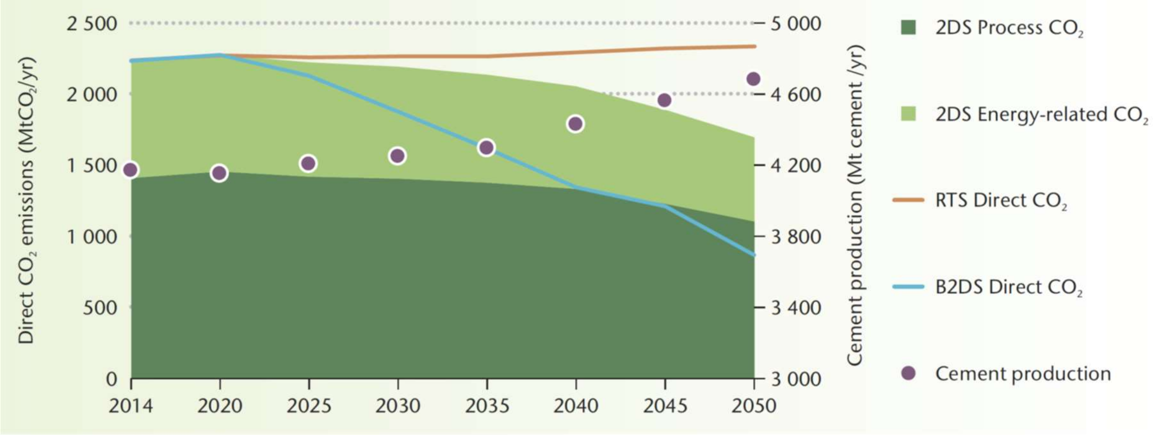
[23] IEA & Cement Sustainability Initiative (2018) Technology Roadmap - Low-Carbon Transition in the Cement Industry, p.5
[24] IEA & CSI (2018) Technology Roadmap - Low-Carbon Transition in the Cement Industry, p. 12
[25] United States Geological Survey, 2018, *Cement: Mineral commodity summaries, 2012-2018*
[26] Global Cement and Concrete Association (GCCA), citing the CEMBUREAU 2017 activity report
[27] Market Report, Global Cement Industry Analysts
[28] IEA & CSI (2018) Technology Roadmap - Low-Carbon Transition in the Cement Industry, p. 8
[29] Global Cement and Concrete Association (GCCA), citing 2016 GNR data
[30] IEA & CSI (2018) Technology Roadmap - Low-Carbon Transition in the Cement Industry, p. 5
[31] Ibid., p.5

instead of 25% in the 2DS.[32]

Figure 5: Global direct CO_2 emissions in cement production by scenario



- **Emission sources**

Emissions from cement production can be categorized in process related emissions, as well as direct and indirect energy related emissions.

- The process-related emissions are due to a chemical process called limestone calcination. For the production of clinker (the main component in cement), limestone is heated in a rotary kiln. It causes the calcium carbonate $CaCO_3$ present in the limestone to decompose into calcium oxide (CaO) and carbon dioxide (CO_2). The limestone calcination process accounts for about 50% of emissions from cement production[33].

- Fossil fuel is combusted to reach the high kiln temperatures that are required to produce clinker. These direct energy related emissions account for about 40% of emissions from cement production.

- Finally, indirect emissions are the result of electricity consumption for powering additional plant machinery.

2.4.6.2 Asset level data

The Global Cement Directory (GCD) is used as asset level database. The database distinguishes between integrated- and grinding plants. It covers 2923 active integrated facilities around the world, with a total cement production capacity of 3.92 billion tonnes of cement per year. Additionally, it covers grinding plants, mothballed plants and plants that are under construction.

In terms of technical specification, the GCD is fairly limited for our use case. For all active integrated facilities, it provides the capacity, the name and the location. Furthermore, for a subset of the plants, it provides the general type of kiln type (wet, dry, semi-dry, etc.). This is important since the dry process is much more thermally efficient than the wet process. However, efficiency gains due to the presence of a preheater and precalciner cannot be reflected as the GCD does not provide this information. In

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[32] Ibid., p.9

[33] Mitigating Emissions from Cement, GNCS Factsheets, Columbia Climate Center, Columbia University

addition, there is little information available on type cement type (white, grey). Therefore, produced clinker is assumed to be grey clinker.

As there is no alternative data source that covers more plant level technical information allowing more detailed plant specific emission factors, the model resolves to country (available for the main cement producing countries[34]) and regional average factors that are key in the cement production process. This data is obtained from the GNR database by the Cement Sustainability Initiative[35].

2.4.6.3 Emissions model

For integrated facilities, the emissions model considers the contributions from the three sources described hereinabove.

The emissions factor (EF) is then calculated as:

$$\mathrm{EF}_{\text{integrated plant}} = \mathrm{EF}_{\text{calcination}} + \mathrm{EF}_{\text{thermal}} + \mathrm{EF}_{\text{electricity}}$$

Where:

- **Calcination**

$$\mathrm{EF}_{\text{calcination}} = \text{Clinker to cement ratio} * \text{ Calcination factor}$$

The clinker to cement ratio reflects the percentage of clinker compared to other non-clinker components. This is ratio not only important for the properties of cement, but also for the emissions intensity, where a lower ratio results in a lower emission factor for the calcination process. The calcination factor $(\text{kg } \mathrm{CO_2} / \text{ tonne clinker})$ gives the emission factor of calcination per tonne of clinker, such that multiplying it by the clinker ratio gives the amount of $\mathrm{CO_2}$ per tonne cement.

In absence of plant-specific data, CSI recommends to use a default calcination factor of 525 $\text{kg } \mathrm{CO_2} / \text{ t clinker}$, which corresponds to the IPCC default corrected for magnesium carbonates. The GNR database covers annual clinker to cement ratios by country and region.

- **Thermal**

$$\mathrm{EF}_{\text{thermal}} = \text{ Clinker to cement ratio} * \text{Thermal energy consumption} * \text{Carbon intensity fuel mix}$$

Both the thermal energy consumption $(\text{MJ} / \text{ t clinker})$ and the carbon intensity of the fuel combusted to heat the kiln $(\text{kg CO2} / \text{ MJ})$ are provided by GNR as country and regional level averages, for grey clinker by kiln type.

- **Power emissions**

$$\mathrm{EF}_{\text{electricity}} = \text{Cement plant power consumption} * \text{Emissions factor electricity}$$

Country and regional averages of cement plant power consumption $(\text{kWh} / \text{ t cement})$ are taken from the GNR dataset. In the 2012 edition of "$\mathrm{CO_2}$ Emissions from Fuel Combustion" from the IEA, country level $\mathrm{CO_2}$ emissions per kWh are provided. Unfortunately, since the 2012 edition, these electricity emission factors are no longer published, hence we resolve to the 2012 data. Note that $\mathrm{EF}_{\text{electricity}}$ includes the grinding process.

2.4.7 Shipping

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[34] Country level data available for: Austria, Brazil, Canada, China+Korea+Japan (combined by CSI), Czech Republic, Egypt, France, Germany, India, Italy, Morocco+Algeria+Tunisia, Philippines, Poland, Spain, Thailand, United Kingdom, United States

[35] GNR Database, Cement Sustainability Initiative, http://www.wbcsdcement.org/index.php/key-issues/climate-protection/gnr-database

2.4.7.1 Methodology (under review)

For the shipping sector, a carbon intensity metric is used. This methodology mirrors that of the Poseidon Principles (PP) with an added layer of accuracy coming from additional intensity information provided by UMAS. A description of how this intensity metric is calculated is given below.

The Poseidon Principles are an industry-led group of financial signatories that commit to assessing and disclosing the climate alignment of their ship finance portfolios. The PP's set the intensity reduction targets in line with the International Maritime Organisations (IMO) target for reducing total annual GHG emissions by at least 50% by 2050 compared to 2008.

This target is used over the IMO's intensity target as there is misalignment between the two and the absolute target is deemed more appropriate.[36] The following is an explanation of how the PP calculate carbon intensity, apply it to a portfolio and assess alignment.

Data on vessels carbon intensity is gathered by the IMO-DCS. The information is gathered either directly from the ship owners or via recognized organizations RO. The parameters recorded included; the amount of fuel consumption for each type of fuel in metric tonnes, Distance travelled, Hours underway, technical characteristics of the ship including design deadweight. From these parameters a carbon intensity proxy is calculated. This proxy is the Average Efficiency Ratio (AER) and is defined as:

- **Notations**

In conformity with the universe index indicated at the beginning of the section, variables whose universe index value is ‘p’ denote a portfolio. Variables whose universe index value is ‘v’ denote voyages.

In conformity with the elements index indicated at the beginning of the section, variables whose universe index value is ‘i’ denote an element of a portfolio, here: a vessel. N is the total number of vessels financed by a portfolio.

- **Variables**

W = vessel's debt outstanding as a share of total debt outstanding,
Δ = alignment
X = carbon intensity
C = carbon emissions
R = required carbon intensity for a ship of a specific type and size as defined by the IMO
AER = Average Efficiency Ratio
D = distance
Dwt = designed deadweight of vessel

$$\mathrm{AER} = \frac{\Sigma_{\mathrm{v}} \mathrm{C}_{\mathrm{v}}}{\Sigma_{\mathrm{v}}\ \mathrm{dwtD}_{\mathrm{v}}}$$

The AER is computed for all voyages performed over a calendar year.

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[36] It should be noted that the IMO set two targets, the first being laid out in the text above and the second being. To reduce CO2 emissions per transport work by at least 40% by 2030, pursuing efforts towards 70% by 2050 compared to 2008. The former being the absolute target and the latter being the intensity target. If the absolute target is converted into a relative intensity it is harder to achieve the intensity target. However, there are multiple intensity paths to reach the absolute target. Further to this, you can achieve the intensity targets without achieving the absolute target. Furthermore, the absolute target is more conducive to assessing alignment with climate goas as per the Paris agreement and thus the alignment used in the PACTA framework. For these reasons, the absolute target is the one used.

It should be noted that is not the most accurate method of measuring carbon intensity, others such as the Energy Efficiency Operational Indicator (EEOI) are more accurate. However due to data availability - i.e. that which is disclosed to the IMO-DCS - it is only possible to calculate the AER. With additional geospatial data from UMAS it may be possible to include a better estimate true transport work and hence calculate the EEOI.

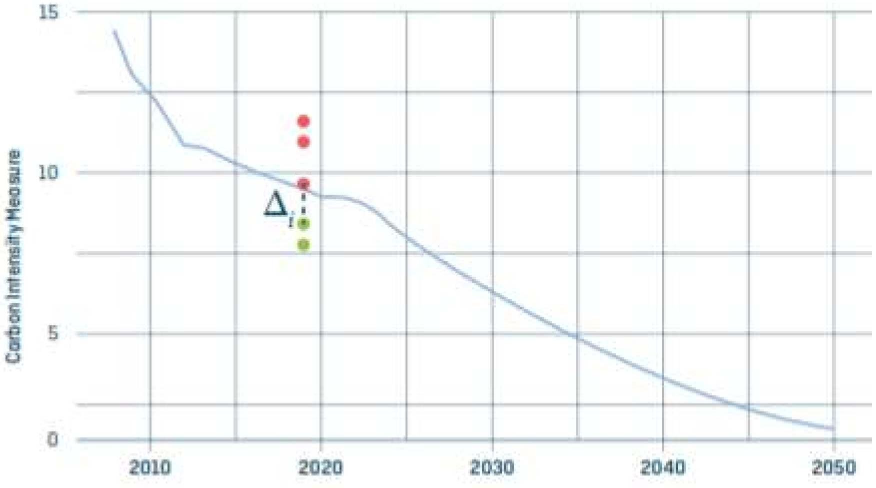
2.4.7.2 Assessing climate alignment

The PP define climate alignment by the degree to which an individual vessel or portfolio of vessel' carbon intensity is aligned with the IMOs decarbonization trajectory as defined by their absolute emission target as online in the above section. This will be adapted to be aligned against climate scenarios, to be consistent with the other sectors under the PACTA framework. However, the methodology is largely the same and here a description of how the PP performs this alignment is given. The only change to be applicable to the PACTA methodology is the decarbonisation trajectory line will be replaced with the curve of a climate scenario – *to be amended when there is consensus on the methodology.*

Aligning vessel carbon intensity to decarbonization trajectory is calculated as the difference in carbon intensity of the vessel to the carbon intensity prescribed by the decarbonization trajectory at any given point in time. This is calculated as a percentage and will be given as a positive or a negative reflecting if the vessel has a higher (ie misaligned) or lower (ie aligned) carbon intensity than the target respectively. Mathematically this is calculated as:

$\Delta_{\mathrm{i}} = \left(\mathrm{x}_{\mathrm{i}} - \frac{\mathrm{r}}{\mathrm{r}}\right) 100$ review this EQ nb r/r =1

Graphically this is represented as:



Applying this to a portfolio of ships involves weighting each vessel's carbon intensity within the portfolio by the outstanding debt that the lender has with that vessel. Hence the alignment deltas for each ship as calculated in the previous equation is weighted by the debt outstanding of each vessel in the bank's portfolio. The sum of each loan is then the total portfolio alignment: Mathematically:

$$\Delta^{p} = \sum_{\mathrm{i}=1}^{\mathrm{N}} \mathrm{w}_{\mathrm{i}} \, \Delta_{\mathrm{i}}$$

2.4.7.3 Poseidon Principles as applied to PACTA

The main difference between the PP and PACTA application of this alignment methodology arises from the difference in decarbonisation trajectory. In the PP case this is taken from the absolute target for carbon reduction set by the IMO, in other words a reduction of total annual GHG emissions of 50% by 2050 which as discussed above is converted into a yearly intensity target.

The intensity values are derived from the RCP 2.6 SSP2 scenario[37]. PACTA on the other hand compares alignment to a variety of climate scenarios including the IEA scenarios where a weighted CO2 intensity for the shipping sector per year is provided. Vessel and portfolio alignment to these scenarios is calculated in the same way and compared to the total market, i.e. the carbon intensity of the whole shipping industry.

2.4.7.4 Scope

The IMO only requires ships above the size of 5,000 gross tonnage to disclosure to the IMO-DCS so any vessels under this size are considered out of scope as an AER cannot be calculated for them. Potentially UMAS as a data provider or another one could provide more granular data and bring more vessels into scope.

2.5 Scenarios

2.5.1 Overview of climate scenarios

Climate change scenarios are “not predictions of the future, but rather projections of what can happen by creating plausible, coherent and internally consistent descriptions of possible climate change futures. They can also constitute [...] descriptions of pathways towards certain goals. Climate change scenarios can come in two different forms, projections “What can happen?" and goal-oriented pathways “What should happen?"."[38]

The targets laid out in backcasted climate scenarios[39] serve as prescriptions in the frame of this analysis. These targets are the standard to which the portfolio’s profile is held, i.e. by which the extent of the portfolio’s alignment is estimated. The projections laid out in forecasted climate scenarios can serve as a point of comparison.

The IEA’s Sustainable Development Scenario (SDS) is currently the main climate scenario used in this analysis.

The SDS, NPS and CPS are the IEA’s https://www.iea.org/weo/weomodel/WEO scenarios (yielded by the WEM).
The 2DS, B2DS and RTS are the IEA’s http://www.iea.org/etp/explore/ETP scenarios (yielded by the ETP model).

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[37] reference to RCP – IMO GHG third report and appendix of PP pdf to explain how they get this figure. Calculating the target carbon intensity, corrected to AER, in a given year as a function of the ship type and size class

[38] SENSES project, Potsdam Institut fur Klimafolgenforschung (PIK), https://climatescenario.org/primer/SENSES website

[39] *“A climate scenario is a plausible representation of future climate that has been constructed for explicit use in investigating the potential impacts of anthropogenic climate change. Climate scenarios often make use of climate projections (descriptions of the modelled response of the climate system to scenarios of greenhouse gas and aerosol concentrations), by manipulating model outputs and combining them with observed climate data."* (IPCC (2001) TAR, Chapter 13, p. 741)

The IEA WEO 2018 scenarios: the CPS, NPS, and SDS

The IEA's 2018 World Energy Outlook (WEO) provides an update of the following scenarios:

- the **Current Policies Scenario (CPS)**, which reflects an absence of change in policies from mid-2018 onwards,
- the **New Policies Scenario (NPS)**, which reflects announced policies and targets, and to which the IEA ETP RTS scenario is close. It displays the "results likely to stem from the implementation of announced policy intentions", and
- the **Sustainable Development Scenario (SDS)**, which is aligned with the former 450 scenario, and "outlines an integrated approach to achieving internationally agreed objectives on climate change, air quality and universal access to modern energy", and whose "emissions trajectory is at the lower end of other decarbonisation scenarios projecting a median temperature rise in 2100 of around 1.7 ° C to 1.8 ° C."[40]

The SDS lays out a pathway aimed at achieving the three closest-energy-related Sustainable Development Goals (SDGs), namely: (i) to achieve universal access to energy (SDG 7), (ii) to reduce the severe health impacts of air pollution (part of SDG 3), and (iii) to tackle climate change (SDG 13).[41]

WEO emission pathways and the decoupling of GDP and emissions

The SDS prescribes that energy-related GHG emissions must "peak around 2020 and then decline rapidly"[42], and will have to have been halved (in comparison with current levels) by 2040 (the scenario's cut-off date) so that they go on to reach a yearly net-zero level by 2070).

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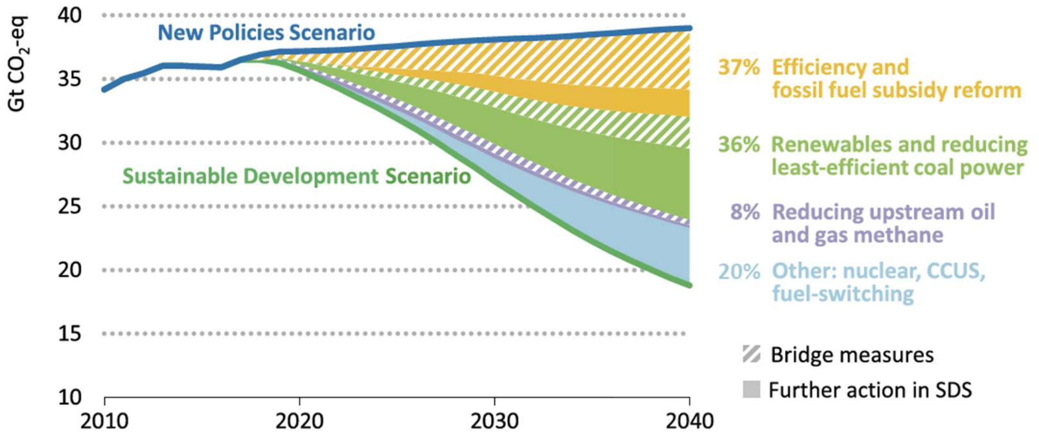
[40] IEA (2018) The Sustainable Development Scenario

[41] Ibid.

[42] Ibid.

Figure 2.16 ▷ **CO_2 and methane emissions reductions by measure in the Sustainable Development Scenario relative to the New Policies Scenario**



Implementation of five measures at no net economic cost would bridge less than half of the gap between current trends and a Paris Agreement trajectory

Notes: Gt CO_2-eq = gigatonnes of CO_2 equivalent; CCUS = Carbon, Capture, Utilisation and Storage; SDS = Sustainable Development Scenario; 100-year global warming potential of methane = 30.

Figure 10 Comparison of emission pathways in the SDS and the NPS Source: IEA WEO 2018, p.113 [7]

A much deeper decoupling between GDP growth and both energy intensity and emission intensity is achieved in the SDS - in comparison with the NPS and CPS -, as a result of the drop (to 61%) of the share of fossil fuels in the SDS primary energy mix in 2040 (oil: 23%; coal: 13%; gas: 25%).

More generally, in the SDS "energy consumption patterns shift, driven first and foremost by energy efficiency across all major sectors", resulting in the global final energy consumption staying "nearly flat through to 2040 despite economic output more than doubling."[43]

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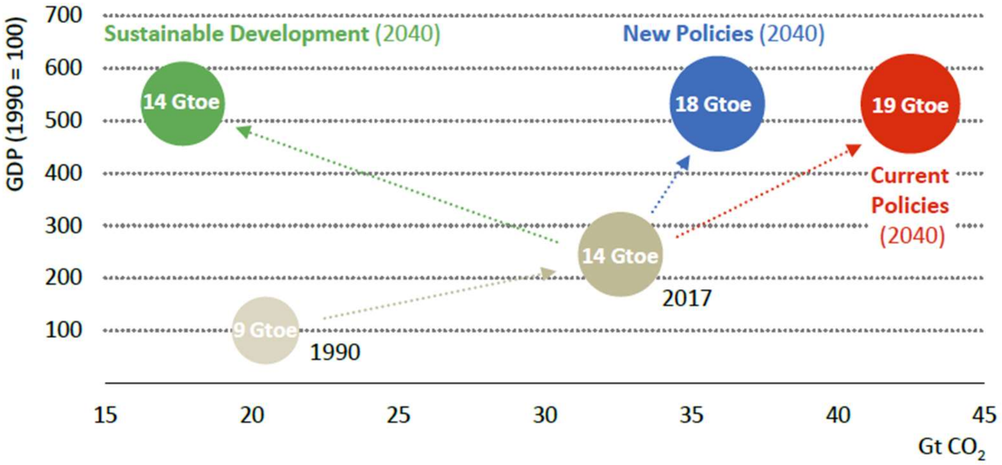
[43] IEA (2018) The Sustainable Development Scenario, p.90

Figure 1.2 ▷ World primary energy demand and energy-related CO_2 emissions by scenario



Achieving sustainable development goals requires a complete reversal of the historic relationship between economic growth, energy demand and emissions

Notes: Bubble size and numbers represent total primary energy demand. Gtoe = gigatonnes of oil equivalent or 1 000 Mtoe; Gt CO_2 = gigatonnes of CO_2.

Figure 11 Decoupling between GDP growth, TPED and CO2 emissions Source: IEA WEO 2018, p.113 [7]

Changes in global primary energy demand

In the CPS global primary energy demand grows by around 40% by 2040 (despite a contraction in the EU and Japan)[44] ; whereas it only grows by 25% in the NPS (mainly driven by Asian and Middle-Eastern developing economies) ; and it stays flat in the SDS (thanks in part to improvements in energy efficiency).

Furthermore, in the CPS “continued strong growth among the incumbent fuels leaves only a small amount of headroom for renewables to step in and meet incremental demand".[45] Figure 12 displays the very slight change in primary energy technology makeup in the CPS between 2017 and 2040.

Coal-demand pathways across the CPS, NPS and SDS

Most notably, coal use is on the rise in the CPS (in absolute terms, not in share of the primary energy mix) ; whereas in the NPS it levels off due to phase-out in some parts of the world, and in the SDS it decreases to its 1975 level.

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[44] Ibid., p.41
[45] Ibid., p.38

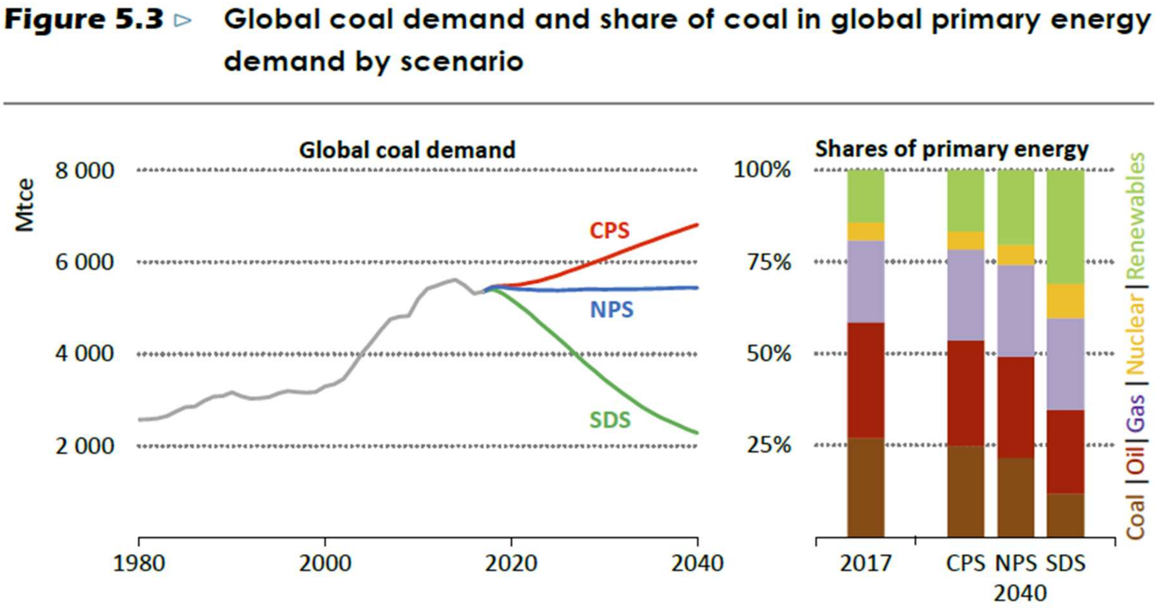

Figure 12 Coal demand and global primary energy demand in the WEO scenarios Source: IEA WEO 2018, p.219 [7]

Oil-production pathways to 2040

In the NPS and the CPS, China and India account for around half of the increase in oil demand to 2040. Corresponding supply comes from the USA before it gets gradually picked up by OPEC countries.

In the SDS to the contrary, oil demand peaks globally as soon as 2020 - only in India and sub-Saharan Africa is it still growing until 2035.

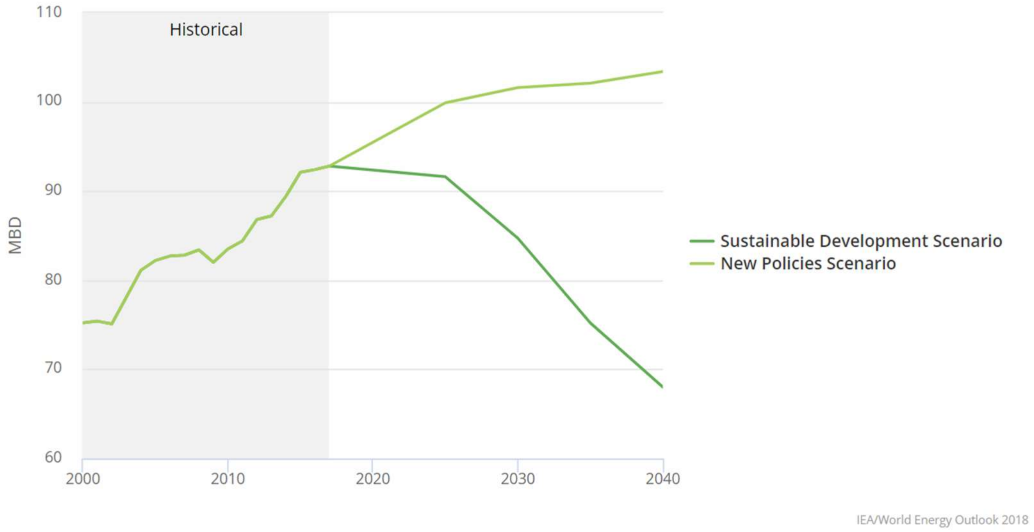

Figure 13 World oil production in the SDS and the NPS. Source: IEA website (2018)

Power generation: “coal and renewables [switch positions]"

In the SDS, “total electricity generated increases by nearly 45% to reach 37 000 TWh by 2040, the share of renewables nearly [tripling] to 66%." Solar PV and wind grow the fastest ; and “renewables account for more than 80% of new capacity additions by 2025."[46]

Though it increases in all three WEO scenarios, in the SDS the increase of natural gas consumption is curbed by “by higher efficiency and the push towards full decarbonisation of the energy system."[47]

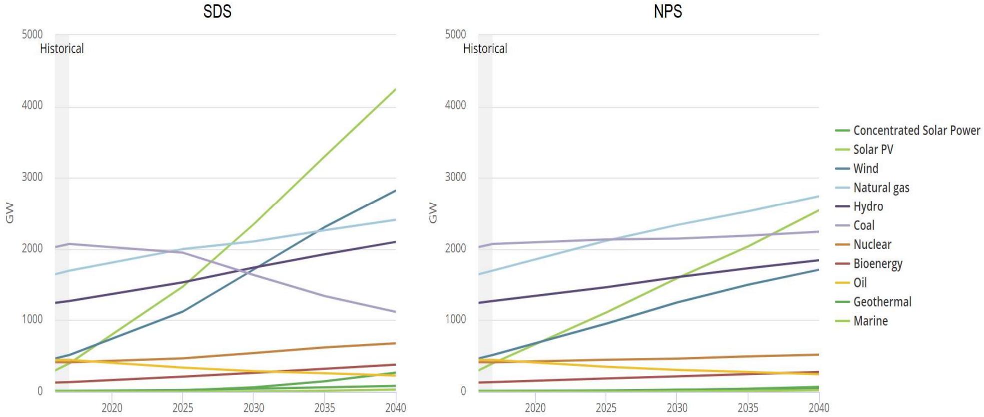

Figure 14 Installed power generation capacity by technology in the SDS and the NPS Source: IEA website (2018)

“Global electricity generation increases by some 60% (15 000 TWh) between 2017 and 2040 in the New Policies Scenario. Fossil fuels remain the major source for electricity generation, but their share falls from around two-thirds today to under 50% by 2040."[48]

In the SDS, coal-fired power generation drops to 5% of the mix in 2040, at which point two-thirds of the remaining coal generation plants are equipped with CCS.

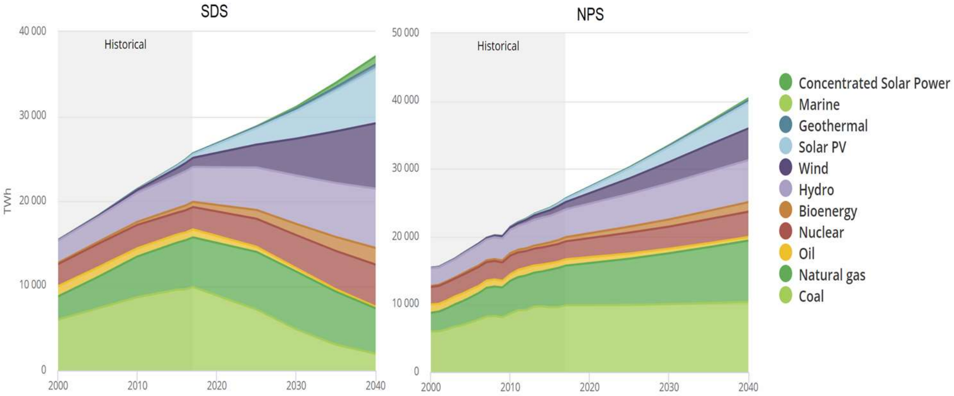

Figure 15 Electricity generation by technology in the SDS and the NPS Source: IEA website (2018)

Transport

In the CPS, the road transport sector does not undergo significant decarbonisation (the “dominant position of gasoline and diesel in the road transport sector" remains) and accounts for much of the rise

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[46] Ibid., p.93
[47] Ibid., p.30
[48] Ibid., p.44

in oil demand (which amounts to +25% by 2040, with around an additional 1.1 million barrels per day every year).

In the NPS, oil use in cars “peaks in the 2020s due to advances in fuel efficiency and an increased use of biofuels and electricity", leaving “trucks, aviation, shipping and petrochemicals" to blame for the ongoing rise in oil use. In the SDS, half of the global car fleet is electric by 2040, and oil demand in aviation starts waning thanks to enhanced efficiency and biofuels.[49]

2.5.2 The IEA ETP 2017 scenarios: the RTS, 2DS, and B2DS

The IEA’s Energy Technology Perspectives (ETP) project has published a report annually since 2006. “ETP 2017 presents three pathways for energy sector development to 2060":[50]

- the **Reference Technology Scenario (RTS)**, which “takes into account existing energy- and climate-related commitments by countries, including NDCs pledged under the Paris Agreement", and as such is “not consistent with achieving global climate objectives",[51]
- the **2 ° C Scenario (2DS)**, the main ETP scenario, linked at inception with the 2 ° C objective discussed in Copenhaguen, and which is deemed “already challenging"[52] by the IEA, and
- the **Beyond 2 ° C Scenario (B2DS)**, which “looks at how far known clean energy technologies could go if pushed to their practical limits",[53] and on which the IEA notes that “the gap between [the B2DS] and current efforts is immense and unlikely to be bridged without an unprecedented acceleration of action on a global level".[54]

Fossil fuels remain prominent in electricity generation under the reference scenario, hampering the reduction in carbon-intensity

The RTS scenario aims to reflect current and announced policies ; it is close to the WEO NPS scenario.

In the RTS, in 2045 gas-fired power generation still accounts for over a quarter of the total. In 2060, renewables are barely on par with fossil fuels, at around 45% of total generation.

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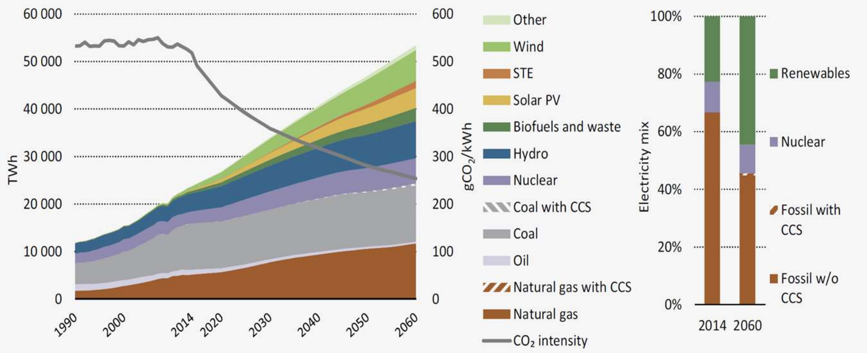
[49] Ibid., p.137
[50] IEA (2017) ETP 2017, p.9.
[51] Ibid., p.23.
[52] Ibid., p.21.
[53] Ibid., p.8.
[54] Ibid., p.21.

Figure 6.3. Global electricity generation in the RTS



Note: STE = solar thermal electric.

Sources: Data for 1990-2014 from IEA (2016a), *IEA World Energy Statistics and Balances* (database), www.iea.org/statistics/; IEA (2016c), *CO_2 Emissions from Fuel Combustion* (database), www.iea.org/statistics/.

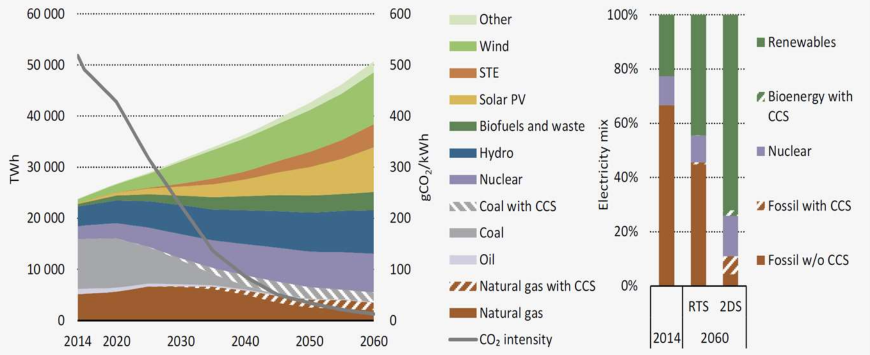
Key point *The share of renewables in global power generation nearly doubles to 45% by 2060 in the RTS, although its CO_2 intensity is only halved relative to today.*

Figure 16 Global electricity generation in the RTS. Source: IEA ETP 2017, p.281. [5]

By contrast with the RTS, in the 2DS global average electricity-generation CO2 -intensity plummets from 519 g CO2 /kWh in 2014 to 35 g CO2 2/kWh in 2050 (a 93% fall) and approaches zero in 2060.

In 2060 the share of unabated fossil fuel generation is at 4% in the 2DS - against 45% under the RTS - and the share of renewables is at 72% in the 2DS - against 44% in the RTS (Figure 17).

Figure 6.4. Global electricity generation in the 2DS



Sources: Data for 2014 from IEA (2016a), *World Energy Statistics and Balances* (database), www.iea.org/statistics/; IEA (2016c), *CO_2 Emissions from Fuel Combustion* (database), www.iea.org/statistics/.

Key point *The share of low-carbon technologies in global power generation is about 96%, and average CO_2 intensity is approaching zero by 2060 in the 2DS.*

Figure 17 Global electricity generation in the 2DS. Source: IEA ETP 2017, p.282.

Close to the 2DS regarding its distribution across technologies, in the B2DS 2060 final electricity demand is however almost as high as in the RTS - whereas it is (a mere) 7% lower in the 2DS.

"Electricity becomes the largest final energy carrier"

In the 2DS, “the share of electricity in final energy demand across all enduse sectors more than [doubles]."[55]

Major features of both the 2DS and the B2DS are the following: “reliance on fossil fuels is halved in absolute terms in the 2DS and falls by almost two-thirds in the B2DS."[56] ; “electricity becomes the largest final energy carrier, slightly ahead of oil" ; “electrification emerges as the major low-carbon pathway for the transportation sector."[57] ; CCS plays a prominent role, accounting for over 14% of the emissions reductions needed in comparison with the RTS ; and biomass use doubles. In both, increased investment in energy technology innovation is critical.

In the 2DS, “the global power sector reaches almost net-zero annual CO2 emissions by 2060".[58]; and in the B2DS, it is the entire energy system that reaches net-zero CO2 emissions by that date. To that end, renewables, CCS and nuclear are ramped up. CO2 emissions remain where they are harder to abate, namely long-haul transportation and industry ().

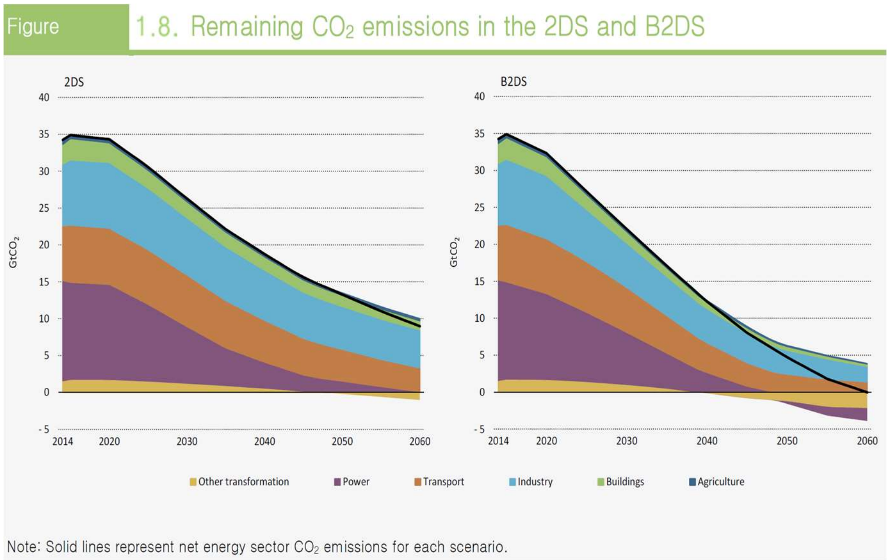


Figure 1.8. Remaining CO_2 emissions in the 2DS and B2DS

Note: Solid lines represent net energy sector CO_2 emissions for each scenario.

Figure 18 Comparison of emission pathways in the 2DS and the B2DS Source: IEA ETP 2017, p.32.

Though they are impacted by the rapid growth of the power-generation sector, “energy-sector CO2 emissions fall to around one-quarter of today’s levels in 2060. Reliance on fossil fuels declines substantially, from around 82% of primary energy demand in 2014 to 35% in 2060."[59]

The B2DS is more ambitious than the 2DS in that it takes an “accelerated technology push approach"[60]. The decarbonisation of the power sector essentially occurs sooner and faster, and implies “much deeper emissions reductions",[61] indeed “achiev[ing energy-sector] net-zero emissions by 2060."[62]

In the B2DS, in comparison with other scenarios, the decarbonisation of the energy sector is set apart by the extent to which it relies on BECCS: “in the B2DS, BECCS delivers almost 5Gt of “negative emissions" in 2060"[63] (having entirely eliminated emissions from both fuel transformation and the power sector).

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[55] Ibid., p.11.
[56] Ibid., p.21.
[57] Ibid., p.11.
[58] Ibid., p.277.
[59] Ibid., p.23.
[60] Ibid., p.21.
[61] Ibid., p.22.
[62] Ibid., p.25.
[63] Ibid., p.11.

Power-sector technology changes deliver a substantial part of emission reductions

In the RTS, “energy-sector CO2 emissions do not peak until around 2050 and are 16% higher in 2060 compared with 2014."[64]

“Moving from the RTS to the B2DS entails a drastic reduction in CO2 emissions from the power sector."[65] Energy efficiency plays a great part across all sectors, contributing “38% of the cumulative CO2 emissions reductions needed to 2060 in the B2DS relative to the RTS." In land-based transport, “electricity becomes the primary fuel."[66]

The following figure represents, for the power sector, the relative shares of the technologies delivering the annual 17 GtCO2 emission savings in 2060 in the B2DS compared with the RTS.

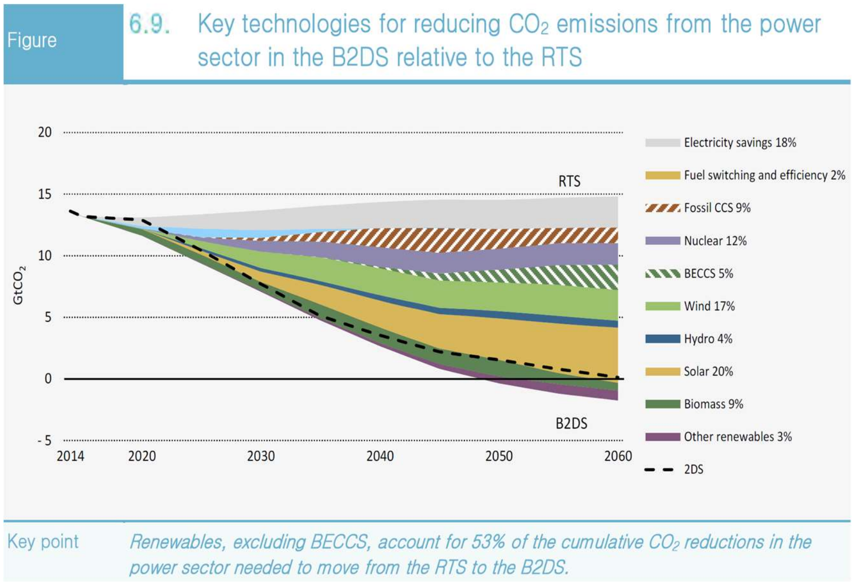

Figure 19 Power-sector technologies delivering emission reductions in the B2DS Source: IEA ETP 2017, p.285. [5]

2.5.3 Greenpeace’s Energy [R]evolution scenarios

Energy [R]evolution scenarios have been continuously developed for over 15 years, and were first published in 2005.[67] In 2015 Greenpeace published:[68]

- the **Reference Scenario (REF)**, based on the IEA WEO 2014 CPS,[69] “reflecting a continuation of current trends and policies"[70]
- the basic **Energy [R]evolution Scenario (E[R])** (83% renewable energy in the power sector)
- the **Advanced Energy [R]evolution scenario (ADV E[R])** (100% renewable energy in the power sector), which is entirely in line with the (E[R]), “with significant additional efforts"[71]

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[64] Ibid., p.21.

[65] Ibid., p.285.

[66] Ibid., p.9.

[67] Greenpeace (2015) Energy [R]evolution - Energy Outlook 2015, p.10. [4]

[68] The scenarios were “commissioned by Greenpeace from the Systems Analysis group of the Institute of Engineering Thermodynamics, part of the German Aerospace Center (DLR)." Ibid., p.61. [4]

[69] Extrapolated from its IEA WEO 2014 2040 cutoff date to 2050, Greenpeace’s cutoff date.

[70] Ibid., p.59. [4]

[71] Ibid., p.59.[4]

The E[R] and ADV E[R] scenarios were modelised using the same GDP-growth and population-growth assumptions as those used for the CPS. They do not, however, use the same energy-intensity assumptions as the CPS, given that both E[R] scenarios include significant energy-efficiency measures. On this, Greenpeace underlines that “assumed growth rates for [...] specific energy demand and the deployment of renewable energy technology are important drivers" of the E[R] scenarios’ conclusions.[72]

In short, Energy [R]evolution scenarios were built on the premise that “the transition from fossil and nuclear fuels to renewables is too slow, and energy demand is still growing too quickly."[73] They aim to demonstrate that “strong efficiency improvements and the dynamic expansion of renewable energy <u>in all sectors</u> are the main strategies to meet the overall target of CO2 emission reductions."[74] In the conclusions that the authors draw from this modelisation work, they argue that “there are no major economic or technical barriers to moving towards 100% renewable energy by 2050."[75]

The following figure is a representation of the sectoral emission pathways laid out in the reference scenario, the Energy [R]evolution scenario, and the Advanced Energy [R]evolution Scenario, displaying the dramatic decarbonisation of the power- and transport sector.

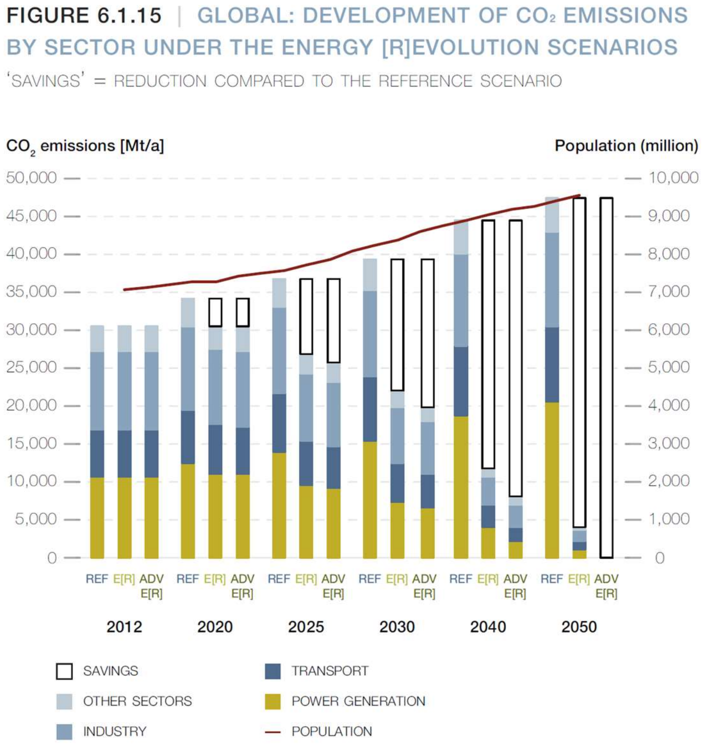

Figure 20 Emission pathways in the Energy [R]evolution scenarios Source: Greenpeace (2015) Energy [R]evolution - Energy Outlook 2015, p.92. [4]

Decarbonisation of the power and heating sectors

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[72] Ibid., p.61. [4]
[73] Ibid., p.11. [4]
[74] Ibid., p.60. [4]
[75] Ibid., p.364. [4]

“The Advanced Energy [R]evolution scenario has a target to [stabilize energy-related CO2 emissions by 2020 and to phase them out] by 2050."[76] The energy sector (including heating)[77] is 100% powered by renewables by 2050, their share soaring from 42% in 2030 to 72% in 2040 and 100% in 2050. Solar (PV and CSP) and wind power are the “main pillars" of the renewable ramp-up, supported by “the implementation of smart grids, [...] transmission grids, storage, and other load balancing capacities."[78]

Further leveraging the shift towards low-carbon power generation technologies, “the [heating] sector [moves] towards an increasing direct use of electricity ([and towards geothermal]), thanks to the enormous and diverse potential for renewable power and the limited availability of renewable fuels for high temperature process heat in industry."[79]

In the ADV E[R] scenario, “[the] introduction of new technologies leads to a complete decarbonisation of the power, [heating] and especially the transportation sector",[80] and renewable power becomes the main primary energy, having replaced natural gas by hydrogen in the power sector, and fossil fuels by power in the heating sector.

The following figure is a representation of total primary energy demand (TPED), displaying the phase-out of fossil fuels in the E[R] scenarios, and the ramp-up of renewables as main primary energy.

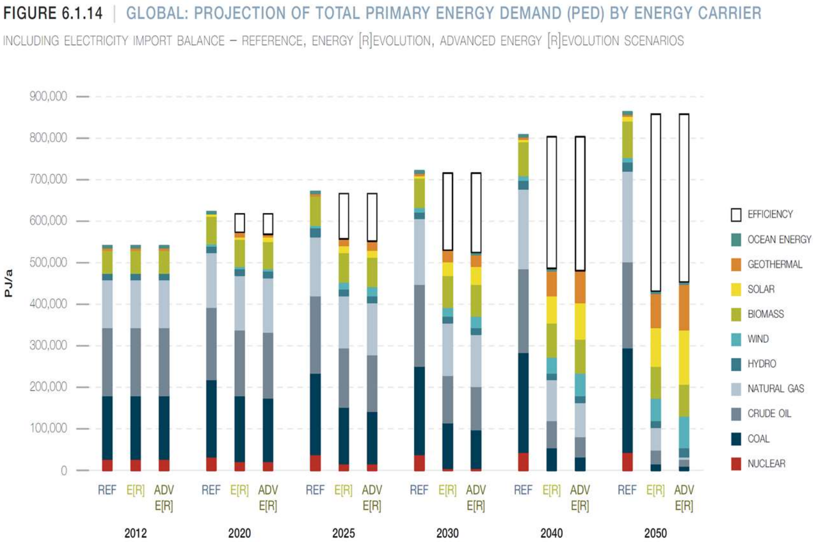

Figure 21 Total primary energy demand in the Energy [R]evolution scenarios Source: Greenpeace (2015) Energy [R]evolution - Energy Outlook 2015, p.92. [4]

Phase-out of nuclear and fossil fuels except in specific industries

CSP and gas-fired capacity serve as back-up to address the dispatchability challenge stemming from the rapid development of intermittent renewables. Nuclear power, lignite and coal are phased out (in this order). By 2050, fossil fuels are only used outside of the energy sector, e.g. in petrochemicals and steel production. Biomass (both in power and as fuel) and large hydro are curtailed for sustainability reasons.[81]

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[76] Ibid., p.37. [4]
[77] Ibid., p.9. [4]
[78] Ibid., p.61. [4]
[79] Ibid., p.60. [4]
[80] Ibid., p.59. [4]
[81] Ibid., p.60. [4]

Shift in the transport sector: “one of the most difficult parts"[82]

Greenpeace acknowledges that “the phase-out of fossil fuels in the transport- and parts of the industry sector still present major challenges, especially air travel and transport."[83]

In the E[R] scenarios, EVs, fuel-efficient combustion engines, battery technology for mobility, and hydrogen are on the rise. Biofuels use is limited, “following the latest scientific reports indicating that biofuels might have a higher greenhouse gas emission footprint than fossil fuels."[84]

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[82] Ibid., p.11. [4]
[83] Ibid., p.9. [4]
[84] Ibid., p.60. [4]

3 References & appendices

3.1.1 Sources

2°II (2018) (With the support of PRI) Website hosting the Paris Agreement Capital Transition Assessment (PACTA) tool www.transitionmonitor.com, September 2018. http://seimetrics.org/publications/assessing-the-alignment-of-portfolios-with-climate-goals/Link to the report

2°II, ADEME, WWF (2017) Aligning financial markets with climate goals: Sector & Technology Methodology, January 2017. https://www.transitionmonitor.com/en/home/Link to the website hosting the PACTA tool

Alexander, W. and Simon H. (2019) "Are battery electric vehicles the future? An uncertainty comparison with hydrogen and combustion engines." Environmental Innovation and Societal Transitions.

Auto Forecast Solutions. (2019) Auto Forecast Solutions [Online]. Available at: https://www.autoforecastsolutions.com/(Accessed: 25 October 2019)

Energy Information Agency (EIA). (2019) Annual Energy Outlook 2019: Reference Case Projections Tables [Online]. Available at: https://www.eia.gov/outlooks/aeo/tables_ref.php (Accessed: 25 October 2019)

Felipe, M. (2019). Global SUV boom continues in 2018 but growth moderates [Online]. Available at: https://www.jato.com/global-suv-boom-continues-in-2018-but-growth-moderates/ (Accessed: 25 October 2019)

Global Cement and Concrete Association (GCCA) (2019) Cement & Concrete: Key facts https://gccassociation.org/key-facts/Link to the GCCA website

GlobalData (2019). Oil & Gas [Online]. Available at: https://www.globaldata.com/industries-we-cover/oil-gas/ (Accessed: 25 October 2019)

Greenpeace (2015) Energy [R]evolution - Energy Outlook 2015, World Energy Scenario - 5th edition, September 2015. https://www.greenpeace.org/archive-international/Global/international/publications/climate/2015/Energy-Revolution-2015-Full.pdfLink to the 5th edition of the World Energy Scenario

IEA & Cement Sustainability Initiative (2018) Technology Roadmap - Low-Carbon Transition in the Cement Industry https://webstore.iea.org/technology-roadmap-low-carbon-transition-in-the-cement-industryLink to the Cement Technology Roadmap

IEA (2000). Greenhouse Gas Emissions From Major Industrial Sources - III Iron and steel Production [Online]. Available at: https://ieaghg.org/docs/General_Docs/Reports/PH3-30%20iron-steel.pdf (Accessed: 25 October 2019)

IEA (2017) Energy Technology Perspectives 2017, 6 June 2017. https://www.iea.org/etp/etp2017/Link to the ETP 2017

IEA (2019). IEA Methane Tracker [Online]. Available at: https://www.iea.org/weo/methane/ (Accessed: 21 October 2019)

IEA (2018) The Sustainable Development Scenario, A cleaner and more inclusive energy future. https://www.iea.org/weo/weomodel/sds/Link a summary of the SDS

IEA (2018) World Energy Outlook (WEO) 2018. https://www.iea.org/weo/Link to the website of the 2018 WEO

IMO (2014) Third IMO Greenhouse Gas Study 2014, http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Third%20Greenhouse%20Gas%20Study/GHG3%20Executive%20Summary%20and%20Report.pdf

IMO (2019) Data collection system for fuel oil consumption of ships, http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Data-Collection-System.aspx

International Energy Agency (IEA). (2019) “Global EV Outlook 2019”. International Energy Agency.

IPCC (2001) Third Assessment Report, Chapter 13 - Climate Scenario Development. https://www.ipcc.ch/ipccreports/tar/wg1/pdf/TAR-13.PDFLink to Chapter 13 of the TAR

IPCC (2019). Emission Factor Database [Online]. Available at: https://www.ipcc-nggip.iges.or.jp/EFDB/main.php (Accessed: 25 October 2019)

IPCC (2018) Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. https://www.ipcc.ch/sr15/Link to the IPCC Special Report

Kühlwein, J., German, J., and Bandivadekar, A. (2014) “Development of the Test Cycle Conversion Factors Among Worldwide Light-Duty Vehicle CO2 Emission Standards”. In International Council on Clean Transportation White Paper. Available at: https://theicct.org/sites/default/files/publications/ICCT_LDV-test-cycle-conversion-factors_sept2014.pdf (Accessed: 25 October 2019)

Li, X., Guttmann, A., Cipière, S., Maigne, L., Demongeot, J., Boire J.V., and Ouchchane, L. "Implementation of an extended Fellegi-Sunter probabilistic record linkage method using the Jaro-Winkler string comparator." In IEEE-EMBS International Conference on Biomedical and Health Informatics (BHI), pp. 375-379. IEEE, 2014.

Nava, M. (2017) “The road ahead for electric vehicles”. In BBVA Research, pp.1-8. Available at: https://www.bbvaresearch.com/wp-content/uploads/2017/02/170213_US_ElectricVehicles.pdf (Accessed: 25 October 2019)

Poseidon Principles (2019) https://www.poseidonprinciples.org/download/Poseidon_Principles.pdf

RightShip GHG Rating Methodology, GHG Emissions Rating. https://site.rightship.com/sustainability/ghg-rating-methodology/Link to RightShip’s website

Science Based Targets Initiative (2015) Quick Guide to the Sectoral Decarbonization Approach, May 2015. https://sciencebasedtargets.org/wp-content/uploads/2015/05/A-Quick-Guide-to-the-Sectoral-Decarbonization-Approach.pdfLink to the publication

Science Based Targets Initiative (2015) Sectoral Decarbonization Approach (SDA): A method for setting corporate emission reduction targets in line with climate science, Version 1, May 2015. https://sciencebasedtargets.org/wp-content/uploads/2015/05/Sectoral-Decarbonization-Approach-Report.pdf/Link to the publication

Science Based Targets Initiative (2017) Sector Development Framework - TWG-PRO-002 | version 1.0, 23 February 2017. https://sciencebasedtargets.org/wp-content/uploads/2017/02/Sector-Development-Framework-v1.0.pdf/Link to the publication

Science Based Targets Initiative (2018) Transport science-based target setting guidance, May 2018. https://sciencebasedtargets.org/wp-content/uploads/2018/05/SBT-transport-guidance-Final.pdfLink to the publication

Sciencebasedtargets.org. (2019). *Science Based Targets*. [online] Available at: https://sciencebasedtargets.org/ [Accessed 11 Nov. 2019].

Smil, V., 2019. Energy in world history. Routledge.

Steel Institute VDEh (2019). About Us [Online]. Available at: https://en.stahl-online.de/index.php/about-us/vdeh/ (Accessed: 25 October 2019)

TCFD (2017) The Use of Scenario Analysis in Disclosure of Climate-Related Risks and Opportunities, Technical Supplement, June 2017. https://www.fsb-tcfd.org/wp-content/uploads/2017/06/FINAL-TCFD-Technical-Supplement-062917.pdfLink to the Technical Supplement

Tiffany, V., Araceli F-P., and Peter L. (2019). IEA Tracking Clean Energy Progress [Online]. Available at: https://www.iea.org/tcep/industry/steel/ (Accessed: 21 October 2019)

UNECE Transport Division. (2019). Worldwide harmonized Light vehicles Test Procedure (WLTP) [Online]. Available at: https://wiki.unece.org/pages/viewpage.action?pageId=2523179 (Accessed: 25 October 2019)

World Steel Association (2018). Steel Statistical Yearbook 2018 [Online]. Available at: https://www.worldsteel.org/en/dam/jcr:e5a8eda5-4b46-4892-856b-00908b5ab492/SSY_2018.pdf (Accessed: 21 October 2019)

WJS News Graphics, (2016). “Barrel Breakdown”. The Wall Street Journal. Available at: http://graphics.wsj.com/oil-barrel-breakdown/ (Accessed: 21 October 2019)

WWF & SBTI (2017) Refinement of transport pathways in the Sector Decarbonization Approach. Presentation given on 25 April 2017. https://sciencebasedtargets.org/wp-content/uploads/2018/05/Kick-off-presentation_Governance.pdfLink to the presentation slidedeck

Zohuri, B. (2019) Hydrogen-Powered Fuel Cell and Hybrid Automobiles of the Near Future. In Hydrogen Energy (pp. 37-59). Springer, Cham.

3.1.2 Photography credits

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3.1.3 Glossary

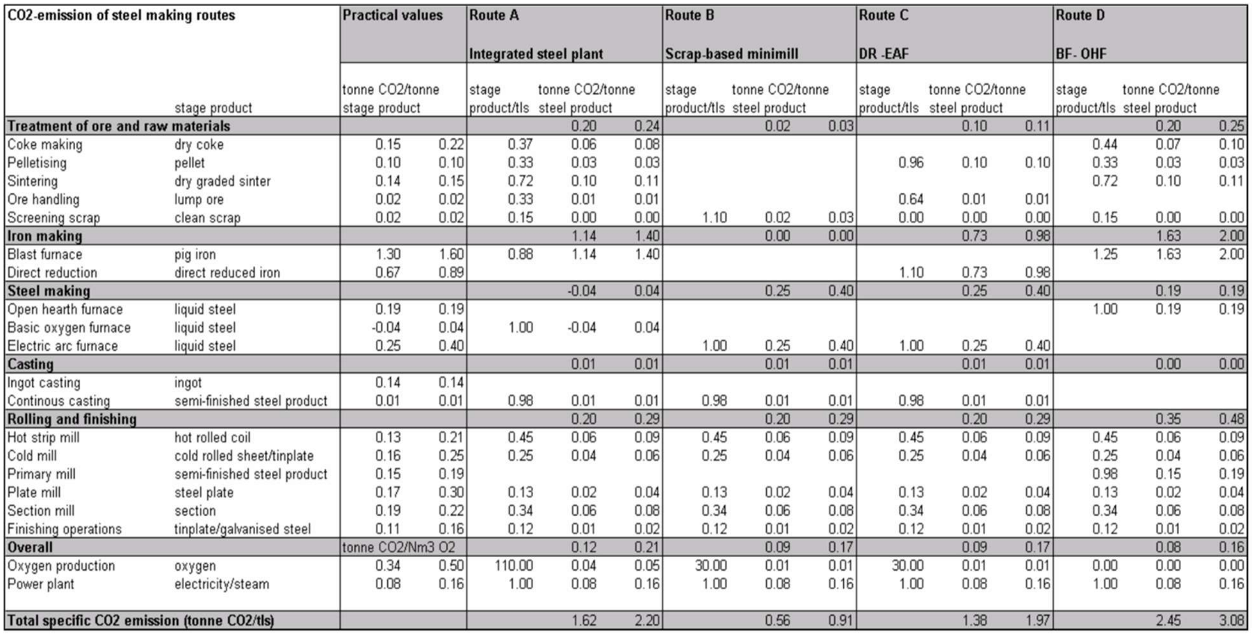
Acronym	Definition
2°II	2° Investing Initiative
2DS	2° Scenario (IEA ETP)
ALD	Asset-Level Data, where “assets” here refers to physical assets (power plants, oil fields, car assembly lines, coal mines, etc.)
Alignment	The deviation between the portfolio’s profile and the profile it should strive towards (as set by climate scenario targets)
B2DS	Beyond 2° Scenario (IEA ETP)
Benchmark	The targets laid out in climate scenarios
BNEF	Bloomberg New Energy Finance
Climate Scenario	“A plausible representation of future climate that has been constructed for explicit use in investigating the potential impacts of anthropogenic climate change.” (IPCC)
CPS	Current Policies Scenario (IEA WEO)
CSI	Cement Sustainability Initiative
ETP	Energy Technology Perspectives: an annual publication authored by the IEA
EV	Electric Vehicle
FSB	Financial Stability Board
GPER	Greenpeace Energy [R]evolution Scenario (Greenpeace)
ICE	Internal Combustion Engine
IDE	Integrated Development Environment
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
NDC	Nationally Determined Contribution: national pledges to reduce emissions taken at CoP21
NEO	New Energy Outlook: annual publication authored by BNEF, focusing on the power generation sector
PRI	Principles for Responsible Investment
R package	A software bundle of functions, sample data, documentation and tests
RCP	Representative Concentration Pathway
RTS	Reference Technology Scenario (IEA ETP)
SBTI	Science-Based Targets Initiative
SDA	Sectoral Decarbonization Approach
SDS	Sustainable Development Scenario (IEA WEO)
SPV	Special Purpose Vehicle
TAR	Third Assessment Report
TCFD	Task Force on Climate-related Financial Disclosures
WEM	World Energy Model (IEA model used to generate the scenarios presented in the WEO)
WEO	World Energy Outlook (IEA’s flagship publication)

3.1.4 Table of figures

3.1.5 Appendices

Appendix 1: Steel Emission Factors (IEA, 2000)

Table 4.2: CO_2-emissions associated with the specific energy consumption specified in Table 4.1 for four steel making routes. Also in this table for each route a high and a low value are given.



CO2-emission of steel making routes		**Practical values**		**Route A**			**Route B**			**Route C**			**Route D**		
				Integrated steel plant			**Scrap-based minimill**			**DR -EAF**			**BF- OHF**		
	stage product	tonne CO2/tonne stage product		stage product/tls	tonne CO2/tonne steel product		stage product/tls	tonne CO2/tonne steel product		stage product/tls	tonne CO2/tonne steel product		stage product/tls	tonne CO2/tonne steel product	
Treatment of ore and raw materials					0.20	0.24		0.02	0.03		0.10	0.11		0.20	0.25
Coke making	dry coke	0.15	0.22	0.37	0.06	0.08							0.44	0.07	0.10
Pelletising	pellet	0.10	0.10	0.33	0.03	0.03				0.96	0.10	0.10	0.33	0.03	0.03
Sintering	dry graded sinter	0.14	0.15	0.72	0.10	0.11							0.72	0.10	0.11
Ore handling	lump ore	0.02	0.02	0.33	0.01	0.01				0.64	0.01	0.01			
Screening scrap	clean scrap	0.02	0.02	0.15	0.00	0.00	1.10	0.02	0.03	0.00	0.00	0.00	0.15	0.00	0.00
Iron making					1.14	1.40		0.00	0.00		0.73	0.98		1.63	2.00
Blast furnace	pig iron	1.30	1.60	0.88	1.14	1.40							1.25	1.63	2.00
Direct reduction	direct reduced iron	0.67	0.89							1.10	0.73	0.98			
Steel making					-0.04	0.04		0.25	0.40		0.25	0.40		0.19	0.19
Open hearth furnace	liquid steel	0.19	0.19										1.00	0.19	0.19
Basic oxygen furnace	liquid steel	-0.04	0.04	1.00	-0.04	0.04									
Electric arc furnace	liquid steel	0.25	0.40				1.00	0.25	0.40	1.00	0.25	0.40			
Casting					0.01	0.01		0.01	0.01		0.01	0.01		0.00	0.00
Ingot casting	ingot	0.14	0.14												
Continous casting	semi-finished steel product	0.01	0.01	0.98	0.01	0.01	0.98	0.01	0.01	0.98	0.01	0.01			
Rolling and finishing					0.20	0.29		0.20	0.29		0.20	0.29		0.35	0.48
Hot strip mill	hot rolled coil	0.13	0.21	0.45	0.06	0.09	0.45	0.06	0.09	0.45	0.06	0.09	0.45	0.06	0.09
Cold mill	cold rolled sheet/tinplate	0.16	0.25	0.25	0.04	0.06	0.25	0.04	0.06	0.25	0.04	0.06	0.25	0.04	0.06
Primary mill	semi-finished steel product	0.15	0.19										0.98	0.15	0.19
Plate mill	steel plate	0.17	0.30	0.13	0.02	0.04	0.13	0.02	0.04	0.13	0.02	0.04	0.13	0.02	0.04
Section mill	section	0.19	0.22	0.34	0.06	0.08	0.34	0.06	0.08	0.34	0.06	0.08	0.34	0.06	0.08
Finishing operations	tinplate/galvanised steel	0.11	0.16	0.12	0.01	0.02	0.12	0.01	0.02	0.12	0.01	0.02	0.12	0.01	0.02
Overall		tonne CO2/Nm3 O2			0.12	0.21		0.09	0.17		0.09	0.17		0.08	0.16
Oxygen production	oxygen	0.34	0.50	110.00	0.04	0.05	30.00	0.01	0.01	30.00	0.01	0.01	0.00	0.00	0.00
Power plant	electricity/steam	0.08	0.16	1.00	0.08	0.16	1.00	0.08	0.16	1.00	0.08	0.16	1.00	0.08	0.16
Total specific CO2 emission (tonne CO2/tls)					1.62	2.20		0.56	0.91		1.38	1.97		2.45	3.08