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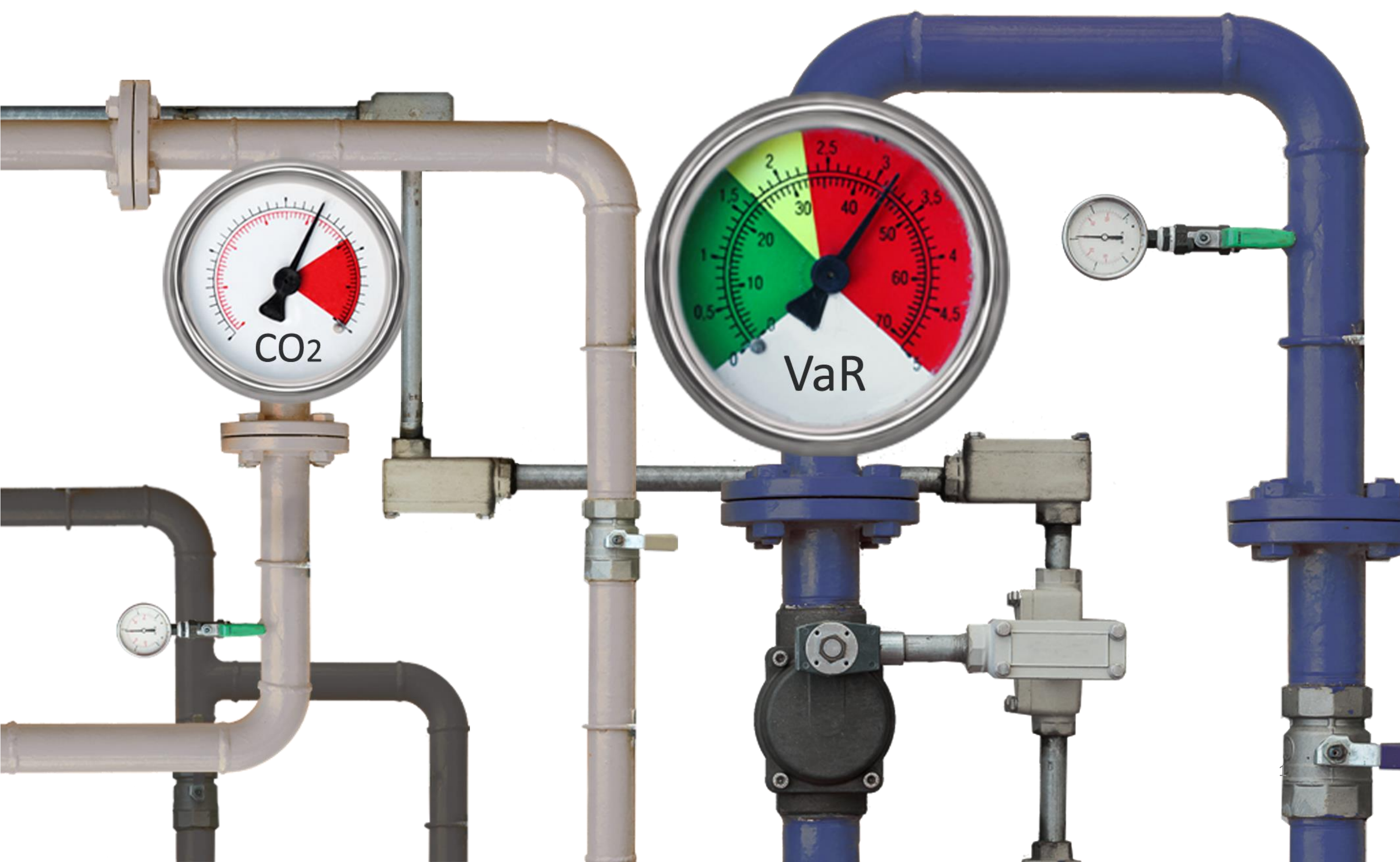
THE TRANSITION RISK-O-METER

REFERENCE SCENARIOS FOR FINANCIAL ANALYSIS



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EXECUTIVE SUMMARY

This report constitutes the first attempt to develop transition scenarios involving over 30 parameters across 8 sectors directly tailored for financial risk and scenario analysis by companies, equity and credit research analysts, and financial institutions.

The report contains two transition risk scenarios – a limited climate transition (LCT) scenario associated with 3°-4°C decarbonisation range and an ambitious climate transition (ACT) scenario, seeking to approximate an outcome associated with a 2°C transition and building in particular on the 2°C scenarios of the International Energy Agency (IEA). The report develops over 30 individual risk parameters across 8 sectors (fossil fuels, electric power, automobile, cement, steel, aviation, and shipping). You can get access to the dynamic version of the indicators through the ET Risk project Scenario Selector online tool here. Part I presents the analytical framework for the scenarios. Part II provides the detailed parameters and indicators for use in financial modelling.

The report responds to the fact that traditional reference decarbonisation scenarios are not designed for financial analysis.

'Traditional' reference decarbonisation scenarios are a core staple of climate policymaking and the dialogue around climate goals. There are a range of actors involved in developing these scenarios in the annual reports of private and public companies or as part of commissioned research. Notable examples include the scenarios of international organizations (e.g. IEA), NGOs (e.g. Greenpeace, WWF), and the private sector (e.g. Shell, Enerdata). The challenge with these so-called traditional decarbonisation scenarios however is that they have not been designed with the question of risk analysis at company or financial market level in mind. By extension, they exhibit a number of key challenges with regard to their use for risk analysis, in particular in regard to the design of the indicators, their coverage and scope, their lack of country-level specificity, as well a lack of agreement on a common reference scenario.

The report overcomes this constraint by enhancing and enriching decarbonisation scenarios. It can be used for free by any third party seeking to respond to the Financial Stability Board Task Force on Climate-related Financial Disclosures recommendations, shareholder pressure on scenario analysis, and potential regulatory guidance.

The report creates a framework around this process that can be replicated by interested third-parties, by defining a five step approach (visualized below). This approach uses traditional decarbonisation scenarios as a base, determines the scope of indicators and sectors (as well as country granularity), and then determines the *scenario belief* with regard to the trade-offs between policy and market drivers, as well as the associated ambition associated with each. It then defines the key sources for enhancement used to expand and, where required, independently model missing indicators. The objective with this framework is thus not to build a general equilibrium, cross-sectorially consistent climate scenario, but rather to collate the best evidence for each sector as to its potential evolution over time.

The next two pages summarize the modelling choices of each scenario, as well as the scope of indicators and geographic granularity provided for each. For indicators values refer to Part II.

TABLE 0.1. MODELLING PRINCIPLES OF THE TRANSITION SCENARIOS

<table>
<tr><th>Risk factor</th><th>Limited Climate Transition Scenario (LCT)</th><th>Ambitious Climate Transition Scenario (ACT)</th></tr>
<tr><td>Production & technology</td><td>• Relies in the first instance on the IEAs Energy Technology Perspectives (ETP) 4DS Scenario for parameters across all industries, where available, as well as the IEA WEO NPS scenario where required.

• Additional parameters are sourced from third-party literature on an ad-hoc basis.

• Where IEA figures are not provided at country level, country estimates are reconstructed using estimates from third-party sources and internal modelling.

NB: Since the LCT doesn’t explicitly solve for a specific temperature limit of global warming, a range of decarbonisation scenarios (e.g. Greenpeace) can be used without prejudice to the other assumptions, assuming policy targets are integrated. Any user can thus replace the IEA with an alternative reference model if desired, assuming it also solves for an limited climate outcome (e.g. 3°C to 4°C)</td><td>• Relies on the IEA ETP 2D scenario for parameters across all industries, where available, as well as the IEA WEO 450 scenarios where required.

• Additional parameters are sourced from third-party literature on an ad-hoc basis based.

• Country estimates are reconstructed using country level estimates from third-party sources, where figures are not provided with the necessary granularity.

NB: The ACT Scenario can use a range of decarbonisation scenarios without prejudice to the other assumptions. Any user can thus replace the IEA with an alternative reference model if desired, assuming it also solves for an ambitious climate outcome (e.g. 2°C or less)</td></tr>
<tr><td>Market prices</td><td>• Uses conservative assumptions around technology development curves that can be identified in industry and / or academic literature. These can either be directly sourced from third-party cost curves or modelled after historical examples of cost curves (e.g. fall in the cost of solar PV 2010-2015).

• Commodity price assumptions are largely taken from IEA as well as country-specific energy prices where available.

• ‘Alternative’ assumptions may be provided based on third party literature.</td><td>• Uses the most optimistic assumptions around technology development curves that can be identified in industry and / or academic literature.

• Commodity price assumptions are largely taken from the IEA, although ‘alternative’ assumptions may be provided based on third-party literature.

• For commodity price curves not directly provided in the IEA published material, third party literature is applied.</td></tr>
<tr><td>Policy mandates, incentives & taxes</td><td>• Concrete policies and measures are derived for each sector individually based on IEA’s indications (e.g. subsidies in accordance with climate targets, National Determined Contribution targets integration into the model), where available, and complemented with expert interviews and third-party literature.

• It is assumed that policy makers will continue with “carrots and sticks” and will only use command and control measures when targets are not reached. In this way, market intervention is limited while still complying with country-specific climate targets.</td><td>• The scenario generally does not differ from the policy mandates elaborated in the LCT. However, in some cases, it provides an additional assumption around policy convergence to the most ambitious policy mandates. The exception to this approach involves carbon prices, which are significantly more ambitious.

• In terms of incentives and taxes, the scenario will be limited to modelling those policy incentives and taxes that accrue directly to the companies, for which risks are modelled, assuming that the impact of all ‘consumer demand’ incentives (e.g. subsidies on electric vehicle purchases, etc.) are captured in the production & technology parameters.</td></tr>
<tr><td>Unconventional risks</td><td colspan="2">• Limited to a qualitative approach, with no quantitative elements. This will cover other macroeconomic trends and other types of risk (e.g. litigation). A separate paper has been developed in partnership with the law firm Minter-Ellison on litigation risks in financial markets.</td></tr>
</table>

TABLE 0.2: KEY INDICATORS

Sector	Type	Indicator	Page	Geography	Main Sources
Cross-sector	Market Pricing	Crude oil price (USD/bbl)	22	World	IEA ETP
		Natural gas price (USD/MBtu)	23	US, EU	IEA ETP
		Coal prices (USD/ton)	24	World	IEA ETP
		Electricity prices (2015 EUR/MWh)	25	BR, MX, USA, FR, DE, IT	IEA WEO, Third-party source
	Policies costs and incentives	Carbon prices (2015 USD / T-Coeq)	26	US, EU, BR	IEA WEO
Power Utilities	Production & Technology	Electricity generation (TWh)	29	World, BR, MX, USA, FR, DE, IT	IEA ETP, EC Trends 2050
		Electricity capacity (GW)	31	World, BR, MX, USA, FR, DE, IT	IEA ETP, EC Trends 2050
	Market Pricing	Levelised costs of electricity (€/MWh)	32	World, BR, MX, USA, FR, DE, IT	NREL
	Policies costs and incentives	Subsidies (€/Mwh)	34	US	NREL
		Effective carbon rates ($/t$CO_2$)	35	BR, MX, USA, FR, DE, IT	IEA WEO
Automotive	Production & technology	Sales by powertrain (%)	38	World	IEA
	Market Pricing	Carbon fibre (USD/pound)	39	World	NREL
		Battery costs (USD/kWh)	40	World	Third-party source, BNEF
	Policy costs and incentives	Fuel efficiency standards (%)	41	BR, MX, USA, EU	ICCT
		Effective carbon rates(EUR/tCO_2)	42	World, BR, MX, USA, FR, DE, IT	OECD, Third-party source
Steel	Production & technology	Crude Steel production (Mt)	45	World, BR, MX, USA, FR, DE, IT	IEA ETP, EC
		Share of primary/secondary steel(%)	46	World, BR, MX, USA, FR, DE, IT	IEA ETP, EC
		Energy Intensity (GJ / t crude steel)	47	World, BR, MX, USA, FR, DE, IT	IEA ETP
		Carbon Intensity (t CO_2 / t crude steel)	48	World, BR, MX, USA, FR, DE, IT	IEA ETP
	Market Pricing	Crude Steel Price (USD / ton)	49	World	Third-party source
		Raw Materials Prices (USD / ton)	50	World	Third-party source
	Policy costs and incentives	Allowances of free CO2 allowances(% of total CO_2 direct emissions)	51	BR, EU, MX, USA	Third-party source
Cement	Production & technology	Cement production (Mt)	54	World, BR, MX, USA, FR, DE, IT	IEA ETP, EC Trends 2050
		Clinker to cement ratio (%)	55	World, BR, MX, USA, FR, DE, IT	IEA ETP
		Energy intensity for clinker production (GJ / t clinker)	56	World, BR, MX, USA, FR, DE, IT	IEA ETP
		Share of alternative fuel use (%)	57	World, BR, MX, USA, FR, DE, IT	IEA ETP
		CCS deployment (%)	58	World, BR, MX, USA, FR, DE, IT	IEA ETP
		CO_2 Intensity (t CO_2 / t cement)	59	World, BR, MX, USA, FR, DE, IT	IEA ETP
	Market Pricing	Secondary Fuels (USD/ton)	60	World	Third-party source
	Policy costs and incentives	Allowances of free CO2 allowances(% of total direct emissions)	61	BR, EU, MX, USA	IEA ETP and Third-party source
Aviation	Production & technology	Demand (passenger-km)	64	World, BR, MX, USA, EU	IEA ETP and Third-party source
		Fuel efficiency (g fuel burned /revenue passenger-km)	65	World	ICCT
		Biofuel penetration (%)	66	BR, MX, USA, FR, DE, IT	ICAO IEA ETP and Third-party source
	Market pricing	Jet fuel prices (USD / gallon)	67	World	IEA ETP
	Policy costs and incentives	Carbon credit mandates (USD/tCO_2)	68	World	ICCT, ENVI
		Fuel efficiency standards (kg/km)	69	World	ICCT
Shipping	Production & technology	Shipping Transport Demand (G ton km / year)	72	World	IMO
		Fuel efficiency (kJ/tonne-km)	73	World	Third-party source
		Alternative fuels penetration (%)	74	World	Third-party source
	Market Pricing	Marine Fuel prices (fraction to 2010 HFO price) and (USD/GJ)	75	World	Third-party source
	Policies costs and incentives	Efficiency Design Regulations	76	World	Third-party source
		Emission/Fuel standard	77	World	Rightship

PART I

TRANSITION RISK SCENARIOS FRAMEWORK

1 INTRODUCTION

This report constitutes the first attempt to develop transition scenarios directly tailored for financial risk and scenario analysis by companies, equity and credit research analysts, and financial institutions.

The report contains two transition risk scenarios – a limited climate transition (LCT) scenario associated with 3°-4°C decarbonisation range and an ambitious climate transition (ACT) scenario, seeking to approximate an outcome associated with a 2°C transition and building in particular on the 2°C scenarios of the International Energy Agency (IEA). The report develops over 30 individual risk parameters across 8 sectors (fossil fuels, electric power, automobile, cement, steel, aviation, and shipping). Section 1 presents the analytical framework for the scenarios. Section 2 provides the detailed parameters and indicators for use in financial modelling.

Parameters for both transition risk scenarios were developed on the basis of best available public information from multiple sources including academic literature, industry experts, government announcements and commercial databases. The objective was not to build a general equilibrium, cross-sectorially consistent climate scenario, but rather to collate the best evidence for each sector as to its potential evolution over time. The objective was not to build a general equilibrium, cross-sectorially consistent climate scenario, but rather to collate the best evidence for each sector as to its potential evolution over time. The transition risk scenarios can be used by companies for internal scenario analysis as well as scenario analysis performed as part of their disclosing obligations for key business segments, equity and credit research analysts, as well as portfolio managers for portfolio risk assessments. All information contained in this report is also available on www.et-risk.eu in combination with a transition risk scenario selector tool.

The development of this report and scenario was fundamentally driven by a recognition of the fact that the current suite of decarbonisation scenarios, as developed by the International Energy Agency and others, are not designed for risk analysis. In focusing on GHG emissions and technology pathways, they lack a range of key parameters that would be required to understand both the volume and price impacts that companies across a range of sectors may face under a 2°C transition. As such, this report does not stand in competition to existing modelling frameworks, but simply seeks to reframe them to make them usable for financial risk and in particular scenario analysis.

The creation of transition risk scenarios for scenario analysis responds to a range of drivers pushing for scenario analysis by companies and financial institutions.

- First **regulatory initiatives** are calling for climate scenario analysis in reporting, notably the French Energy Transition for Green Growth Law (2015), which calls on investors to disclose *"any element enabling a relevant assessment of the entity's exposure to climate change-related risks and its contribution to compliance with the international objective to limit global warming..."* (Article 173 2015). Best disclosure practices were later, in 2016, highlighted through the International Award on Investor Climate-related Disclosures co-organized by the French Environment Ministry, the French Treasury, and 2° Investing Initiative. Since then, other governments have explored the possibility of adapting such frameworks to their national context.

- **Investor networks and coalitions** are urging companies to conduct and disclose 2°C scenario analysis, notably through the Aiming for A coalition and engagement by US investor association Ceres.

- Working transversally, the recommendations of the **Task-force on Climate-related Financial Disclosures** (TCFD) of the Financial Stability Board have escalated internationally the discussion around scenario analysis for companies in both the financial and non-financial sectors. The recommendations conclude that *"The Task Force believes that all organizations exposed to climate-related risks should consider (1) using scenario analysis to help inform their strategic and financial planning processes and (2) disclosing how resilient their strategies are to a range of plausible climate-related scenarios."* (TCFD 2017)

- **International standardization bodies** are exploring avenues towards defining a common framework for assessing and reporting investments and financing activities related to climate change. This is the case of the recently launched ISO 14097 working group, which is also set to reference scenario analysis.

1.1 THE 2°C SCENARIO / TRANSITION RISK TOOLBOX

2°C and transition risk scenario analysis requires three types of tools.

The first step to understanding how transition risk scenarios operate involves understanding how they fit into the general scenario and risk analysis framework. From a transition risk perspective, this framework involves three elements that together constitute what the authors of this report call the *Energy Transition Risk Toolbox* (2dii 2016a). These three elements are: *i.) transition risk scenarios, ii.) transition risk data (company, financial, and asset level), and iii.) transition risk models (see Fig. 1.1)*:

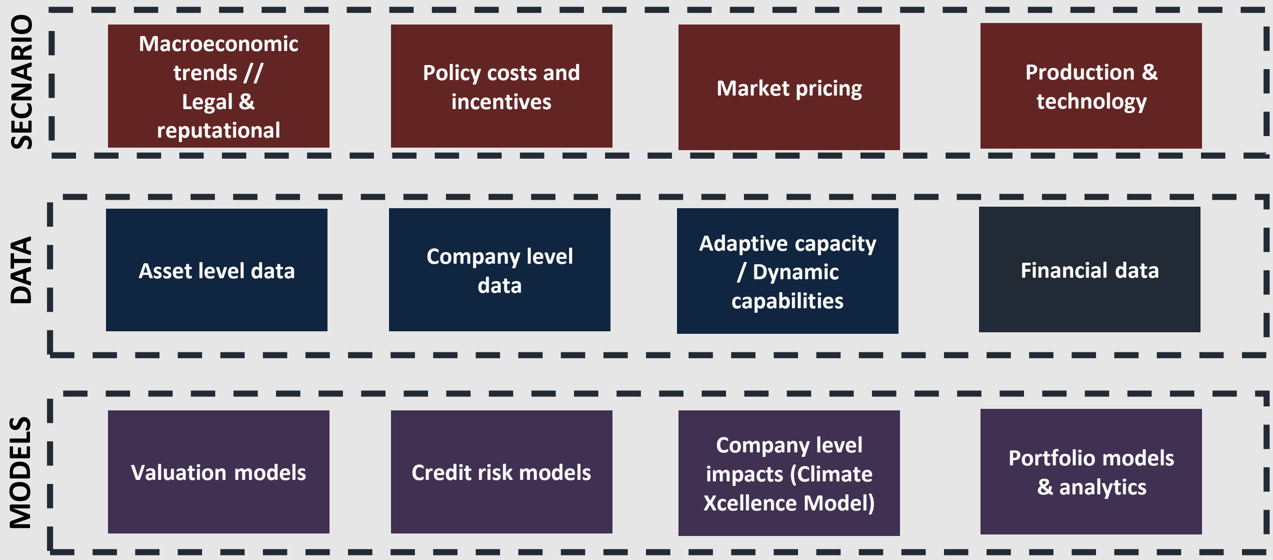
Transition risk scenarios. The first tool is the definition of the actual external risk driver or shock i.e. the transition risk scenario that generates the risks for companies. This tool is at the focus of this report. Developing transition risk scenarios that are actually usable and material for risk analysis requires enhancing traditional decarbonisation scenarios, which as a rule are not designed with risk management considerations in mind.

The *Energy Transition Risk Toolbox* developed by the ET Risk consortium and outlined in this report frames two types of transition risk scenarios: i) an ambitious climate transition scenario designed to mirror or approximate a 2°C transition and using as its base or reference the '~2°C scenarios' of the IEA (2D & 450 scenario); and ii) a limited climate transition scenario representing a world with extended current and planned policies and technology trends and using as its basis the IEA (New Policy Scenario & 4D scenario). Scenarios are set to cover a set of key indicators, notably policy costs and incentives, market pricing, and production & technology. They also situate themselves in the context of broader macroeconomic and social trends. Sectors covered in this report include fossil fuels (cross-sectoral indicator), cement, steel, electric power, automobile, shipping, and aviation.

Transition risk data. The second tool is transition risk data at sector, company, and asset levels in order to inform the exposure to transition risk scenarios by companies, their potential impact, and the ability of companies to mitigate this impact. Notably, these data include asset-level production and investment data, company-level data (e.g. R&D expenditures), and financial data. A sister paper is planned developing on the question of asset-level data as part of the *ET Risk project* that is set to be launched in Q3 2017.

Transition risk models. The final tools are the models that combine transition risk scenarios and transition risk data to calculate financial risk. Partners for transition risk models in the context of the project are S&P Global in its credit risk model, Kepler-Cheuvreux in its equity valuation models, the CO-Firm in its company financial risks ClimateXcellence Model and 2°ii in its existing 2°C portfolio scenario analysis model.

FIG 1.1 ASSESSING TRANSTION RISK SCENARIOS ACROSS THE INVESTMENT CHAIN (SOURCE: AUTHORS)



1.2 RISK SCENARIOS VS. TRADITIONAL DECARBONISATION SCENARIOS

Traditional decarbonisation scenarios are not designed for financial analysis.

'Traditional' decarbonisation scenarios are a core staple of climate policymaking and the dialogue around climate goals. There are a range of actors involved in developing these scenarios in annual reports of private and public companies or as part of commissioned research, notably international organizations (e.g. IEA), NGOs (e.g. Greenpeace, WWF), and the private sector (e.g. Shell, Enerdata).

The challenge with these so-called traditional decarbonisation scenarios however is that they have not been designed with the question of risk analysis at company or financial market level in mind. By extension, they exhibit a number of key challenges with regard to their use for risk analysis:

- **Indicators not designed for risk assessment.** Most of the current economic decarbonisation scenarios are designed to show the technical feasibility and / or economic viability of various roadmaps that solve for a climate-related constraint (e.g. carbon budget). They are thus more interested in indicators that speak to that constraint, rather than risk-related production metrics that reflect demand changes. One example is the International Energy Agency annual updates on the evolution of the automobile sector where indicators are reported as 'stocks' of cars on the road (relevant for the carbon budget), rather than annual production (relevant from a risk perspective). It is critical to note here that frequently these scenarios will solve for the relevant indicators, but not communicate them (e.g. the IEA provides for annual production figures in their model, but doesn't integrate these figures into the publication).

- **Coverage on indicators incomplete.** Given the focus on economic pathways, decarbonisation scenarios may miss indicators that are relevant from a risk perspective. For example, battery costs or electricity prices are a critical component for understanding the margin impacts of decarbonisation scenarios on automobile manufacturers or cement companies respectively. These indicators however are lacking in most if not all reported scenarios.

- **Lacking country-level specificity.** Bottom-up risk analysis will involve looking at country-specific trends in order to understand specific risks to companies. Many scenarios lack this granularity and provide – for most countries – only regional or in some cases only global figures.

- **Lack of agreement on common reference scenarios.** Finally, for some use cases related to risk analysis (e.g. comparability of disclosures, stress-testing of market and network risks), 'standardized' (i.e. indicators covered and granularity) reference scenarios may be desirable. At this stage, these standards do not exist even within the most commonly used reference scenarios such as the IEA.

This gap creates a significant challenge for stakeholders wishing to respond to the growing momentum around 2°C scenario and risk analysis highlighted in the beginning of this report.

In response, this research stream on the *Energy Transition Toolbox* seeks to develop publicly-available 2°C aligned and 'limited climate transition' decarbonisation scenarios that can be used for risk analysis. These scenarios will build on and use as the starting point existing 'traditional' decarbonisation scenarios, notably in the two scenarios developed here the work of the IEA, and then enrich and expand these scenarios to make them usable for risk analysis.

2 DESIGNING 2°C AND TRANSITION RISK SCENARIOS

2.1 FROM TRADITIONAL TRANSITION TO TRANSITION RISK SCENARIOS

The following summarizes the key steps required to enrich and expand upon a traditional decarbonisation scenarios to make it usable as a risk scenario.

- **Choosing the scenario base.** The first step, intuitively, is to choose the starting point in terms of the traditional scenario that should be enhanced and expanded for financial risk analysis. The choice of the scenario base depends on the sectors and geographies that the user wishes to cover, the analysts' belief about the likely level of ambition desired for the use case (e.g. for stress-testing exercises, it may make sense to apply more ambitious scenarios, for normal market analysis, it may make sense to apply the 'most likely' outcomes), and the associated technology beliefs (e.g. views about the deployment of Carbon Capture and Storage (CCS) and nuclear). The table below summarizes some of the pros and cons of using different reference scenarios.

Type of scenario	Pros	Cons
International Energy Agency (annual)	• Widely accepted by market • Relatively comprehensive in terms of sector coverage	• Historically misaligned with trends • High reliance on nuclear and CCS • Limited granularity for industry and transport
Greenpeace (2015)	• More aligned with renewable trends • Doesn't rely on carbon capture and storage	• Not updated annually • Lack of market acceptance given branding • Limited sector coverage
BNEF (ongoing)[1]	• Linked to bottom-up industry trends • Higher reliance on 'market optimistic trends' around deployment	• Not directly connected to climate outcome (relevant for 2°C scenario analysis objective) • Limited to power and auto transport
ICCT shipping (2013)	• High level of granularity for the shipping sector • More closely aligned with indicators relevant for risk analysis	• Limited to shipping sector • Not updated annually

- **Scope of indicators (sectors, type, geography, time horizon).** The second choice once the scenario base has been identified is to decide on the scope of the indicators in terms of sectors and type. The sector indicators may be limited to one or more sectors, and may also include 'cross-sector' indicators that drive risk within the sector. **This document is written very much for sector analysts and with sector focus.** For example, understanding financial risk for the utility sector requires an understanding of fossil fuel prices and associated production plans, indicators that are risk indicators both for the fossil fuel sector itself and the utility sector. In addition to the choice of indicators, the scope also needs to be framed in terms of the types of indicators that are included. This depends on the sophistication and calibration of the risk analysis and the nature of the model that is being applied, as well as the capacity to correlate transition risk scenarios with company level data to identify their specific impacts.

Beyond macro trends and indicators that are implied in every model, there are four categories that can be considered:

- **Production & technology parameters** relate to all parameters that comment both on the volume of goods and services bought and sold annually (e.g. electric vehicle vs. petrol vehicles) and the technologies / fuels associated with the production of these goods and services (e.g. renewable kWh vs. coal kWh, technology differences in cement production, etc.). Production in effect captures demand.

- **Market price parameters** relate to all parameters that comment on the expected evolution of non-policy related prices of goods and services, both for commodities (e.g. oil prices, gas prices, etc.) and various technology inputs in the production process (e.g. batteries, composite materials, etc.). As for most scenarios, technology input price shifts are exogenous as any indirect policy effects (e.g. R&D incentives) are assumed to be already captured. This category also covers carbon prices associated with emissions trading schemes, since these act technically as market-driven price parameters.

- **Policy mandates, incentives & policy cost parameters** relate to all policy-related performance standards and production standards (e.g. fuel efficiency standards, electric vehicle sale mandates), tax incentives as well as policy costs. These can be defined either as a specific incentive or as so-called 'effective carbon rates', which account for a range of policy instruments that can be aggregated to yield an effective cost on carbon.

- **Unconventional parameters** relate to all other parameters that may act as risk drivers for companies and financial assets. Notable examples include litigation risks and costs, as well as potential reputational assumptions.

In addition to identifying the scope of sector and types of indicators, the scenarios also need to be framed in terms of their geographic granularity (and coverage) as well as their time horizon. The choice here similarly depends on the type of companies and sectors covered in the risk analysis, with some sectors more globally integrated (e.g. oil & gas) and others relatively local (e.g. electric power). As will be highlighted in the course of the scenario discussion, the key challenge with geographic granularity is that the type of granularity generally required for risk analysis for some sectors (e.g. country level) is rarely modelled and if it is modelled it covers only a sample of key geographies (e.g. United States, China, etc.). The time horizon then depends on the time horizon of the model, which is three to five years in some cases and +20 years in others. One critical issue to flag in the context of time horizons is the fact that most scenarios exhibit limited 'disruption' in the short-term (e.g. next 5 years) as they orientate themselves at least in part towards an existing pipeline of investment plans. This implies the need to either consider more disruptive short-term scenarios or extend the time horizon of the model in order to capture fully the whole suite of transition risks.

- **Policy vs. market.** At this stage, the scenarios are prepared for enhancement and expansion in order to make them usable for financial analysis. The enhancement – beyond the technical and methodological choices inherent in the development of additional indicators – will in most cases need to emphasize 'market pricing' and 'policy costs & incentives' since those tend to be the indicators least developed in the 'traditional' decarbonisation scenarios or most poorly represented with regard to their usability as a next step. As the enhancement focuses on these two aspects, in addition to any potential missing indicators for the other two categories (e.g. production & technology and Unconventional), a conflict arises between the expected ambition of each. Thus, a scenario more optimistic in terms of the development of the levelised cost of solar PV electricity or battery prices would be expected to have lower levels of policy intervention, since less policy intervention is required as these technologies become cost-competitive. Similarly, higher levels of policy intervention may be expected should market prices and technology maturity with regard to low-carbon technologies evolve at a less ambitious rate. The following illustrative example demonstrates the interface between these two elements. To note, the ambitious climate transition scenario developed in this report seeks as a rule to align with a 'market optimist' view.

	Low-carbon technology (€/MWh)	High-carbon technology (€/MWh)	Remaining policy incentive (€/MWh)
Expected costs of deployment – Market optimist	6	5	1
Expected costs of deployment market pessimist	10	5	5

- **Sources for enhancement – consistency or detail.** The majority of risk-related indicators identified in the research for this report are modelled by someone, somewhere, and in some cases by multiple different organizations. This implies a choice as to the indicators that will be used to enhance the scenario. The choice depends on the same type of factors highlighted earlier (i.e. scenario base, scope and type of indicators) with regard to the choice of scenario, notably the credibility of the organization that parametrized the indicator, its accessibility, and its alignment with the belief of the scenario (e.g. market optimist / pessimist). Crucially, unless a comprehensive general equilibrium model was designed to build both the scenario base and the enhanced indicators, these enhanced indicators may not even be consistent with the original scenario. Given that such a scenario doesn't exist, transition risk scenarios either have to be limited to the indicators that do exist in the scenario base, making them only marginally useful for risk analysis, or they have to be enhanced, recognizing that this may generate inconsistency across sectors. Within a sector there is the most need for consistency and it is the sector level that counts in company analysis. At a second level, consistency across sectors is needed for portfolio analysis and assessment of multi-sector company exposure. This point is crucial to consider when reading the sector specific sections and is highlighted when relevant.

- **Modelling missing indicators.** The final step then is to potentially model or interpolate any missing sector indicators not identified in the literature. This step depends on the extent to which indicators are covered in the literature. The types of choices here are obviously wide-ranging, from simple interpolation / extrapolation to more sophisticated models.

2.2 TRANSITION SCENARIOS IN PRACTICE

Ambition choice. This report develops two transition risk scenarios: An Ambitious Climate Transition (ACT) scenario designed to mirror or approximate a 2°C transition and a Limited Climate Transition (LCT) scenario representing a world with extended current and planned policies and technology trends. Both use the IEA scenarios as a base for enhancement. These two different visions of the world generally capture investors views on efforts made or to be made against climate change. A survey run by the authors to the investment community in December 2016 showed that 3 out of 39 participants believed that either the 2°C climate target was going to be met or was very likely to be met, while 36 participants expressed that high efforts were needed to meet the target (see Figure 2.1).

Furthermore, a side event at the Industrial Summer Study 2016 hosted by the European Council for an Energy Efficient Economy (ECEE) was organized, a questionnaire listing three to five different developments of key indicators until 2050 (i.e. CO_2-allowances price, crude oil price, renewable electricity share, electricity share in energy for transport, share of CCS in electricity generation, share of CCS of total industrial CO_2 emissions) was distributed among participants. No indication that some of the developments were derived from IEA data was provided. 22 of 57 valid responses found developments consistent with IEA 4DS as most probable for Europe. 18 of 57 valid found developments consistent with IEA 2DS as most probable for Europe. 17 of 57 valid responses, less the one third, found a development other than IEA data more probable (see Figure 2.2).

FIGURE 2.1 SURVEY EXTRACT: PERCEPTION ON THE PROGRESS TOWARDS A 2 DEGREE COMPATIBLE WORLD (SOURCE: AUTHORS)

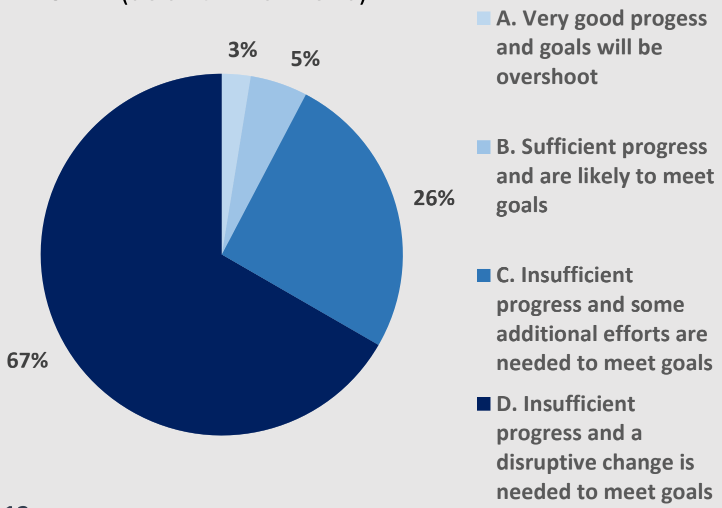
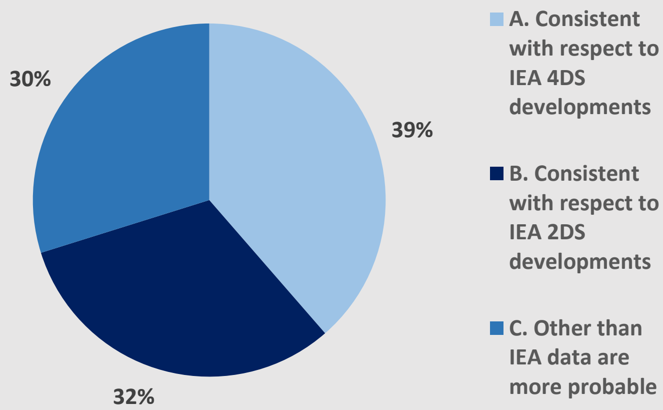


FIGURE 2.2 QUESTIONAIRE EXTRACT: CONSISTENCY OF DEVELOPMENTS OF KEY INDICATORS UNTIL 2050 WITH IEA SCENARIOS (SOURCE: AUTHORS)



Sector choice. The scenarios develop here focus on 8 GHG-intensive business activities, namely: oil&gas, coal, electric power, automobile, aviation, shipping, cement and steel sectors. In addition, the scenario provides a range of cross-sectoral indicators that act as risk drivers for these sectors and can be used for financial analysis for fossil fuel companies (e.g. oil prices, oil production, carbon tax, etc.).

The choice of sectors is based on both technical feasibility and materiality questions. Thus, these sectors are among those to which a typical financial institution will have the largest exposures in their credit and equity portfolios. Moreover, they are those for which the IEA scenarios have the most developed base to build upon. In addition, from an *Energy Transition Risk Toolbox* perspective, they can best be linked to asset level and financial data, as well as mapped through supply chains. Arguably the biggest gaps in sector choice involve real estate, agriculture, and forestry, areas that will require further research in the future. Scenarios are also missing for sectors for which no traditional decarbonisation scenario exists (e.g. pharmaceuticals, IT).

Geography choice. The scenarios developed here present results for six countries: Brazil (BR), France (FR), Germany (DE) and Italy (IT), Mexico (MX) and USA. In addition, global indicators are provided for all relevant parameters in order to allow for both a more macro financial analysis (not considering geographic idiosyncrasies and exposures) as well as a country level deep-dive. A survey run by the authors to the investment community showed that 6 out of 13 participants think that country granularity is needed in transition scenarios (see Fig 2.3).

The country selection was based on the most significant geographic exposures (at production and sales level) for the companies in the key sectors covered in the scenarios in the MSCI World. Thus, despite their materiality for climate change, China and India were not considered in terms of country level trends, although their demand profile will be captured in the global indicators The limitation on country analysis provided here implies that for certain companies these scenarios will only be of limited use, given that they may have exposures to other countries. Further analysis across a broader set of countries is planned for 2018.

Time horizon choice. The scenarios developed here cover trends until 2040. The time horizon selection considered current practices in financial risks analysis and the need to capture risks materializing in the medium-to-long-term moving forward (2dii 2017a). A survey run by the authors to the investment community showed that 10 out of 13 participants think that the temporal resolution needed for transition scenarios should be either 5 or 10 years (see Fig. 2.4).

Part II provides the detailed scenario parameters derived based on the choices described above and the specific modelling choices by type of indicator further detailed on the next page. Page 5 provides specific details as to the indicators presented in Part II and where they can be found in the report.

FIGURE 2.3 SURVEY EXTRACT: GRANULARITY LEVEL REQUIRED IN RISK ASSESSMENT (SOURCE: AUTHORS)

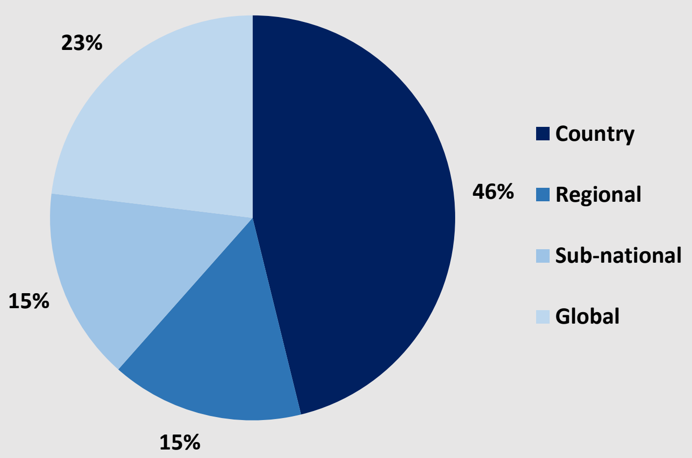


FIGURE 2.4 SURVEY EXTRACT: TEMPORAL RESOLUTION REQUIRED IN TRANSITION SCENARIOS (SOURCE: AUTHORS)

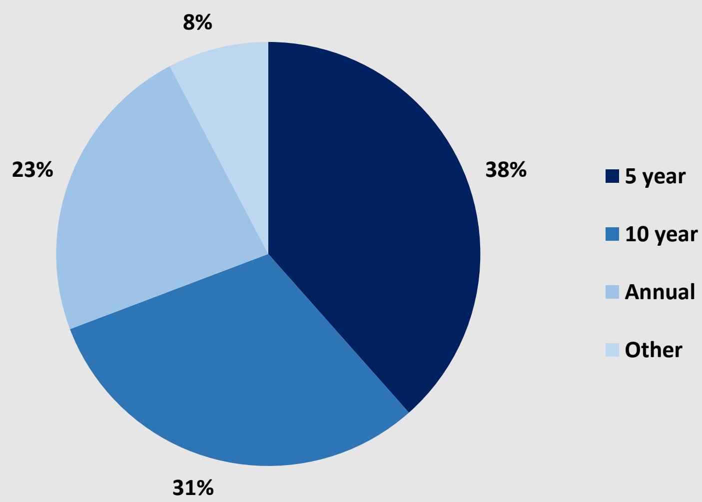


TABLE 2.1. MODELLING PRINCIPLES OF THE TRANSITION SCENARIOS

<table>
<tr><th>Risk factor</th><th>Limited Climate Transition Scenario (LCT)</th><th>Ambitious Climate Transition Scenario (ACT)</th></tr>
<tr><td>Production & technology</td><td>Relies in the first instance on IEA Energy Technology Perspectives (ETP) 4D Scenario for parameters across all industries, where available, as well as the IEA WEO NPS scenario where required.
Additional parameters are sourced from third-party literature on an ad-hoc basis.
Where IEA figures are not provided at country level, country estimates are reconstructed using estimates from third-party sources and internal modelling.
NB: Since the LCT doesn’t explicitly solve for a specific temperature limit of global warming, a range of decarbonisation scenarios (e.g. Greenpeace) can be used without prejudice to the other assumptions, assuming policy targets goals are integrated. Any user can thus replace the IEA with an alternative reference model if desired, assuming it also solves for an limited climate outcome (e.g. 3°C to 4°C)</td><td>Relies on the IEA ETP 2D scenario for parameters across all industries, where available, as well as the IEA WEO 450 scenarios where required.
Additional parameters are sourced from third-party literature on an ad-hoc basis based.
Country estimates are reconstructed using country level estimates from third-party sources, where figures are not provided with the necessary granularity.
NB: The ACT Scenario can use a range of decarbonisation scenarios without prejudice to the other assumptions. Any user can thus replace the IEA with an alternative reference model if desired, assuming it also solves for an ambitious climate outcome (e.g. 2°C or less)</td></tr>
<tr><td>Market prices</td><td>Uses conservative assumptions around technology development curves that can be identified in industry and / or academic literature. These can either be directly sourced from third-party cost curves or modelled after historical examples of cost curves (e.g. fall in the cost of solar PV 2010-2015).
Commodity price assumptions are largely taken from IEA as well as country-specific energy prices where available.
‘Alternative’ assumptions may be provided based on third party literature.</td><td>Uses the most optimistic assumptions around technology development curves that can be identified in industry and / or academic literature.
Commodity price assumptions are largely taken from the IEA, although ‘alternative’ assumptions may be provided based on third-party literature.
For commodity price curves not directly provided in the IEA published material, third party literature is applied.</td></tr>
<tr><td>Policy mandates, incentives & taxes</td><td>Concrete policies and measures are derived for each sector individually based on IEA’s indications (e.g. subsidies in accordance with climate targets, National Determined Contribution targets integration into the model), where available, and complemented with expert interviews and third-party literature.
It is assumed that policy makers will continue with “carrots and sticks” and will only use command and control measures when targets are not reached. In this way, market intervention is limited while still complying with country-specific climate targets.</td><td>The scenario generally does not differ from the policy mandates elaborated in the LCT. However, in some cases, it provides an additional assumption around policy convergence to the most ambitious policy mandates. The exception to this approach involves carbon prices, which are significantly more ambitious.
In terms of incentives and taxes, the scenario will be limited to modelling those policy incentives and taxes that accrue directly to the companies, for which risks are modelled, assuming that the impact of all ‘consumer demand’ incentives (e.g. subsidies on electric vehicle purchases, etc.) are captured in the production & technology parameters.</td></tr>
<tr><td>Unconventional risks</td><td colspan="2">Limited to a qualitative approach, with no quantitative elements. As outlined above, this will cover other macroeconomic trends and other types of risk (e.g. litigation). A separate paper has been developed in partnership with the law firm Minter-Ellison on litigation risks in financial markets.</td></tr>
</table>

2.3 INDICATORS OUT OF SCOPE

In defining transition risk-related indicators for scenario analysis it is critical to distinguish indicators related to the transition to a low-carbon economy more generally, and those that specifically help to inform assessments around financial risk. Relevance of one indicator over another may change depending on the scenarios use case (see following section) (e.g. financial and company risks analysis, ESG analysis etc.), as well as the level of granularity in the analysis (e.g. top-down vs bottom-up). In general, indicators in which one or more of the following factors are applicable were not considered (see Table 2.3 for practical examples):

Indicators that only inform on climate change. As highlighted before, traditional decarbonisation scenarios are generally tools used to provide policy guidance, and as such most of the indicators provided tend to inform more on the effects of climate change. From a risk perspective, the key question is how these indicators impact companies' value drivers, which requires in some cases to change the way they are presented (e.g. cars on the road vs. sales by powertrain). Some of these indicators in turn simply will never create financial risk for companies because of their macro nature that doesn't directly inform on the bottom line. These will frequently be GHG emissions indicators, whose materiality for companies only arises indirectly (e.g. through its impact on policy).

GHG intensity and efficiency indicators in which no policy constraint is foreseen. It could happen that an indicator with no relation to company value drivers can become material due to the enforcement of future policy or standards. When these cases are not observed, the indicator is disregarded due to the lack of exposure to policy risks. For example, sectoral averages of GHG intensity are interesting from a climate change perspective, but when they are not 'enforced', they do not create financial risk by themselves.

Lack of clarity on the specificities around the indicator's impact in policy targets. To achieve policy targets, countries might set "sub-targets" on instruments/measures to promote the achievement of policy targets. Quantification of the sub-targets impact is generally difficult due to lack of disclosure around the implications in the overall policy. The indicators included in the scenarios developed here are thus focused on the overarching policy targets.

Indicators are already embedded in more material ones. Sector trends can be captured in multiple indicators. When this is the case, the challenge is then to assess the indicators on three factors: i.) the ability to communicate on the trend; ii.) the materiality for risk analysis; and iii.) the ease with which the indicator can be integrated to risk analysis.

TABLE 2.3 OVERVIEW OF INDICATORS OUT OF SCOPE (SOURCE: AUTHORS)

Sector	Indicator	Factors			
		Climate change indicator	No Policy risks	Uncertain policy impact	Embedded in another indicator
Power utilities	CO_2 emissions/ CO_2 Intensity (g/kWh)	x	x		
	Energy efficiency certificates			x	
Automotive	CO_2 emissions/CO_2 Intensity (kg/tkm)	x	x		
Aviation	CO_2 emissions/CO_2 Intensity (kg/pkm)	x	x		
Steel	Electricity intensity (kWh/t crude steel)				x
	Share of low carbon steel producing incl. CCS (% of total production)				x
Cement	Electricity intensity (kWh/t cement)				x
	Share of new low carbon cement (% of total production)				x

3 USE CASES

3.1 OVERVIEW

This section explores the potential application of the risk scenarios developed in this report for different users. The scenarios developed here are in our view potentially of particular use for two types of applications:

- 2°C scenario and transition risk analysis by companies as part of their internal risk management and reporting obligations (e.g. related to FSB TCFD recommendations);
- Equity and credit risk research by buy-side and sell-side sector analysts in terms of implications of the transition for the price of and risk to financial securities;

In addition to these two core use cases, they may also find use in more top-down portfolio analysis tools and by financial supervisory authorities as part of their regulatory activities. This section will provide three case studies on use case at company and security analysis and briefly discuss other potential uses.

CASE STUDY 1: COMPANY-LEVEL CLIMATE RISK MODELLING BY THE CO-FIRM

"Our ClimateXcellence model (see Page 18) integrates the risk drivers (i.e. cross-sector and sector-specific) presented herein in the modelling in various ways. In the utilities sector, cross-sector risk drivers include commodity and carbon prices (e.g. natural gas price) which serves a modelling input parameter for electricity generation costs of individual power plants. Sector-specific risk drivers comprise production and technology indicators such as electricity generation and electricity capacity which serve as target indicator for forecasting the structure of electricity markets.

We carry out climate risk modelling in five subsequent tasks:

1. Identification of consistent risk drivers describing transition risk scenarios. The identified risk drivers are a subset of the input parameters (see Point 2) that are required to model the sector.

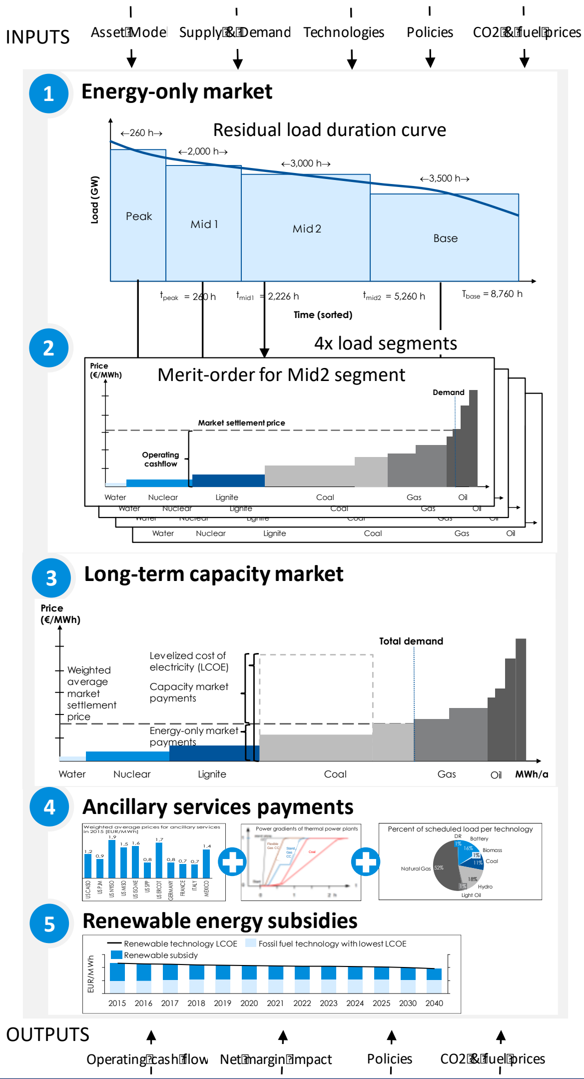
2. Integration of a comprehensive set of regulatory, market and technology parameters in line with risk drivers. Detailed data on these parameters is derived on a risk driver's basis e.g. the price for lignite and coke is based on cross-sector risk drivers such as coal price. Information is needed as well on the outlook of the energy-only, long-term and short-term capacity markets today and until 2050 within the countries in focus.

3. Techno-economic assessment of risk mitigation measures. Here parameters for risk mitigation measures like increased wind power capacities are assessed from a technological (e.g. power, efficiency) and economical perspective (e. g. capital expenditure).

4. Build-up of an asset-level database. The asset-level database contains detailed information on technology type, location, owner structure, year of commission, capacity, efficiency and CO_2 intensity at individual asset-level.

5. Modelling. The functional relation of market dynamics and climate-related impacts on capital expenditure, operating cash flow and net margin is modelled. Sensitivity analysis is conducted to test the robustness of model. For electric utilities, we take into account operating cash flow from four different sources, selling electricity on energy-only market, selling capacity as an ancillary service and to long-term capacity markets and renewable energy subsidies."

FIGURE 3.1 MODEL DIAGRAM



CASE STUDY 2: THE OPPORTUNITY COST OF E-MOBILITY BY KEPLER CHEUVREUX

"Our Head of Thematic Auto Michael Raab investigated what the shift to e-mobility meant for suppliers and Original Equipment Manufacturers (OEMs). By forcing the auto sector into a phase of double spending, he believes that the long-term move to e-mobility raises fixed costs as well as operational gearing, and therefore uncertainty and earnings risk for the auto sector.

He looked at OEMs' cost of opportunity represented by the expected spending on e-mobility for the coming years and how much of the present value of OEMs' shares this removes relative to a scenario in which there is no structural shift to e-mobility. He finds that his target prices for OEMs could on average be 8% higher if he did not have to account for spending for the rollout of e-mobility.

For suppliers he looked at the value at risk of the sales related to the combustion powertrain which needs to be offset by new products for e-mobility to avoid value destruction. He finds that on average 14% of the value per share of suppliers is at risk by the change to e-mobility."

FIGURE 3.2 OEM's TP UPGRADE WIPED OUT BY E-MOBILITY INVESTMENTS

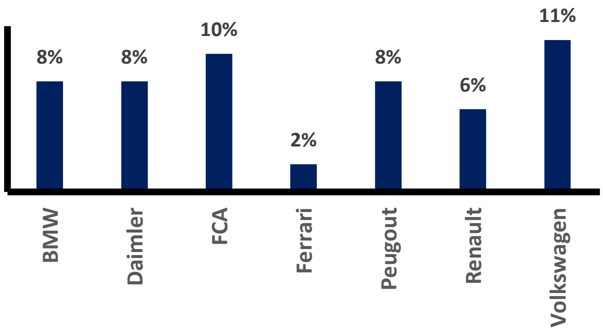
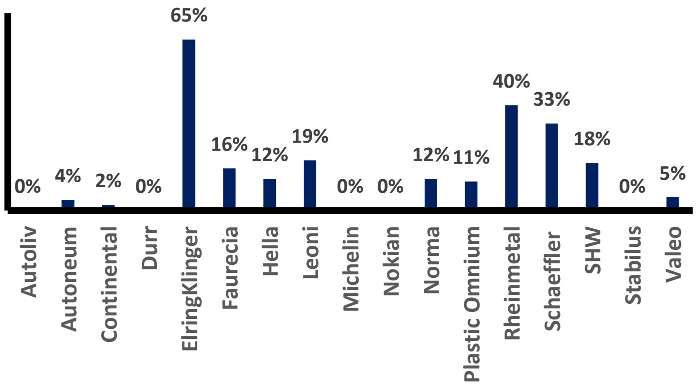


FIGURE 3.3 SUPPLIERS' VALUE AT RISK AS A PERCENTAGE OF TARGET PRICE



CASE STUDY 3: COMPANY-LEVEL CLIMATE RISK MODELLING BY KEPLER CHEUVREUX

"Our Head of Banks Jacques-Henri Gaulard tested in January 2016 the potential impact of the energy transition on French Banks energy financing policy; using the following scenario:

What would it mean financially if French banks had to give up all their fossil fuel financing (including oil) over a 20-year period and substitute oil & gas financing with renewable energies?

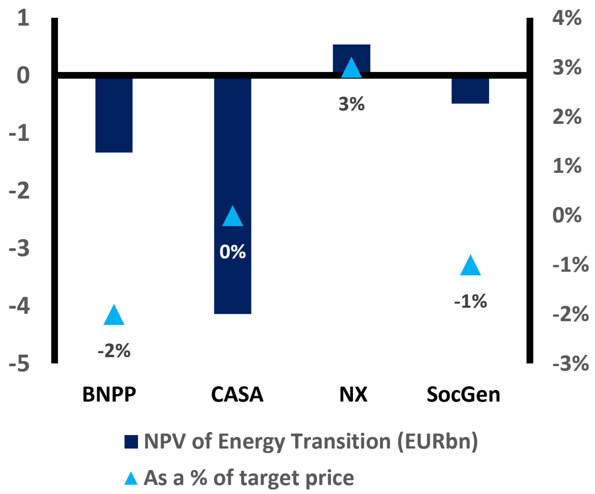
To do so, he looked at the various analyses of the Banks' fossil fuel commitments by groups such as Rainforest Action Network, BankTrack and Profundo and focus on the gross fossil fuel exposures given by the different reports.

The negative Net Present Value (NPV) of the energy transition ranks between -EUR0.5bn for SocGen and -EUR4.1bn for CASA, but we expect the latter to become a global leader with a long-term ROE of 14% and profits in energy finance potentially reaching EUR2.5-3.0bn beyond the usual horizon.

In a nutshell, the NPV impact as a percentage of share price hovers between a manageable -2% for BNP and +3% for Natixis. He concluded that French banks announcements in the running up to the COP 21 had thus more to do with a reputational damage limitation exercise than avoiding losses.

Further analysis could involve testing the sensitivity of each bank being analysed according to various factors, including their commitment to fossil fuels & renewables, but also the cost of risk and margins for O&G, coal and renewables."

FIGURE 3.4 IMPACT OF ENERGY TRANSITION ON ENERGY FINANCING POLICY



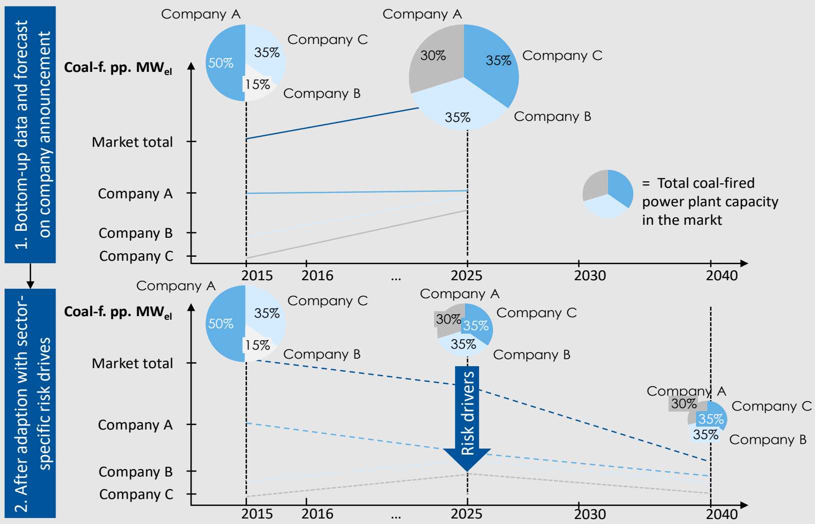
FOCUS: CLIMATEXCELLENCE MODEL

ClimateXcellence extends the work of Allianz Global Investors, Allianz Climate Solutions, WWF Germany for Investment Leader's Group (ILG). ClimateXcellence enables company-level, financial climate risk modelling, supporting companies and financial institutions in voluntary reporting. Based on a set of scenarios, it links climate transition risks with companies' production and product portfolios to derive sector- and market-specific impacts on key financial performance. Performance figures include capital expenditure, operating cash flows and margins; transition risks include regulatory, technological, market-based, reputation and litigation risks. The analysis is performed before and after companies have had the chance to adapt to climate and energy pathways. The risk assessment builds on an in-depth analysis of individual assets per company and country, which allows to capture the complexity and inhomogeneity of production processes while considering the individual adaptive capacity of assets and companies and its mitigation potential on the initial climate-related risk.

The forecasting consists of two steps: i.) use of bottom-up data and company announcements; and ii.) Integration of sector-risk drivers and company's adaptive capacity.

An application of the model for an electric utilities company requires: First, to derive the capacity and owner structure of each generation capacity (e.g. subcritical coal-fired power plants) for the start year and forecasted according to company's announcements, e.g. company B and C announce each to increase coal-fired power plant capacity until 2025 (see Fig. 3.5). Thus, the total coal-fired generation capacity increases until 2025. Second, if sector-specific risk drivers dictate a lower total coal-fired generation capacity in 2025 in order to be in line with an ACT or LCT scenario, the coal-fired generation capacity equally decreases among market participants meaning company A is mothballing some of its capacity while company B and C might not pull through their announced capacity increase.

FIGURE 3.5 ILLUSTRATIVE EXAMPLE OF THE FORECASTING PRINCIPLES OF THE CLIMATEXCELLENCE MODEL



3.2 ALTERNATIVE USE CASES

In addition to these use cases and case studies highlighted above, transition risk scenarios with enough granularity can also create opportunities for portfolio managers and financial supervisory authorities / policymakers:

- **Portfolio analytics**. In terms of portfolio analysis, while line-by-line security level analysis may not be in scope in terms of portfolio analytics and asset allocation consulting by investment consultants, the scenarios can nevertheless help to inform these models, in particular with regard to their analysis around the implications of different sector exposures (although here questions of consistency may get more pronounced). Mercer took this approach as part of their TRIPS model which also applies more granular sector level scenarios. Transition scenarios can also enrich some of the portfolio tools developed in the *Sustainable Energy Investing Metrics (SEIM)* project, which currently focuses on 2°C alignment using IEA production forecasts and asset-level data for individual securities and specific sector benchmarks. Thus, a limited top-down see-through that also incorporates some security level information can be linked to both an alignment logic and a financial risk logic. This second step however requires scenarios of the kind developed in this report.

- **Financial supervisory authorities.** From a financial supervisory authority perspective, transition risk scenarios can be used in internal risk monitoring tools. Some central banks for example have started running internal analysis on the transition risks associated with the portfolios of their regulated entities, using 2°C scenario analysis. Such analysis can be enriched with more sophisticated scenarios of the kind developed in this report. In addition to internal analysis, such scenarios could also eventually inform public guidance on stress-testing scenarios for companies and / or financial institutions, as well as guidance on reporting frameworks.

4 CONCLUSION

This report marks one of the first comprehensive attempts to develop transition risk scenarios for 8 energy-intensive sectors as well as fossil fuels and provides practical examples on how the scenarios are currently being used in equity valuation models and for company-level risk modelling. It is noteworthy to highlight the potential challenges and barriers to the use of these scenarios. This is particularly relevant in the context of the reporting ambition under the FSB TCFD recommendations. These challenges can be summarized as follows:

- **Consistency**. The more consistent the data becomes from various sources the more consistent the analysis itself will become. At this stage, risk scenarios still have to rely on a range of different sources that aren't necessarily coordinated or fully aligned in a single model, even if they all seek to reflect an ambitious decarbonisation pathway. Hence the sector level emphasis.

- **Missing indicators.** While attempting to be as comprehensive as possible and drawing on a wide range of sources, certain critical indicators for risk analysis in some sectors are still lacking or are not sufficiently developed in terms of geographic granularity (e.g. sales by powertrain in the auto sector).

- **Continuity of sources.** The scenarios developed relied on a total of over 15 sources across eight sectors. While only the most reliable and technically sound analysis was accepted for inclusion in these scenarios, not all data inputs are related to publications with annual updates. Some of the indicators relied on what may be 'one-off' reports. While it seems reasonable to assume that analysis will continue to be developed on these indicators, it is unclear whether these specific reports will be re-issued, which may create complications around replicating the indicators in the future (as a result of the need to identify alternative sources and potentially discontinued analysis) or reliance on more outdated indicators.

- **Ease of access.** The analysis presented here is provided as a report and associated spreadsheet with the parameter information (go here to access the spreadsheet). Such analysis can be easily used by analysts and further users. More generally speaking however, actors interested in 'picking & choosing' their indicators, relying on alternative scenarios to the IEA as starting points (e.g. Greenpeace, IPCC, etc.) will struggle to easily put indicators together. In this spirit, the FSB TCFD has recommended a scenario depository. Further investment is likely required in the future in improving the ease of access to scenarios – both in terms of the access to the indicators themselves and the ability to manipulate them to align the parameters with the beliefs (e.g. around carbon capture and storage, nuclear, etc.) and the objective of the exercise (e.g. stress-testing, 2°C scenario analysis, etc.) being conducted by the user.

- **Coverage and costs.** The scenarios presented here, while providing global, regional, and country level indicators, did not develop comprehensive indicators for each region/country in the world. While the choice of countries and the addition of global indicators is expected to cover the majority of operations for a developed markets portfolio or at least a significant share across all key transition sectors developed here, it is not universal in terms of granular analysis for all countries and regions. Such universality would have been significantly more cost-intensive and challenging, given the relative lack of scenarios and indicators outside developed markets and large emerging market economies (e.g. China, Brazil). Actors interested in such further scenarios will thus rely either on more macro, global indicators, or develop alternative scenarios with associated additional costs.

PART II

SECTOR SCENARIOS' VALUES FOR RISK ANALYSIS

1 CROSS-SECTOR INDICATORS

GENERAL OVERVIEW

Cross sector risk drivers (see table below) have an impact on all the sectors in scope of the Energy Transition risk project. Two types of cross-sector risk drivers are considered, notably commodity prices and carbon prices / incentives. In addition, the box on the next page also reviews indicators around commodity production although these elements would be integrated into the downstream energy and commodity use assumptions and act as risk drivers for the commodity producers (e.g. oil & gas, coal companies).

The market price of a commodity is generally speaking a function of supply and demand. This function can be influenced in several ways:

- If a sector deals with commodities that are limited such as fossil fuels, the whole supply chain can face an irregular supply and high price fluctuations are resulting.
- Sourcing or generation costs can change (e.g. due to changes in regulations).
- For commodities traded via an exchange, there can be exchange price fluctuations that are caused by expectations about the future price developments of the market participants.
- Energy prices are influenced by a variety of other factors such as GDP, or population growth or the availability of substitutes (e. g. use of natural gas instead of oil). The scenarios presented here are based on IEA scenarios, thus the prices described in this report are dependent on the supply and demand assumptions set by IEA ETP.

The scenario involves the following parameters:

MARKET PRICING	
Crude oil prices (USD / bbl) Natural gas prices (USD /Mbtu)	Coal price (USD / ton) Electricity prices (EUR / MWh)
POLICY MANDATES, INCENTIVES & TAXES	
Carbon prices (EUR / MWh)	

1.1 CRUDE OIL PRICES

Overview. Oil prices are one of the most important influencers of the global economy, important enough to be included in the adverse growth scenarios of bank stress-tests (for example the ESRB 2016 stress-test). In the transport sector, for instance, the price of oil, along with taxes, is the core driver of fuel costs, directly affecting production and consumer decision-making variables (e.g. fuel efficiency considerations). For aviation and marine shipping, oil prices will influence production decisions and processes for products that use oil derivatives (e.g. chemicals, etc.). One key challenge around oil price estimates relates to forecasting both short-term and long-term prices, given the prominence of non-'market' drivers in setting the price (e.g. output quotes among OPEC members), as well as the relatively new unconventional oil markets that still exhibit significant volatility in terms of costs.

Risk pass-through mechanism. Changes in oil prices can generate risks to companies in terms of rising input prices in some sectors (e.g. power, agriculture, etc.), as well as potential changes in consumer preferences as companies seek to pass on these costs or consumers directly face these costs (e.g. automobile).

Sources. Long-run prices for oil are generally modelled as a function of the projected global energy demand vs. supply. Given their prominence, they form a core part of most standard integrated assessment and energy technology scenario models (e.g. IEA 2D Scenario, IEA 450 scenario). Alternative modelling approaches exist, adding assumptions around e.g. geopolitical events (Lee & Huh, 2017).

Method. Oil prices are taken from IEA Energy Technology Perspectives. The ACT scenario is built upon the 2DS scenario, likewise the LCT scenario is built upon the 4DS. The ETP scenario is preferred over the WEO scenario to keep consistency around underlying assumptions of other sector-specific risk drivers (e.g. power, aviation). Analysts assessing the impact of other drivers in the oil price (e.g. imbalances between supply and demand) need to consult the production and supply estimates (of ETP).

Results. The ACT scenario projects lower oil prices compared to the LCT scenario as it considers that lower demand for the fuel will make the production from more costly fields higher up the supply curve less likely. After the last fall in oil prices – with a historic low in 2016 — the projections show a price increase by 2020. The 2014 price level will be reached by 2030 in the ACT scenario and 2025 in the LCT scenario. The ACT will maintain a similar trend in prices up to 2040, while the LCT scenario expects a 24% increase with respect to 2014 prices.

TABLE 1.1 BRENT OIL PRICE (USD/BBL) UNDER THE ACT AND LCT SCENARIOS (SOURCE: AUTHORS, BASED ON IEA ETP 2016)

Year	ACT	LCT
2014	97	97
2020	77	80
2025	87	97
2030	97	113
2035	96	121
2040	95	128

1.2. NATURAL GAS PRICES

Overview. Natural gas plays an important role in decarbonisation scenarios, by being the "cleanest fossil fuel" when it comes to CO_2 emissions. Prices for natural gas are directly affected by demand, which as described in the previous section, will have a higher uptake. Indirectly, gas prices are often affected through the underlying link to oil prices present in long-term gas supply contracts. This oil price link is expected to become weaker as the price indexation business model is gradually being phased out in international markets. Similarly, many 'non-market' drivers, as in oil, make the forecasting of gas prices challenging.

Risk pass-through mechanism. The rise in gas prices will have an impact across sectors, for example through its impact on input prices in the most energy intensive sectors (e.g. power generation, chemicals and petrochemicals industry). However, for other sectors in which the penetration of natural gas is expected as an alternative fuel source (e.g. transportation) the exposure could be limited due to the effect of other market prices mechanisms (e.g. carbon taxes, carbon offsets).

Sources. Generally, gas prices models assume a correlation with the price of oil, due to the historical similarity in price behaviour. Factors that impact crude oil have – in most cases – impacted natural gas, as their production and explorations mechanisms are similar (IEA 2016b). Other models consider assumptions around domestic resource and technology exploration, moving away from the correlation with oil (EIA 2017).

Method. Natural gas prices for the US and Europe are taken from IEA ETP estimates. The ACT Scenario was built upon the 2DS scenario, likewise the LCT Scenario on the 4DS. As in the case of oil prices, this scenario is preferred to keep consistency with other projections.

Results. The ACT scenario projects a price recovery after the last fall in gas prices. In the EU market, the ACT scenario will match 2014 prices by 2030 and the LCT by 2025. The downward pressure for lower prices pushed by a decreasing demand will revert the trend, reaching a price of $ 8.9/MBtu by 2040. The ACT scenario will have a decrease of 4% respect to 2014 levels and the LCT scenario a rise of 33% by 2040. The US gas prices differ to that of the EU, as its production is domestic. The LCT Natural gas prices have an increasing trend through 2040.

TABLE 1.2 NATURAL GAS PRICE (USD/MBTU) FOR BOTH SCENARIOS (SOURCE: AUTHORS, BASED ON IEA 2016A)

Year	European Market		US Market	
	ACT	LCT	ACT	LCT
2014	9.3	9.3	4.4	4.4
2020	7.5	7.8	4.5	4.7
2025	8.5	9.5	5.1	5.5
2030	9.4	11.2	5.7	6.2
2035	9.2	11.8	5.8	6.9
2040	8.9	12.4	5.9	7.5

1.3 COAL PRICES

Overview. Coal prices vary in relation to the regional markets (differences are primarily due to transportation cost, infrastructure constraints and coal quality), however, the overall trading price is determined by the international coal market. Global demand for coal, the main driver of price, is expected to decrease under the decarbonisation scenarios, where a switch from high-carbon-intensive coal to other technology sources is expected. Besides market drivers, coal demand will be affected by worsening geological conditions that will decrease coal quality, and policy changes resulting in the decommissioning of coal mines.

Risk pass-through mechanism. Changes in coal prices will have an impact across sectors, resulting in an increase of input prices and thus companies' operational costs. The most exposed sector is power utilities, followed by the cement and iron and steel industry due to the prevalence of coal derived energy in their industrial processes.

Sources. Coal price futures are generally based in forecasts of the different sub-markets, with assumptions in supply-demand, domestic consumption and import-export rates among others. The international price is an average that connects the regional prices. In terms of application however for companies, it is relevant to understand regional pricing models. Models focused on decarbonisation scenarios also integrate current and expected policy changes around coal phase-out (e.g. IEA ETP 2016, IEA WEO 2016).

Method. The coal prices presented here correspond to the OECD average price of the 2DS and 4DS scenarios modelled in IEA's Energy Technology Perspectives. These estimates were preferred to keep consistency across scenarios, as several sectors covered in the report (e.g. power, cement and iron and steel) base some indicator's estimations upon IEA's ETP scenarios. As outlined above, alternative coal prices may be more appropriate for certain companies.

Results. The ACT scenario projects a low variation in the price of coal from the current value of 78 USD/ ton in 2014 to a slightly lower price of 77 USD/ton by 2040. This responds to a context with strong policy support for coal phase-out and low recovery costs of coal plants, thus creating a supply-demand balance that sustains prices (IEA 2016b). The LCT scenario considers a higher global demand for coal, especially coming from India alongside an overall supply drop. This will partially absorb overcapacity driving the coal prices to a rise trend line reaching a value of 108 USD/ton by 2040.

TABLE 1.3 COAL PRICE (USD/TON) FOR BOTH SCENARIOS (SOURCE: AUTHORS, BASED ON IEA 2016A)

Year	Coal Price (USD/ton)	
	ACT	LCT
2014	78	78
2020	80	94
2025	80	98
2030	79	102
2035	78	105
2040	77	108

1.4 ELECTRICTY PRICES

Overview. Electricity prices to end-users are a function of wholesale power generation costs (capital and operation and maintenance costs), transmission, distribution and retail costs, subsidies and taxes, as well as of course mark-ups by retailers. In the transition to a low-carbon economy electricity prices are expected to increase due to additional capital costs associated with the deployment of renewable sources, but these will be partially offset by the reduction of fuels costs (i.e. raw material and taxes) as the share of clean technologies increases.

Risk pass-through mechanism. Electricity prices may act as risk drivers for companies where electricity is a key driver of production costs, and through changes in consumer preferences around electronics and their associated energy efficiency. They also help to contextualize impacts on other risk indicators.

Sources. Electricity prices are not specifically given as parameters in the 2°C scenario of the IEA and others. IEA's WEO 2016 edition publishes the electricity prices for their NPS scenario, these are disclosed however with limited regional country-level granularity, which is seen as a caveat due to the need to provide highly granular country specific price estimates in most cases (with some exceptions for fully or partially integrated electricity markets e.g. Europe).

Method ACT. Estimates for electricity prices rely on two third party sources using electricity price modelling techniques. One critical element to consider is that the prices shown here are average prices and do not capture potential price fluctuations. The starting points for country estimates are taken from IEA 2016 Energy Prices and Taxes. Brazil current estimates are taken from BEN 2016. Prices for Mexico and Brazil were computed using US prices growth rate. France, Germany and Italy prices were computed using EU prices growth rate.

These prices include taxes but do not include renewable energy subsidies in their calculation. The effect of the subsidies in the electricity price increase will mainly depend on the economics of renewable sources. Most sources will not require a subsidy already in 2025 (see Page 34 and 87), thus a significant impact on the electricity price is not foreseen. Based on the LCT method, analyst assuming a price increase should consider on average a <5% increase[2].

Method LCT. In the LCT Scenario starting points are taken from the IEA 2016 Energy Prices and Taxes. Brazil current estimates are taken from BEN 2016. Future prices for European and Latin-American countries are computed using regional growth rates of IEA WEO 2016. These prices include taxes and renewable energy subsidies.

Results. Table 1.4 shows the electricity prices for the ambitious and limited climate transition scenarios. In the ACT scenario, a high penetration of renewable energy is enabled by advanced technological improvements with a lower costs structure allowing for lower electricity prices. In the EU prices are expected to increase, as a result of the retirement of old fossil fuel plants and the replacement with capital-intensive renewable energies.

TABLE 1.4 ELECTRICTY PRICES FOR INDUSTRY UNDER THE ACT AND LCT SCENARIOS (SOURCE: AUTHORS, BASED ON CAPROS ET AL. 2012, TRIEU ET AL. 2013, IEA 2016A, IEA 2016C)

Country	Price reference	2020		2025		2030		2035		2040	
		ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT
Brazil	2015 EUR/MWh	151	162	154	163	157	164	162	168	167	173
France	2015 EUR/MWh	90	105	92	108	94	111	93	111	93	111
Germany	2015 EUR/MWh	111	143	113	147	116	151	115	151	115	151
Italy	2015 EUR/MWh	250	252	255	259	260	266	259	266	258	266
Mexico	2015 EUR/MWh	79	98	81	102	83	106	85	106	88	106
US	2015 EUR/MWh	60	71	61	71	63	72	65	74	67	76

1.5 CARBON PRICES

Overview. Carbon prices and/or taxes are considered a critical policy tool for achieving the transition to a low-carbon economy. At the same time, implementation of carbon price policies is not consistent across all geographies, with differences in application in terms of sector coverage, accounting, pricing mechanism, and geographic reach. Carbon pricing can be considered either in terms of 'social cost of carbon' or a policy intervention to align relative prices (which may or may not reflect social costs).

Risk-pass through mechanism. Depending on the scope of the carbon price regulation, the risks will materialize in different sectors, primarily in the form of changing the relative economics for inputs, production processes and / or end products.

Sources. Carbon prices are a standard element of most if not all transition scenarios, albeit modelled at various degrees of geographic granularity and precision (e.g. either as an 'actual' price or an 'implied' policy price).

Method. Carbon prices for both scenarios are taken from IEA 450 and NPS scenarios. These estimates are line with and were preferred to, the CO_2 marginal abatement costs assumed in IEA ETP 2015 due to higher granularity. In the case of Mexico, it was assumed an increase in the current carbon price (3.5 $2015 / t-COeq) in line with the US increase for both scenarios. Values for 2025 and 2035 were interpolated. The LCT scenario assumes that those countries that have already announced their intention to introduce carbon prices or emissions trading systems effectively do so. The ACT scenario assumes that use of carbon price instruments become more widespread affecting all countries under scope.

Results. Carbon prices are expected to increase in both scenarios. Notably, the ACT scenario assumes a higher increase in prices due to more stringent government efforts to strengthen climate policies to spur innovation in low-carbon technologies and enable the phase out of coal.

TABLE 1.5 CARBON PRICE (2015 USD / T-CO_2eq) (SOURCE: AUTHORS, BASED ON IEA 2016b, SEMARNAT 2016)

Year	EU		USA		Brazil		Mexico	
	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT
2020	20	20	20	0	10	0	18	7
2025	60	29	60	15	43	0	53	13
2030	100	37	100	30	75	0	88	18
2035	120	44	120	35	100	0	105	23
2040	140	50	140	40	125	0	123	28

2 POWER UTILITIES

GENERAL OVERVIEW

In 2013, 42% of global CO_2 emissions originated from the power sector. The sector was responsible for 60% of coal and 40% of gas demand (IEA 2015b). From an energy transition perspective, it is by far the most important sector.

The transition risk story for the electric utilities sector articulates itself through a few trends:

- **Consumption is expected to increase globally**. Demand changes will respond mainly to efficiency measures, and macroeconomic and demographic factors. These factors imply that dynamics in developed and developing economies will be different, with the demand in the latter increasing at a higher pace in some countries.

- **Fuel switch.** The shift from fossil fuels to renewable energy-based power is going to be driven by three main forces: The increase of thermal coal, gas and CO_2 prices, the support from policymakers for the development of new low-carbon technologies and the decreasing marginal costs of renewable power production. Under both the LCT and the ACT scenarios, the total share of fossil fuels will decrease. Under the ACT the share of renewables need to surpass that of fossil fuels to achieve the 2°C target.

- **Policy- and market induced technology change.** Incentives from policymakers will enable the transition from a fossil fuel-based economy to a renewable-based one. Policy instruments such as subsidies, taxes and levies can be put in place to enable this transition. Most of the countries under scope have already started to incentivize renewables and/or disincentivize fossil fuels-based power generation as part of their strategy to achieve their long-term renewables share targets. In addition to policies, changes in the relative economics of renewable technologies versus fossil fuels are similarly expected to drive fuel switching.

The scenario involves the following parameters:

PRODUCTION & TECHNOLOGY
Electricity production (TWh) Electricity capacity (GW)
MARKET PRICING
Levelised costs of electricity (EUR/Mwh)
POLICY MANDATES, INCENTIVES & TAXES
Subsidies (EUR/Mwh) Effective carbon rates (EUR/tCO_2)

5 THINGS BEFORE GETTING STARTED

1. **Latent Forces.** Two major forces are going to shape developments in the power sector: End-users and governments:

    - Changes in preferences, purchasing power and sensitivity to higher electricity prices (which may vary) will all be factors in any reduction in the sector's overall demand and thus the production levels required to meet the demand. Moreover, consumer preferences may also extend to fuel sources of electricity generation, driving a shift to renewables.
    - Governments will be responsible for setting the policy framework associated with decarbonisation pathways and targets (2°C or otherwise).

    Each of these forces will both reinforce and be influenced by technology drivers.

2. **Fossil Fuel Prices vs. Technology Costs.** The link between fossil fuel prices and technology learning rates will determine the economic case of shifting towards renewable sources. In particular, the forecasted increase in the fuel prices during the next 10 years (see Section 1.2) is likely to accelerate the deployment of renewable technologies.

3. **Impact of Consumers Awareness.** In some geographies, consumers' awareness of the use of renewable sources may increase renewables uptake. This development has mostly been observed in developed countries with an active program for the energy transition, such as Germany. Simultaneously, higher consumer awareness has a positive effect on renewable energy electricity producers as it affects their reputational risks.

4. **Effect of Infrastructure and Storage Investments.** The ability for the electricity system to absorb a higher share of variable generation capacity is conditional upon the future infrastructure and storage needs. The IEA estimates in its 450 scenario that total infrastructure investments in the sector will add up to $7.2 trillion. Spending towards the enhancement of distribution and transmission grids represent around 85% of the total investment needed, while only 15% is estimated to be needed for the integration of variable renewable energy sources into the grid. Investments necessary to increase today's storage capacity by 150% will be required by 2050 to meet a 2°C scenario (IEA 2016b). The effect of these costs on the sector's supply and demand is still an open question.

5. **Costs Granularity.** Fuel costs and capital costs can be highly variable for individual utilities. They are driven both by specific contract structures around fuel purchases in the case of natural gas for example, as well as different capital costs depending on geography, financing requirements, etc. By extension, the cost figures quoted in the scenarios presented here represent only high-level 'averages' for sector analysts interested in taking a generalized view.

2.1 ELECTRICITY GENERATION

Overview. Electricity generation in the context of the transition to a low carbon economy relates to the power needed to meet demand while aligning with the energy mix required to achieve country targets on emissions reduction. Electricity supply is generally determined by the market structure (e.g. regulated vs competition) and the availability of resources. Under the scenarios in scope, additional factors will come into play. Electricity supply will change:

- In magnitude, driven by energy efficiency gains and purchasing power increase of end-users, set to follow significantly different trajectories in developing and developed markets.
- In its energy mix, driven by the evolution of renewable technology prices and the policy framework supporting market dynamics, as well as the infrastructure necessary to meet demand needs.

Risk pass-through mechanism. The total electricity generated will affect, ceteris paribus, company expected revenues. The degree of exposure to transition risk depends on the relationship between changes in demand and the energy mix. In particular, companies with operations in countries set to experience a decrease in aggregate demand rates may face lower revenues due to overcapacity. This effect could be amplified if the company is dependent on fossil-fuel based generation due to carbon pricing mechanisms and price incentives for renewable production.

Sources. Electricity generation is an indicator that is widely covered in the literature and one of the core pieces of transition scenarios, given the prominence of the electricity sector more generally. Thus, several scenarios at a global, regional and country scale (e.g. ETP, CTI 2017, EIA 2017) exist, associated with different levels of climate ambition. As an example, the Carbon Tracker Initiative (CTI 2017) in partnership with Imperial College developed 12 scenarios, relating to solar PV and electric vehicles, considering different levels of demand, technology and policy ambition, thus reaching different climate targets (2.3°C to 4.1°C). Under its most ambitious scenario, 51% of the total power generated could come from renewable energy sources by 2050, of which 29% is set to come from solar PV.

Method. The IEA Energy Technology Perspective scenario provides the basis for the ambitious and limited climate transition scenario. This scenario is preferred due to its geographic and technology differentiation granularity. To compute country estimates for France, Italy and Germany, the technology weights of the 2016 EU Reference Scenario are taken as base. It is assumed that these weights are equivalent under both, the ACT and LCT scenarios, across all periods. The 2DS and 4DS growth rates of the EU technology mix are applied to these weights for each country and year. This process leads to the inclusion of current and announced country renewable share targets. For the US, Mexico and Brazil scenarios, generation is taken as well from IEA's 2DS and 4DS scenarios. These were compared to current national policy targets in order to ensure consistency.

When considering these models, a number of potential shortcomings can be identified that may influence users preference in using this or another reference scenario. The 2DS assumes that significant deployment of CCS technologies is necessary to stay in the carbon budget associated with the scenario, together with a high share of nuclear energy sources. While, these projections are overall consistent with the results of other scenarios (e.g. Enerdata 2017, ETC 2017), it raises questions around the economic and social viability limitations underlying the scenarios' assumptions.

Results. Table 2.1 on the next page presents the growth in total electricity generation respect to 2013 levels by country and Table 2.2 the global breakdown by type of source (for results by country please refer to Annex 1). In the ACT scenario, the lower supply is explained by a reduction in demand from the industrial sector and households due to efficiency gains in end-user devices and electric motor systems. The ACT and LCT scenarios foresee lower electricity generation compared to BAU scenarios. Generation steadily increases, with developing economies showing a higher annual increase. The share of renewable energy is expected to be higher under a 2°C scenario. Differences in renewables share (excluding nuclear) of developing and developed countries in scope are not that significant, with Brazil having the highest expected share (84%) and Mexico (54%) outpacing that of the US (47%) and France (42%) by 2040.

TABLE 2.1 GROWTH IN TOTAL ELECTRICITY GENERATION (TWh) UNDER THE ACT AND LCT SCENARIO BY COUNTRY (SOURCE: AUTHORS, BASED ON IEA 2016A, EC 2016, WORLD BANK)

Country	2015	2020		2025		2030		2035		2040	
		ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT
World	24 421	10%	13%	20%	26%	30%	41%	40%	55%	49%	67%
Brazil	600	12%	13%	22%	29%	36%	45%	54%	67%	67%	82%
France	563	10%	6%	15%	7%	18%	8%	21%	7%	22%	8%
Germany	599	4%	0%	0%	1%	-14%	2%	-27%	2%	-23%	3%
Italy	291	0%	9%	-3%	8%	-3%	11%	-7%	21%	-12%	30%
Mexico	319	17%	18%	36%	43%	55%	64%	75%	91%	96%	116%
USA	4 319	-1%	5%	-2%	7%	-3%	9%	-3%	10%	-3%	12%

TABLE 2.2 GROWTH IN TOTAL GLOBAL ELECTRICITY GENERATION (TWh AND GROWTH RESPECT TO 2015) UNDER ACT AND LCT SCENARIOS BY TECHNOLOGY (SOURCE: AUTHORS, BASED ON IEA 2016A, EC 2016)

Country	2015	2020		2025		2030		2035		2040	
		ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT
Total	24 421	10%	13%	20%	26%	30%	41%	40%	55%	49%	67%
Oil	971	-22%	-13%	-40%	-25%	-54%	-35%	-64%	-38%	-74%	-47%
Coal	9 853	3%	9%	-10%	14%	-29%	19%	-49%	25%	-62%	27%
% Coal w/ CCS	*0%*	*0%*	*0%*	*2%*	*0%*	*10%*	*1%*	*28%*	*2%*	*64%*	*3%*
Natural gas	5 158	0%	8%	6%	23%	15%	42%	20%	58%	11%	66%
% Natural Gas w/ CCS	*0%*	*0%*	*0%*	*1%*	*0%*	*5%*	*1%*	*10%*	*1%*	*18%*	*1%*
Nuclear	2 655	17%	16%	48%	34%	82%	48%	108%	57%	132%	72%
Biomass and waste	574	62%	36%	113%	74%	180%	114%	274%	157%	349%	203%
% Biomass w/ CCS	*0%*	*0%*	*0%*	*0%*	*0%*	*1%*	*0%*	*1%*	*0%*	*2%*	*0%*
Hydro*	3 981	12%	12%	29%	23%	43%	33%	57%	43%	70%	52%
Geothermal	83	36%	35%	180%	111%	314%	195%	469%	293%	664%	415%
Wind onshore	843	79%	74%	188%	141%	309%	218%	408%	296%	484%	371%
Wind offshore	225	-53%	507%	-5%	736%	73%	993%	172%	1242%	268%	1479%
Solar PV	190	181%	-47%	409%	-22%	705%	15%	1045%	65%	1609%	115%
CSP	85	-63%	531%	108%	863%	440%	1307%	1016%	1664%	1610%	2077%

*(excl. pumped storage) **Ocean and Other technologies are not included

2.2 ELECTRICITY CAPACITY

Overview. Under the transition, meeting the capacity requirements needed to guarantee the forecasted (and then actual) demand levels and the policy-related energy source needs will require changes in the installed capacity. Changes in the installed capacity relate to capacity retirements of fossil fuel power plants and additions of renewable-based electricity, as well as the potential evolution of nuclear and hydropower.

Risk pass-through mechanism. Capacity changes can affect both cash flows and revenues, as well as the write-down of assets. Investment in new installed capacity has a negative impact on company free cash flows due to increased capital expenditures. On the other hand, investments leading to an increase in the capacity factor (e.g. storage) could have a positive impact in revenues through an associated increase in the electricity generated and sold.

Sources. Several scenarios model the capacity needs of the power sector either at a country-specific (e.g. CCC 2015, négaWatt 2017), regional (e.g. IEA) and / or global level (e.g. Greenpeace). Disaggregated results by type of energy source are generally provided, allowing analysts to integrate projections around capacity factors in their analysis. Even though most scenarios integrate assumptions around the uptake of CCS technologies, few of them disclose the power capacity associated with the technology, making it more difficult to interpret the concrete deployment of CCS in terms of its scale and effect on infrastructure.

Method. The ambitious and limited climate transition scenarios take as a basis the IEA 2DS and 4DS scenarios. Data points for France, Italy and Germany are computed using the electricity generation estimates (see previous section) and converted to capacity units, using the capacity-to-generation conversion factors from the EU region projections of IEA Energy Technology Perspective. A more intuitive approach would be to use electricity demand estimates as a starting point, however, estimates by type of source are not provided in the ETP scenarios.

Results. Table 2.3 presents the growth in total electricity generation respect to 2013 levels by country and Table 2.4 presents the capacity growth at a global scale by type of source (refer to annex 2 for country-specific data). Electricity capacity is expected to increase in both the ACT and LCT scenarios (98% and 86%, respectively) by 2040 due to a higher demand and renewables share. However, to achieve the emissions reduction needed to reach each scenario, different dynamics in regional capacity retirements, additions and shifts are required over time. Mature economies will have a high change of stock requiring the retirement of more plants (both from coal and renewables sources) compared to emerging economies in scope as installed is more recent. Overall, installation of new generation capacity is expected to be higher in emerging economies responding mainly to consumption growth assumptions in the context of higher economic growth and a different stage in renewable plants development.

TABLE 2.3 GROWTH IN ELECTRICITY CAPACITY (GW) UNDER THE ACT AND LCT SCENARIOS BY COUNTRY (SOURCE: AUTHORS, BASED ON IEA 2016A, EC 2016)

Country	2015	2020		2025		2030		2035		2040	
		ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT
World	6 293	20%	20%	33%	30%	50%	44%	62%	57%	82%	72%
Brazil	144	32%	33%	44%	45%	56%	58%	70%	76%	82%	98%
France	120	1%	1%	1%	1%	2%	2%	3%	3%	4%	4%
Germany	193	21%	9%	24%	10%	17%	15%	4%	7%	9%	11%
Italy	126	2%	9%	-4%	2%	-5%	1%	-11%	-4%	-8%	11%
Mexico	75	37%	28%	71%	52%	104%	92%	145%	112%	163%	112%
USA	1 139	3%	4%	8%	2%	13%	5%	10%	7%	17%	11%

TABLE 2.4 GROWTH IN GLOBAL ELECTRICITY CAPACITY (GW) UNDER THE ACT AND LCT SCENARIOS BY TECHNOLOGY* (SOURCE: AUTHORS, BASED ON IEA 2016A, EC 2016)

Country	2015	2020		2025		2030		2035		2040	
		ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT
Total	6 293	20%	20%	33%	30%	50%	44%	62%	57%	82%	72%
Oil	459	6%	10%	-12%	-8%	-29%	-25%	-45%	-40%	-60%	-47%
Coal	1 929	7%	11%	-1%	11%	-7%	13%	-31%	14%	-43%	14%
% Coal w/ CCS	*0%*	*0%*	*0%*	*2%*	*0%*	*6%*	*1%*	*16%*	*2%*	*33%*	*2%*
Natural gas	1 630	17%	17%	19%	26%	17%	39%	18%	53%	22%	67%
% Natural Gas w/ CCS	*0%*	*0%*	*0%*	*1%*	*0%*	*2%*	*0%*	*5%*	*1%*	*8%*	*1%*
Nuclear	416	11%	10%	33%	21%	60%	32%	82%	39%	102%	50%
Biomass and waste	134	55%	38%	87%	62%	129%	80%	193%	99%	260%	128%
% Biomass w/ CCS	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*1%*	*0%*	*2%*	*0%*
Hydro**	1 074	16%	16%	28%	22%	43%	32%	58%	41%	71%	51%
Geothermal	14	39%	35%	144%	89%	253%	156%	387%	237%	562%	334%
Wind onshore	398	72%	56%	168%	109%	275%	167%	361%	223%	428%	275%
Wind offshore	14	127%	119%	326%	203%	633%	323%	1023%	479%	1370%	619%
Solar PV	219	94%	94%	231%	184%	408%	302%	598%	385%	921%	489%
CSP	6	91%	64%	963%	305%	2327%	682%	4337%	1449%	6576%	2144%

*(excl. pumped storage)
** Values in GW
***Ocean and Other technologies are not shown

2.3 LEVELISED COSTS OF ELECTRICITY

Overview. Levelised Cost Of Electricity (LCOE) is the key economic indicator for determining the economic viability or competitiveness of different technologies. It allows comparison of the opportunity costs associated with investments in one technology or another. Differences between LCOE of renewables and fossil fuel-based technologies will depend mainly on three factors: i.) declining capital costs (e.g. capital expenditures), ii.) changes in the relative economics of fuel costs; and iii.) increasing/decreasing capacity factors.

Risk pass-through mechanisms. The relevance of integrating country/region estimates of LCOEs for risk analysis highly depends on the type of model used. Top-down models can integrate the parameter as part of their macro analysis, while bottom-up models may use it as a benchmark to map the competitive environment in which the analysed companies operate. Whether bottom up or top down, LCOE estimates ultimately determine the margins at which electricity can be sold.

Sources. LCOE is considered in all scenarios modelling the energy mix of a country or region, however, only until recently more visibility around assumptions and results have been provided (e.g. Lazard 2016, CTI 2016). In general, the granularity provided is quite poor, disclosing data at a global level; thus, preventing the analysis of country-level differences.

Method. The ACT and LCT scenarios take the scenarios developed by the National Renewable Energy Laboratory (NREL) in its Annual Technology Baseline as their basis. NREL has developed scenarios in the US for the most relevant technologies through 2050. The steps to compute the LCOE were the following:

- Estimation of country factors: 2014 LCOE of the US were taken as baseline. These were compared against those of other countries to define the starting point. Current values were taken from IEA Projected Costs of Electricity for each technology. In those cases where technology estimates were not available, estimates of countries with similar characteristics were used.
- Estimation of the starting point: The starting point is computed by multiplying the country factor and the estimated LCOE by technology from NREL scenarios.
- Estimation of LCOE trajectory: The trajectory follows the US learning curve.
- Selection of technology scenarios: All scenarios selected consider the capacity factors estimates of ETP 2DS and 4DS scenarios. For gas and coal plants an average capacity factor was selected and it is assumed to be constant through 2040. For renewable sources, the capacity factor is assumed to increase with time. These assumptions could apply to companies that have a relative equal share of old and new power plants but could be contestable for those that do not.

Results. Table 2.5 shows the estimated LCOE in the US (for other countries see Annex 3). Under both decarbonisation scenarios, the LCOE of renewable sources is, in general, projected to be lower than that of fossil fuel power plants. These estimates do not include the effect of a carbon tax. Lower costs in the ACT scenario are driven by a higher reduction of capital costs, the main cost driver for renewable technologies.

TABLE 2.5 LCOE (EUR/MWh) IN THE USA UNDER THE ACT AND LCT SCENARIO (SOURCE: AUTHORS, BASED ON NREL AND IEA 2015)

Technology	2014	2020		2025		2030		2035		2040	
		ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT
Coal SC	86	85	88	85	88	84	90	83	91	82	94
Coal with CCS	115	110	112	107	110	104	109	101	109	99	110
Gas CT	71	70	83	64	92	76	94	76	99	77	102
Gas with CCS	55	55	65	57	72	59	73	59	77	59	79
Nuclear	79	79	79	79	79	78	78	77	77	76	76
Wind onshore 26% CF	76	61	74	53	74	51	74	50	74	49	74
Wind onshore 30% CF	59	47	57	41	57	39	57	38	57	38	57
Solar PV 14% CF	127	70	122	54	122	46	122	42	122	37	122
Solar PV 20% CF	89	49	85	38	85	32	85	29	85	26	85

2.4 SUBSIDIES

Overview. In the transition to a low-carbon economy, policy options on subsidies will operate in two ways: i.) governments will phase out consumer- and producer-related fossil fuels subsidies; and ii.) governments will gradually decrease renewable power subsidies per unit, although some regions and countries that have lagged to date on climate policies may see a phasing in of subsidies in the short-term, following a phase out as technologies become competitive.

Risk pass-through mechanisms. A reduction of consumer-related fuel subsidies will result in an increase in end user electricity prices which may change consumer behaviour and the application of energy efficient measures. This, in turn, may affect companies through a decrease in revenues. On the other hand, a decrease in the subsidies given to renewable energy power plants may affect the economic viability of both planned and current renewable power capacity and production.

Sources. Few scenarios integrate in their model assumptions around changes in the subsidy structure. Those that do so, generally disclose results with a single indicator preventing the analysis of the consequences at sector, technology and company level. The subsidy assumptions provided here were thus modelled by the authors (see description below)

Method. The subsidy estimates presented here build on the previous estimates of LCOE. It is assumed that under both scenarios LCOEs of fossil fuel and renewable-based technologies reach parity. To do so, the spread between LCOEs is covered through a policy subsidy. Thus, subsides of renewable technologies are computed using the difference between the technology's LCOE and the lowest priced fossil fuel LCOE for each country in each year. While these are presented here as subsidies, this 'gap' can also be filled through a 'tax'. An alternative approach is to use 'announced' or planned policies for developing the subsidy forecasts. However, given the limited time horizon around many of these policies and the fact that in particular the ACT scenario will likely have to rely on 'unknown' policies, this approach seems more appropriate for the LCT scenario. Crucially, this approach treats carbon taxes independent of this calculation. Given the lack of visibility as to whether the policy intervention will take place in the form of a cost or subsidy, carbon taxes / prices could be used as the basis for the overall policy subsidy, assuming these taxes are higher than the required limits defined here.

Results. Table 2.6 presents the estimated subsidies by country for selected technologies (see Annex 4 for geography breakdown). Subsidies in the ACT scenario tend to diminish due to a higher learning rates for renewable technologies compared to thermal generation. In the LCT, subsidies are more constant across time.

TABLE 2.6 ACT AND LCT SCENARIOS SUBSIDIES IN THE UNITED STATES (EUR/MWh) (SOURCE: AUTHORS, BASED ON NREL)

Technology	2014	2020		2025		2030		2035		2040	
		ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT
Nuclear	24	24	14	22	7	19	5	18	0	17	0
Wind onshore - 30% CF	21	6	9	0	2	0	1	0	0	0	0
Wind onshore - 26% CF	4	0	0	0	0	0	0	0	0	0	0
Solar PV - Utility - 14% CF	72	15	57	0	50	0	49	0	45	0	28
Solar PV - Utility - 20% CF	34	0	20	0	13	0	12	0	8	0	0

2.5 EFFECTIVE CARBON RATES

Overview. Effective carbon rates in the power sector generally encompass three main policy instruments: taxes on electricity, carbon taxes, and permit prices from exchange trade systems. The application of these instruments has different effects in the sector depending on the existing regulatory framework and the market structure. In countries where the regulation allows electricity producers to pass on the increase in production costs to consumers, a tax on energy use and a carbon or fuel tax may have the same overall effect in the economy, a decrease in consumption and window to shift to low-carbon technologies (e.g. Meng, et al. 2013).

Risk pass-through mechanisms. Effective carbon rates can only be considered as a risk driver when these are absorbed by the company and thus cannot be totally transferred to the consumer. Given current effective carbon rates levels and policy goals under both scenarios, it is highly likely that companies will have to internalize the associated costs as lower production costs from renewable technologies could push down market electricity prices.

Sources. There are no public forecasts on effective carbon rates nor on the rates needed to achieve either an ACT or LCT equivalent scenario. The only instrument currently being forecasted is the carbon price, disclosed in several scenarios (see Indicator 1.5).

Method. Since the effective carbon rates encompass several instruments, including carbon taxes, it is assumed that the rates under each scenario will at least equal the country's expected carbon price in cases where the current effective carbon rates are lower. This approach thus defines a threshold rather than establish the optimal rate that companies should account for. The values identified with an asterisk where interpolated using a linear regression**.**

Results. Table 2.7 shows the rates for the ACT and LCT scenarios. 2020, 2025 and 2035 estimates were interpolated. The current rates in the countries in scope are very low (from EUR 3 to 30 per ton CO_2), with all of them having specific taxes on electricity evenly applied through the power sector and some of them pricing emissions through emission trading schemes at a very low price.

TABLE 2.7 EFECTIVE CARBON RATES UNDER THE ACT AND LCT (EUR/tCO_2) (SOURCE: AUTHORS, BASED ON IEA 2016b, OECD 2016)

Year	Brazil		France		Germany		Italy		Mexico		USA	
	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT
2012	11		20		34		23		3		4	
2020	39	11	56	28*	63	35*	57	29*	18	7	47	16*
2025	57	11	78	32*	82	36*	79	33*	53*	13*	73	23*
2030	75	11	100	37	100	37	100	37	88	18	100	30
2035	100*	11	120*	44*	120*	44*	120*	44*	105*	23*	120*	35*
2040	125	11	140	50	140	50	140	50	123	28	140	40

*Interpolated figures

3 AUTOMOTIVE SECTOR

GENERAL OVERVIEW

The transition risk story for the automobile sector plays out along a few general trends:

- **The switch to zero-carbon powertrains.** The IEA estimates that Internal Combustion Engine (ICE) powered cars (e.g. petrol, diesel) will only account for around 10% of total car sales in 2050 under the 2°C scenario, with a rise in electric and fuel cell alternatives. Zero-carbon powertrains are similarly set to grow under a 4°C transition, albeit at a less rapid pace.

- **Changing economics around car production.** The 'car production chain' will evolve with the introduction of new actors (e.g. battery manufacturers) and the associated shift in revenues and margins within that chain. This can work to the benefit of car manufacturers as they 'internalize' a larger part of the value-add of the car manufacturing process or to their detriment as this may squeeze their margins.

- **Increasing fuel efficiency standards (both policy- and demand driven).** Fuel efficiency standards now exist in basically all major economies at varying degrees of ambition. In the same vein, consumers are more sensitive to fuel efficiency considerations when purchasing cars (in part as a function of oil prices).

- **A broader context of changing consumption patterns and technology changes.** Beyond questions around decarbonisation, the car industry is undergoing other fundamental shifts, noticeably the growth of 'car-sharing' models, urbanization and associated changes in car ownership patterns, as well as the potential rise of autonomous driving, each potentially reinforcing each other and having impact an overall sales volumes.

The scenarios developed here focus on risk assessment for the passenger light-duty vehicle sector.

The scenarios involve the following parameters:

PRODUCTION & TECHNOLOGY	Sales by powertrain (%)
MARKET PRICING	Low-weight composites costs (e.g. carbon fibre) (USD/pound) Battery costs (USD/kWh)
POLICY MANDATES, INCENTIVES & TAXES	Fuel efficiency standards (% reduction) Effective carbon rates (EUR/tCO_2)

5 THINGS BEFORE GETTING STARTED

1. **Long-term Business Model Risk.** In addition to questions around decarbonisation, the automobile industry is facing a fundamental shift in the way mobility is delivered and used. This relates notably to the rise of car-sharing systems, changes in demographics, and the technological evolution of autonomous driving. Each of these on their own represent potentially disruptive risks for the automobile sector. They will also affect the individual risk drivers presented in this section (e.g. total automobile sales, etc.) and by extension both the probability of various decarbonisation scenarios and their nature. Considering these trends in the context of the risk drivers presented in this section is thus critical.

2. **Production Differentiation.** The automobile sector is arguably the sector with the highest level of product differentiation among the sectors discussed in this scenario. By extension, industry average estimates around drive train, fuel efficiency, and even qualitative assumptions around consumer preferences may affect different manufacturers differently. This differentiation may also extend to the cost structures faced in the supply chain by different manufacturers. For example, a review of the literature on battery prices suggests different manufacturers face significant differences in terms of battery costs. This may then extend similarly to the evolution of battery prices in the future.

3. **Variability in Usage.** As for other sectors, risk and climate considerations may not always align in the automobile sector. For example, sports vehicles may have a relatively low fuel efficiency, but emit significantly less GHG emissions over their lifetime, given less use than, for example, sedan commuter cars. This similarly complicates questions around the remaining carbon budget associated with various levels of car production associated with various levels of fuel efficiency and powertrains.

4. **Regional Differentiation**. While most of the automobile scenarios are presented as global scenarios, different manufacturers have more or less exposure to different markets and may thus be particularly affected by regulatory trends in one or the other market (e.g. Volkswagen in China, Ford in the United States, etc.).

5. **Subsidy Impact.** Current subsidies for the light-passenger duty vehicle sector accrue effectively exclusively to consumers (e.g. credits on EV purchases, gas subsidies etc.), the upstream supply chain (e.g. fossil fuel subsidies) or research and development. The role of policy prices or subsidies in risk assessment is unclear. This implies that many policy incentives may only indirectly affect producers and may have a higher impact in terms of changes in consumer preferences (responding to policy incentives), rather than direct exposure to policy incentives or taxes.

3.1 SALES BY POWERTRAIN

Overview. The primary GHG emissions driver in the automobile sector is related to the emissions from the internal combustion engine used in cars. Emissions can be reduced both through efficiency measures (see next section) and a switch to alternative low-carbon powertrains (e.g. electric vehicles, hybrid, fuel cells, etc.).

Risk pass-through mechanism. Changes in consumer preferences, relative prices, and / or policy signals will require companies to adjust their production profile to respond to these changes thus requiring capital and R&D expenditures. Failure to adjust is likely to primarily impact sales volume, although the economics of different drive trains will also impact margins associated with sales.

Sources. A number of industry data providers and consultants provide forecasts and future sales / production of light passenger duty vehicles by drive train. However, these are not usually designed to forecast trends with regard to specific climate scenario. The International Energy Agency has in the past not consistently provided this indicator and where it has, it usually is expressed as numbers of cars on the road, rather than production / sales, a figure which the IEA model generates internally, but doesn't always publish.

Methodology choice. The figures presented here are based on IEA information currently not published in their report. They can be derived from the estimates of cars on the road. An alternative source may be the forecasts, for example, from Bloomberg New Energy Finance (BNEF), although these are not explicitly linked to a climate outcome given their sector specific nature and thus may be more or less ambitious than the IEA.

Results. Given the lack of geographic granularity in the IEA data, the results are presented at global level. Due to inconsistencies identified in their more recent scenarios, the values are taken from IEA ETP 2014. The following table summarizes the results for the global market by powertrain, based on the classification provided by the IEA[3]. While the results are global, these can be complemented by some national targets on electric vehicle stock that may be relevant depending on car manufacturers market exposure in the United States (3.3 million by 2025), France (2 million by 2020), and Germany (1 million by 2020) (IEA 2016d). In the LCT scenario, the share of hybrid LDV sales grows to 6.0% and that of electric vehicles to 2.9% in 2040. In the ACT scenario, almost two-thirds of sales in 2040 will be of hybrid or electric vehicles. CNG sales remain in a lower single-digit range.

TABLE 3.1 PERCENTAGE OF TOTAL AUTOMOBILE SALES BY POWERTRAIN FOR THE ACT AND LCT SCENARIOS
(SOURCE: AUTHORS, BASED ON IEA 2014)

Year	EV		Hybrid		Petrol		Diesel		Fuel Cell		CNG / LPG	
	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT
2020	3.1%	0.4%	6.0%	0.2%	74.0%	77.5%	12.5%	18.3%	0.1%	0.0%	4.2%	3.6%
2025	6.0%	0.7%	13.2%	0.6%	65.0%	77.4%	10.9%	17.4%	0.4%	0.1%	4.4%	3.8%
2030	11.0%	1.2%	22.3%	1.6%	53.1%	76.5%	8.3%	16.4%	1.1%	0.1%	4.4%	4.1%
2035	15.6%	2.0%	32.5%	3.4%	39.5%	74.4%	5.9%	15.6%	1.9%	0.2%	4.6%	4.4%
2040	20.4%	2.9%	43.4%	6.0%	26.6%	71.5%	3.7%	14.8%	3.1%	0.3%	2.6%	4.5%

3.2 LOW-WEIGHT COMPOSITE COSTS

Overview. Materials make up nearly 50% of the cost of producing a car (Market Realist 2015) and can thus be a critical risk driver in the context of the transition to a low-carbon economy. There are a range of materials that go into a car, with steel accounting for over 50% according to some estimates (Russo 2012). At the same time, new alternative low-weight composites are starting to compete (e.g. carbon fibre), influencing both the economics of electric vehicles and ICEs. Both, low-weight composite costs or high-weight alternatives (e.g. steel) in terms of price competition are considered here.

Risk pass-through mechanism. Estimates around the evolution of material costs can be positive or negative for a car producer. For example, lower costs of low-weight materials will support margins around electric vehicles that are likely to rely more on low-weight materials to sustain range. In addition, they may increase the probability of electric vehicle pick-up as they extend ranges. Should electric vehicle mandates be instituted without price drops around low-weight composite costs, margins are squeezed.

Sources. Estimates around future steel prices range widely (see Section 4.5). One key question is the extent to which carbon taxes on steel are passed on to car manufacturers (and in turn end consumers) and the impact this has on the relative economics of different materials and composites. Similarly, estimates are also lacking for low-weight composite alternatives (e.g. carbon fibre).

Method. The scenarios developed here focus on carbon fibre, a prominent low-weight composite alternative. Although there are no 2°C scenarios on carbon fibre, estimates for both scenarios were built following literature review. Research suggests a $5/pound price is necessary for wide-scale adoption (Lucintel 2012). Current estimates suggest carbon fibre costs around $7-11/pound [~$15-$24 / kg] (Das, et al. 2016, Bregar 2014).

Results. The ACT and LCT scenarios define the following indicators around projections for low-weight composite costs at the global level, using carbon fibre as an example, although the results are likely to be similar for other materials, independent of which exact material wins out.

TABLE 3.2 COSTS OF CARBON FIBRE IN THE LCT AND ACT SCENARIO (GLOBAL) (SOURCE: AUTHORS, BASED ON NREL)

Year	Carbon fiber costs (USD/pound)
2016	7-11
2020	7
2025	5

3.3 BATTERY COSTS

Overview. Battery costs differ across different market providers. Current estimates for 2015 around battery cost ranges as low as $190/kWh (Ayre 2015) to market average estimates between $273/kWh (ETC 2017) and $350/kWh (PRNewswire 2016). This makes market average forecasts difficult since the starting point is unclear and the range across the starting points quite significant. This relates to what has been highlighted earlier as to a non-homogenous capital cost curve faced by companies (see Page 37). As an example, Tesla already claims their battery costs could be of $ 100/Kwh by 2020 (Coren 2016).

Risk pass-through mechanism. Similar dynamics appear as for composites where the evolution of the cost structure can have both positive and negative effects on different producers and accelerate or inhibit scaling of the electric vehicle market.

Sources. In general, scenarios include battery costs assumptions as these are required to model the scale-up of electric vehicles. These are however not disclosed by these scenarios, the estimation of cost requires industry research coupled with company reporting (e.g. through announcements, etc.). Sources thus include academic research and BNEF.

Method ACT. 2016 estimates are taken from BNEF (ETC 2017). The ambitious climate transition scenario applies the ‘optimistic market’ approach, thus assuming optimistic technology assumptions around cost evolution and leaving policy as the remaining variable to offset price differentials. Thus, it takes the most optimistic estimates from Nykvist et al. 2015 meta-analysis. Battery costs in 2020 are in line with the US Department of Energy targets (USDEP 2016).

Method LCT. 2016 costs are taken from BNEF (ETC 2017). Future estimates are adjusted using the learning curve of its most recent public forecasts (Randall 2016). It should be noted that the BNEF estimates do not solve for a specific scenario and thus are considered to reflect a more ‘central scenario’.

Results. The following table summarizes two different battery cost estimates, with estimates limited to 2025, given the lack of forecasts and the uncertainty around these predictions. It should be noted that individual battery costs for individual companies may still differ significantly, in particular, in the short-term given the relatively nascent market.

TABLE 3.3 FORECASTED BATTERY COSTS (USD/kWh) IN THE ACT AND LCT SCENARIOS (SOURCE: AUTHORS, BASED ON NYKVIST B. 2015, RUSSO 2012 AND BNEF)

Year	ACT	LCT
2016	273	273
2020	125	204
2025	110	142

3.4 FUEL EFFICIENCY STANDARDS

Overview. As outlined above, fuel efficiency is the other part of the decarbonisation equation for the automobile sector. For these scenarios, we assume that fuel efficiency standards will set the baseline for actual fuel efficiency with limited 'additional' impact from consumer preferences. Moreover, given the diversity in preferences, without fuel efficiency standards, certain car producers could still be expected to potentially produce automobiles with low fuel efficiency. As a result, the risk driver is presented in the context of policy costs and incentives.

Risk pass-through mechanism. From a risk perspective, efficiency standards create both potential additional costs as new car models have to be designed to satisfy the policy mandate as well as potential risks as consumer preferences shift to more fuel-efficient cars. Conversely, they create opportunity for those car manufacturers that produce more fuel-efficient cars.

Sources. There is no general information on fuel efficiency standards in the IEA scenarios, however some third party research from industry and NGOs provides insights into potential ambitious trends, even if not explicitly linked to a climate outcome (e.g. ICCT).

Method. The LCT scenario considers current policy announcements. To develop the ACT Scenario, the following assumptions are considered:

- A convergence around the US fuel economy target of 34% reduction relative to the respective baseline year that formed the basis of the existing country-level policy mandates by 2025. This assumption largely extrapolates the trends that the current policy mandates would suggest in the EU and China, and provide a somewhat more ambitious timeline for Brazil and Mexico, although for these countries the base year is earlier and thus less ambitious.
- A convergence to the Global Fuel Economy Initiative[4] target of 50% efficiency gains by 2030.

Results. The following table summarizes the current fuel efficiency mandates and their expected evolution under both scenarios. Since the US has already reached its 2025 fuel efficiency targets, market reduction rates could surpass the LCT data points through 2030 and potentially the ACT data points. The EU has already reached its 2020 target. This is not the case for Brazil and Mexico, whose current efficiency levels will have to more than double in order to reach the required policy targets under a 2°C scenario.

TABLE 3.4 FORECASTED FUEL EFFICIENCY TARGETS IN THE ACT AND LCT SCENARIOS (SOURCE: AUTHORS, BASED ON ICCT 2016)

Year	Brazil		EU		Mexico		USA	
	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT
Baseline year	2013		2015		2011		2016	
Implementation period	2013-2017		2020-2021		2014-2016		2017-2025	
Reduction in gCO_2/km	12.0%		27.0%		13.0%		34.0%	
Est. reduction 2020	17%	12%	27%	27%	17%	13%	34%	34%
Est. reduction 2025	34%	12%	34%	27%	34%	13%	34%	34%
Est. reduction 2030	50%	12%	50%	27%	50%	13%	50%	34%

3.5 EFFECTIVE CARBON RATES

Overview. Effective carbon rates in the automobile sector are the highest across all sectors in scope. These are mainly present in the form of specific sector taxes (e.g. road transport fuel taxes), with few countries integrating carbon taxes as well with a significant impact (OECD 2016). As with most of the market pricing instruments, effective carbon rates may influence both consumer preferences and production choices.

Risk pass-through mechanism. It should be noted that this indicator may not be a core risk driver in any event, since the effective carbon rates in most cases will be paid by the consumer (e.g. at the petrol station) and not the producer. The only quantitative impact then of ratcheting prices will be an increased preference for fuel-efficient vehicles as well as changes in use (e.g. car pooling, etc.).

Sources. There are no publicly available specific forecasts for effective carbon rates under a 2°C transition for specific countries, nor at global or regional level. This makes it difficult to quantify the expected future effective carbon rates under an ambitious transition. The challenge of estimating future effective carbon rates is exacerbated since in many countries, with existing high effective carbon rates, this policy lever may no longer be applied. For example, in Germany the current effective carbon rate is EUR 210 / ton CO_2. Thus, the current policy discussion in Germany has focused more on electric vehicle subsidies, fuel efficiency standards, and electric vehicle sales targets rather than ratcheting carbon pricing for the automobile sector.

Method. There are three options for defining changes in effective carbon rates: i) keep current rates constant, assuming alternative policy channels; ii) develop bottom-up, country-level estimates; iii) ratchet rates at a pre-determined level. The approach chosen here is a mix of different approaches:

- It estimates no change in effective carbon rates for Europe under the assumption that further ratcheting seems unlikely as existing effective carbon rates are already relatively high.
- For US, Mexico and Brazil, effective carbon rates hit carbon prices (see Page 26), however, the instruments achieving these rates can be either specific sector taxes, carbon taxes and/or permit prices from exchange trade systems. Data points marked with an asterisk were interpolated.

Results. The following table summarizes the results for both scenarios. Brazil, Mexico and the US will require a significant increase in the effective carbon rates of the sector in both, the ACT and LCT scenarios. However, these are not expected to reach EU effective carbon rates levels.

TABLE 3.5 FORECASTED EFFECTIVE CARBON RATES (EUR/tCO_2) (SOURCE: AUTHORS, BASED ON OECD 2016 AND ALBERICI ET AL. 2014)

Year	Brazil		France		Germany		Italy		Mexico		USA	
	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT
2012	11		180		210		240		8		17	
2020	20	11	180		210		240		18	12*	54*	23*
2025	48*	11	180		210		240		53*	15*	75*	26*
2030	75	11	180		210		240		88*	18	100	30
2035	100*	11	180		210		240		105*	23*	120*	35*
2040	125	11	180		210		240		123	28	140	40

*Interpolated figures

4 STEEL SECTOR

GENERAL OVERVIEW

After chemicals, the iron and steel sector represents the second largest industrial energy consumer globally. It amounts to 20% of industrial consumption of energy. Furthermore, it emits the largest industrial amount of CO_2 if the process emissions of coke ovens and blast furnaces are also taken into account (Wortswinkel & Nijs 2010). The sector is currently only affected by the energy transition to a limited extent due to its organisation into diverse associations whose strong negotiating power has led to a high share allocation of free certificates in regions such as the European Union.

The transition risk story for the steel sector articulates itself along a few trends:

- **Growth of the Electric Arc Furnaces (EAF) production route**. Due to an improvement in recycling and circular economy, more scrap steel will be available, which is required to apply EAF more widely.

- **Incremental technological changes with short payback times**. Profitability of steel companies is low and therefore large investments in emission reduction measures are considered unrealistic. Selected measures (e.g. efficiency measures and heat recovery) and some technologies (e.g. Top Gas Recovery for Blast Furnaces (TGRBF) may see increased deployment in the next years, due to their emission savings potential of 20% to 30%. Its implementation is even foreseen in scenarios without policy subsidies.

- **Increased quality requirements and growing demand for specialized steels**. Increased quality requirements and demand for specialised steels, such as composite materials and high ductility steel for the automobile industry, will arise more and more in the future.

The scenario involves the following parameters:

PRODUCTION & TECHNOLOGY	
Crude Steel production (Mt) Share of primary/secondary steel (%) Energy Intensity (GJ / t crude steel)	Carbon Intensity (t CO_2 / t crude steel)
MARKET PRICING	
Crude steel price (USD/ton) Raw material prices (USD/ton)	
POLICY MANDATES, INCENTIVES & TAXES	
Allocation of free CO_2 allowances (%)	

5 THINGS BEFORE GETTING STARTED

1. **Carbon Leakage Issues.** The steel industry plays a significant role for industrial countries. Steel often stands at the beginning of many industrial and engineering products such as machines, tools, cars, ships, bridges and buildings and can enable future low carbon technologies to come. Iron and steel production is perceived as an integrated and significant part of industrial nations' economies. Steel associations often point out that carbon leakage, i. e. the relocation of carbon-intensive production into an area not covered by CO_2 emission trading schemes or CO_2 taxes, could have a significant impact on the competitiveness of affiliated industrial sectors, as transportation distances lengthen and benefits of long-term built mutual trust is lost.

2. **Steel Oversupply.** The global financial and economic crisis has pushed the world steel industry into recession and the steel industry is still just slowly recovering. Global steel production almost doubled in less than a decade at the turn of the century due to a massive capacity increase in China, Brazil and India. The combination of oversupply and a sharp contraction of global steel demand led to a drop in the steel price which resulted in zero or even negative profit margins for steel production. As a result, steelmakers have introduced major production cuts and trade of steel has declined dramatically. In the ongoing aftermath of the crisis, steelmaking capacity continued to increase despite the market downturn.

3. **Energy Intensity of Steelmaking Processes.** There are three major routes to produce steel, i.e. oxygen or primary route, electrical or secondary route and Direct Reduced Iron (DRI). On the global level, around 70% of steel is produced via the oxygen or primary route. This route uses coke (from coal) and iron ore and is carbon intensive. Around 25% of the steel is produced via the electrical or secondary route. Here, electric arcs are used to melt steel scrap which requires only one third of the energy and with only a fourth of the direct CO_2 emissions per ton of crude steel in comparison to the oxygen route. 5% is produced as DRI. It is the most recently developed route and requires iron ores and high amounts of natural gas, which is why it is usually located in areas of cheap gas (e.g. USA, Middle East). The transition to a low carbon economy will require scaling production of the secondary route.

4. **Carbon Intensity of Steelmaking Processes.** Oxygen or primary steel is the most common type of steel but it is also the most carbon-intensive of all production routes. Without accounting for external effects, it has the lowest production costs as coal and iron ore can be imported comparatively cheaply. Besides energy-related CO_2 emissions, reducing iron ore (mostly iron oxide) to iron is associated with process-related CO_2 emissions. New and capital-intensive production processes or CCS are required to abate process-related CO_2 emissions.

5. **Steel Types Substitution.** The substitution of primary to secondary steel seems a viable option to abate CO_2 emissions. However, the substitution is limited to two factors: the availability of steel scrap, which serves as an input material, and the demand for special steel, as some processes require a high level of purity of steel which only the oxygen route or DRI are able to produce. The availability of scrap depends on price, recycling infrastructure and the amount and lifetime of steel products.

4.1 STEEL PRODUCTION

Overview. Steel is (currently) one of the major building blocks of modern society. It is widely used in buildings (e.g. reinforced concrete), infrastructure (e.g. bridges), vehicles, machinery and tools. Steel demand is often positively correlated with GDP. Additionally, steel will be needed to satisfy the demand of low carbon technologies such as wind turbines, rail transport, district heating and CCS. Over the last 25 years, global crude steel production has more than doubled. The increasing global population and GDP suggest an increase in the demand for steel which will require more ambitious CO_2 intensity reductions to meet the climate targets.

Risk pass-through mechanism. The massive increase of steel production capacity in Brazil, China, Russia and India over the last decade added to the effects of the global economic crisis, resulted in falling crude steel prices in 2009 and 2010. These factors lowered utilization rates and increased pressure on revenue margins of traditional steel producers in Europe and USA. Current and future overcapacity will continue to play an important role for steel producers in terms of revenue margins and capacity utilization.

Sources. Scenarios present inputs around crude steel production generally at macro-level (e.g. IEA 2016, Greenpeace 2015). As an example, in IEA's ETP global crude steel production is given on a global level and on aggregate level for OECD and non-OECD countries. As the future demand is associated with high uncertainties, other studies tend to give results according to different demand patterns. For example, Morfeldt et al. 2015 assume a stagnating global steel demand in the long run (e.g. 2050 and beyond).

Method. In line with the IEA ETP scenario, the same global steel demand and steel production is assumed in both the ACT and LCT scenarios. The process to compute the estimates is the following:

- Current global and country-specific steel production are taken from World Steel Association (2016) statistics.
- Production of USA, Mexico and Brazil are forecasted using their respective regional production growth (i.e. Latin-America, OECD) from ETP 2015 until 2025.
- Production pattern of USA, Mexico and Brazil between 2015 and 2025 (e.g. USA steel production increase less compared to Mexico's production) is estimated in relation to the global steel production of ETP 2016 until 2040.
- The crude steel production of Germany, France and Italy is forecasted following a linear relation to the prospective sectoral GDP growth of each country until 2040 according to the EU Reference Scenario Trends to 2050 (EC 2016).

Results. Crude steel production will continue to increase steadily over next 35 years of a global level. The growth rate, however, is expected to be lower in comparison to the significant increase observed during the last 25 years. Production increase varies significantly among regions. While European steel production is more or less stagnating, even decreasing in France, Brazil and Mexico continue their momentum and are expected to increase steel production by more than a third until 2040. During the same period, US steel producers are set to recover and surpass production levels of 2015 in 2040. It is important to highlight that for 2015, 87% of the global steel is produced outside the countries in focus. By 2050, the share increases to 89%.

TABLE 4.1 GLOBAL AND COUNTRY-SPECIFIC CRUDE STEEL PRODUCTION (MT) FOR BOTH SCENARIOS (SOURCE: AUTHORS BASED ON, IEA ETP 2016, 2015, EC 2016 AND WSA 2016)

Country	2015	2020	2025	2030	2035	2040
World	1 621	1 750	1 938	1 989	2 093	2 174
Brazil	33	38	44	46	49	52
France	15	15	15	14	14	14
Germany	43	44	46	48	48	48
Italy	22	22	22	22	22	22
Mexico	18	21	24	25	27	28
USA	79	82	86	87	89	91

4.2 SHARE OF PRIMARY AND SECONDARY STEEL

Overview. There are three major methods of steel production: oxygen, electrical and DRI. At a global level, around 70% of the steel is produced via oxygen or primary route, 25% via the electrical, and the remaining share though DRI. The two latter methods use electric arcs to melt steel scrap which requires only one third of the energy and with only a fourth of direct CO_2 emission per ton of crude steel (i.e. emissions from combustion) in comparison to the oxygen route.

Risk pass-through mechanism. The production cost structure varies between primary and secondary steel significantly. While for primary steel producers over 50% of the production cost originates from coal and iron ore, for secondary steel producers steel scrap makes up for more than 50% of total production costs (SOTN 2016). Production costs of primary steel producers are more sensitive to carbon pricing mechanisms, as the primary route emits four times more CO_2 per ton of crude steel compared to the electrical route.

Sources. In general, scenarios present inputs around primary and secondary steel production at macro level (e.g. IEA, Greenpeace). As an example, in IEA's Energy Technology Perspectives 2015 crude steel production is given per production routes on a regional level (e. g. Latin America). Morfeld et al. 2015 calculate that steel scrap can supply 50% of the crude steel production until 2050 based on typical turnover rates of heavy steel equipment and machinery.

Method. In line with the IEA ETP 2016 and 2015 assumptions, the same steel production structure under different climate targets is assumed. The utilization of steel scrap is mainly driven by its price which in turn depends on its availability. Estimates of the ACT and LCT scenarios are computed as follows:

- Current crude steel production share by type of route is taken from WSA 2016 statistics.
- Until 2025, country-specific production is forecasted in linear relation to the production share of the respective region (i.e. Latin America, USA and Canada, Europe) following ETP 2015.
- The country-specific production share pattern between 2015 and 2025 (e. g. Italy's share of secondary steel is twice to that of the global average) is continued in relation to the global secondary steel share, which increases up to 50% in 2040 according to WEO 2016.

Results. The share of secondary steel in global steel production will double from 25% in 2015 to 50% in 2040 in both scenarios. Today, the secondary steel share varies significantly between regions. In countries like Mexico, Italy and USA secondary steel already outweighs primary steel production. Low electricity prices or a rapidly developing economy tend to drive the investment decision for secondary steel. In these countries, secondary steel share will increase less (e.g. by 6 and 8 percentage points in Mexico and USA, respectively). Countries like Germany, France and Brazil with a high production share of primary steel tend to have a long history of steel production or access to cheap coal. Here, the secondary steel share will increase, respectively, by 20, 35 and 29 percentage points, in Brazil, France and Germany until 2040 with respect to 2015 levels.

TABLE 4.2 SHARE OF SECONDARY STEEL PRODUCTION IN TOTAL CRUDE STEEL PRODUCTION FOR BOTH SCENARIOS
(SOURCE: AUTHORS, BASED ON IEA 2016A, IEA 2015 AND WSA 2016)

Country	2015	2020	2025	2030	2035	2040
World	25%	29%	32%	38%	47%	50%
Brazil	20%	23%	26%	31%	38%	40%
France	34%	39%	44%	52%	65%	69%
Germany	30%	34%	38%	45%	56%	59%
Italy	78%	79%	80%	82%	84%	85%
Mexico	70%	71%	72%	73%	76%	76%
USA	63%	64%	65%	67%	70%	71%

4.3 ENERGY INTENSITY

Overview. Steel is one of the most energy-intensive industries. Primary steel production utilizes a range of fossil fuels such as coal, coke, gas and oil. Carbon-rich gases are produced as by products in coke oven, blast and blast oxygen furnaces which are further used to generate electricity in Combined Heat and Power (CHP) plants on-site or to heat the rolling mills. In electrical steel production electricity, natural gas and coal is used. The wide range of energy carriers and the high level of process integration makes determining the energy intensity of a steel mill a challenging task. Studies like Tanaka 2012 show that the energy intensity can vary significantly depending on the calculation method used.

Risk pass-through mechanism. Energy costs like coal for primary steel production and electricity for secondary steel production make up to one third of the total production costs (SOTN 2017). Increasing the energy efficiency is often a viable option for steel producers to gain a competitive advantage. Failing to decrease energy intensity in relation to competitors could lead to lower market volumes and revenues.

Sources. As with most of the indicators in the sector, scenarios generally present total final energy consumption and total crude steel production at the macro level. ETP 2015 reports the aggregate energy intensity at regional level in 2012 and for 2025. Some sector-specific organizations developing climate constrained scenarios disclose the indicator but only cover their region of interest (e.g. EUROFER 2013).

Method. In the ACT scenario, ETP 2016 2DS global estimates are used to compute the global aggregated energy intensity. Energy intensity is computed using the ratio of total final energy consumption and total crude steel production until 2040. In the LCT scenario, energy efficiency gains of EUROFER (2013) are applied to the ETP 4DS estimates of global energy intensity until 2030. A linear regression is used to extrapolate to 2040.

To compute country-specific data, 2014 OECD statistic data on the sector's final energy consumption is used and put into relation to the total crude steel production from World Steel Association 2016. This resulted in a lower energy intensity as, among other things, energy consumption of coke ovens is not listed under steel production. Thus, OECD energy intensity of ETP 2015 2DS and 4DS scenarios is used as a correction factor of global energy intensity. The country-specific intensity is then forecasted in linear relation to the steel production shares of the respective region (i.e. Latin-America, US and Canada, Europe) in ETP 2015 until 2025. Based on the development pattern from 2015 to 2025, the country-specific intensities are forecasted until 2040 in relation to the global intensity of ETP 2016.

Results. In the ACT scenario, the global energy intensity needs to be reduced by 30% until 2040 in relation to 2015. The energy intensity varies among the countries depending on the secondary steel share and energy efficiency. Thus, increasing the secondary steel share in total steel production will reduce the aggregated energy intensity. Countries with a low energy intensity like Germany and Italy have limited options to reduce energy intensity by 25% or more until 2040 compared to 2015. Brazil, as one of the most energy intensive producers in the world, will have to decrease its aggregate energy intensity by more than 35%. In the LCT scenario, the global energy intensity decreases by less than 15% despite having the same increasing share of secondary steel as in the ACT scenario.

TABLE 4.3 GLOBAL AND COUNTRY-SPECIFIC AGGREGATE ENERGY INTENSITY IN THE ACT AND LCT SCENARIOS (GJ/T CRUDE STEEL) (SOURCE: AUTHORS, BASED ON IEA ETP 2016, 2015, OECD 2016, WSA 2016)

Country	2015	2020		2025		2030		2035		2040	
		ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT
World	21.3	21.2	20.5	18.9	20.0	16.5	19.5	15.7	19.0	14.8	18.5
Brazil	24.5	24.6	23.7	20.8	23.1	17.8	22.4	16.8	21.8	15.8	21.3
France	18.6	17.0	17.9	14.9	17.5	13.4	17.0	12.9	16.6	12.4	16.1
Germany	11.7	11.6	11.3	11.6	11.0	10.6	10.7	10.3	10.4	10.0	10.2
Italy	12.8	13.5	12.3	11.9	12.0	10.9	11.7	10.6	11.4	10.3	11.1
Mexico	14.4	14.8	13.9	12.5	13.6	11.4	13.2	11.1	12.9	10.7	12.5
USA	14.8	14.2	14.3	12.5	13.9	11.4	13.5	11.1	13.2	10.7	12.8

4.4 CARBON INTENSITY

Overview. Production of iron and steel is the second largest CO_2 source of all industry. Besides the utilization of a range of fossil fuels such as coal, coke, natural gas and oil, further process-related CO_2 emissions occur during the reduction from iron oxide to iron in primary steel production. Secondary steel production has a more than four time lower CO_2 intensity. Secondary steel uses steel scrap which only needs to be melted and not chemically reduced. This means three times less energy and no process-related CO_2 emissions. Furthermore, the steel scrap is melted with electricity. If the electricity is generated by renewables sources, the remaining CO_2 emissions come from natural gas and coal which are required for process control, but only on a small scale.

Risk pass-through mechanism. Primary steel production currently emits 1.3 to 1.8 ton CO_2 per ton of crude steel. With increasing CO_2 certificate prices, the costs for CO_2 can make up to one fourth of the total production costs in an ACT scenario by 2050 (Morfeld et al. 2015). Decreasing the CO_2 intensity could become an import leverage for steel producers to gain a competitive advantage as most of the production inputs like coal, iron ore as well as the product crude steel are globally traded bulk commodities. Failing to decrease CO_2 intensity in relation to competitors could lead to lower market volumes and revenues.

Sources. Scenarios disclose total CO_2 emissions and total crude steel production generally at macro level (e.g. IEA 2016a, Greenpeace 2015). Some sector-specific organizations developing climate constrained scenarios disclose the indicator but only cover their region of interest (e.g. EUROFER 2013).

Method. For both scenarios, ETP 2016 2DS and 4DS global aggregated CO_2 intensity is computed by building the ratio of total final energy consumption and total crude steel production for the years 2010 until 2040. To compute the country-specific data, OECD statistical data on the sector's fossil fuel related CO_2 emissions by country in 2014 is used and put it into relation to the total crude steel production from World Steel Association 2016. The global CO_2-intensity is lower compared to ETP 2016 as the OECD statistical data does not include process-related CO_2 emissions e.g. originating from reducing iron oxide. Thus, OECD CO_2 emission data is used as a correction factor of ETP global CO_2 emissions. The country-specific intensity is forecasted until 2025 in linear relation to the production shares of the respective region (i.e. Latin-America, USA and Canada, Europe) provided in ETP 2015. Based on the development pattern during 2015 to 2025, the country-specific intensities are then forecasted in relation to the global intensity of ETP 2016.

Results. In 2040, the CO_2-intensity under both scenarios will differ significantly. In the LCT scenario, the CO_2 intensity needs to be reduced by only 12% until 2040 compared to 2015. In contrast, the ACT requires a 53% reduction. The less ambitious reduction in the LCT is to some degree the result of the high marginal CO_2 abatement costs relative to other sectors. The CO_2 intensity varies among countries depending on the secondary steel share, energy efficiency and fuel types. For instance, as of today, Brazil has a comparatively high energy intensity but utilizes biomass (e.g. Biochar). Countries with a lower intensity like Italy and Mexico are more limited in low cost CO_2 abatement options (e.g. higher share of electrical steel) and are required to reduce intensity by 15-20% in the ACT scenario by 2040. Countries like France and Brazil with a higher CO_2-intensity are required to reduce it about 30% until 2040 in comparison to 2015.

TABLE 4.4 GLOBAL AND COUNTRY-SPECIFIC AGGREGATE CO_2 INTENSITY IN THE ACT AND LCT SCENARIOS (T CO_2/T CRUDE STEEL) (SOURCE: AUTHORS, BASED ON IEA ETP 2016, 2015, OECD 2016, WSA)

Country	2015	2020		2025		2030		2035		2040	
		ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT
World	1.7	1.6	1.8	1.4	1.7	1.1	1.6	1.0	1.6	0.8	1.5
Brazil	1.1	1.1	1.1	1.1	1.1	0.9	1.0	0.8	1.0	0.8	0.9
France	1.1	1.0	1.1	1.0	1.1	0.8	1.0	0.8	1.0	0.7	1.0
Germany	0.8	0.8	0.8	0.8	0.8	0.7	0.8	0.6	0.8	0.6	0.7
Italy	0.5	0.5	0.5	0.5	0.5	0.4	0.5	0.4	0.5	0.4	0.4
Mexico	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6
USA	0.9	0.8	0.8	0.8	0.8	0.7	0.8	0.6	0.8	0.6	0.7

4.5 CRUDE STEEL PRICE

Overview. Crude steel is a heavily traded commodity. The rapid growth in steel production during the first decade of the 21st century and the financial and economic crisis resulted in a global oversupply of steel. Subsequently, steel prices dropped by more than 50% compared to their peak price in 2008 and continued to experience a high volatility in a comparatively low price band until today.

Risk pass-through mechanism. In contrast to crude steel prices, production costs including raw material prices such as iron ore and steel scrap tend to be more stable. Thus, steel producer's margins are highly impacted by the highly volatile price of steel.

Sources. There is no specific steel price associated with a 2°C or less ambitious scenarios. Estimates around future steel prices range widely. The price of crude steel is in general influenced by three factors: steel demand, steel production, and production costs. The first two factors are covered by the steel production indicator (see Page 45), assuming that the future supply and demand matches. Other authors use global energy system models. For example, Morfeldt et al. 2015, uses a global energy system model and a scrap availability assessment model to analyse the relationship between steel demand, recycling and the availability of scrap and their implications for steel production costs in different regions for 2060 and 2100.

Method. For the LCT scenario, regional crude steel prices of the "reference scenario" of Morfeldt et al. 2015 are used. This scenario assumes steel demand stagnation in 2100. For the ACT scenario, the "RF climate" scenario including CCS is used. Thus, this scenario is expected to be largely in line with IEA's 2D scenario assumptions. Morfeldt et al. 2015 lists prices only for 2060. Current regional prices are thus used to interpolate the prices from 2015 to 2040.

Crude steel prices of Morfeldt et al. 2015 are not directly translatable to currently traded benchmarks for steel commodities such as Hot Rolled Coils (HRC) as they represent end products whilst Morfeldt et al. 2015 represent an intermediate product. Therefore, raw material costs of Morfeldt et al. 2015 are compared against current raw material costs and no margins are applied following the findings of DBS Group (DBS 2017). A constant correction factor to adapt the price to HRC steel is used.

Results. In contrast to the historical HRC price development which tends to have a high fluctuation, the forecasted price for HRC increases steadily in both scenarios until 2040. This price behaviour can be related to the choice of method. In the LCT scenario, a price increase of 7% is expected until 2040 compared to 2015. This is less than the increase of energy carriers and CO_2 certificate prices in the LCT. In the ACT, the steel price increase by 33% until 2040 compared to 2015 due to the higher CO_2 certificate costs and the higher capital expenditures for low carbon technologies.

TABLE 4.5 GLOBAL PRICE DEVELOPMENT HRC OF CRUDE STEEL (USD/TON) (SOURCE: AUTHORS, BASED ON MORFELD ET AL. 2015, BDS 2017, WSE 2016, SOTN 2017)

Scenario	2015	2020	2025	2030	2035	2040
LCT	350	355	359	364	369	373
ACT	350	373	396	420	443	466

4.6 RAW MATERIAL PRICES

Overview. Raw material costs play a significant role in the production cost structure of steel. In terms of electric or secondary steel, raw material costs can make up to two third of the total production costs, while for primary steel, raw material costs can contribute up to one third of the total production costs. The main raw material for primary steel production is iron ore. For secondary steel production it is steel scrap.

Risk pass-through mechanism. From an economic perspective, both steels, i.e. primary and secondary steels, have the same attributes and are, thus, the same commodity with the same price. However, both have a highly different cost structure. For instance, a relative increase in steel scrap (for secondary steel) price in comparison to iron ore price (for primary steel) will increase production costs for electric steelmaking, but have a more limited effect on the global steel price. Thus, the margin for electrical steel making decreases in comparison to primary steel making.

Sources. As with crude steel prices, there are no specific raw material prices associated with 2°C or alternative less ambitious scenarios. The raw material prices are in general influenced by three factors: steel demand, steel production and production costs. The first two factors are covered by the steel production indicator (see Page 45), assuming matching supply and demand. Production costs are generally addressed in sector-specific literature (e.g. Morfeldt et al. 2015) although few publications on the topic exist.

Method. For the LCT scenario, the scrap and iron ore prices of the “reference scenario” of Morfeldt et al. 2015 are used. These prices assume a steel demand stagnation in 2100. For the ACT scenario, the “RF climate” scenario including CCS is used. Morfeldt et al. 2015 lists prices only for 2060. Thus current prices are used to interpolate the prices for 2015 until 2040. Current prices cost structure is taken from SOTN 2017.

Results. In contrast to the historical steel scrap and iron ore price development which tends to have a high fluctuation, the forecasted prices increase steadily in both scenarios until 2040. This is mostly related to the choice of method. In the LCT scenario, a steel scrap price increase of 11% until 2040 compared to 2015 is expected. This is less than the increase of energy carriers and CO_2 certificate prices in the LCT. In the ACT scenario, the steel scrap price increases by 50% until 2040 compared to 2015 due to the higher CO_2 certificate costs and the higher capital expenditure for low carbon technologies.

TABLE 4.6 GLOBAL PRICE DEVELOPMENT FOR STEEL SCRAP AND IRON ORE IN USD PER TON OF CRUDE STEEL (USD/TON) (SOURCE: AUTHORS, BASED ON MORFELD ET AL. 2015, SOTN 2017)

Scenario	Commodity	2015	2020	2025	2030	2035	2040
LCT	Steel scrap	195	199	204	208	213	217
	Iron ore	89	89	89	89	89	89
ACT	Steel scrap	195	215	235	255	274	294
	Iron ore	89	89	89	89	89	89

4.7 ALLOCATION OF FREE CO_2 ALLOWANCES

Overview. The combination of high production volumes and high carbon intensity groups the iron and steel industry among the highest CO_2 emitters of all industry. Further, steel is a heavily traded commodity as demonstrated by its high trade intensity. Both characteristics -high carbon and high trade intensity- allow the steel sector to be qualified as a carbon leakage risk, meaning that there is a high risk that production will move to areas not with no or less ambitious climate policies. Some initiatives to minimize the risk are currently in place. As an example, in Europe, steel producers are granted a volume of free CO_2 allowances which are allocated according to CO_2 intensity benchmarks to minimize carbon leakage risk and their negative impacts on the national economy. The application of these mechanisms will be a key transition risk indicator for the steel industry.

Risk pass-through mechanism. Currently, primary steel production emits in the range of 1.3 to 1.8 ton of CO_2 per ton of crude steel. With increasing CO_2 certificate prices, production costs can be one fourth higher compared to an area not covered by CO_2 emission trading schemes or similar policies (Morfeld et al. 2015).

Sources. Neither IEA's Energy Technology Perspective nor its World Energy Outlook gives detail information on future CO_2 emission trading schemes or free CO_2 allowances. Third party sources focusing only on the steel industry analyze the carbon costs for the steel sector (e.g. Ecofys 2016), but these can be limited in geography.

Method. Due to the lack of scenarios for other geographies, it is assumed that future emission trading schemes in USA, Mexico and Brazil will follow a similar trend to that of the EU ETS. According to Ecofys, the European steel industry will face an annual shortage of free CO_2 allowances for direct emissions increasing from 32% in 2020 to 49% in 2030 based on the proposed ETS revision (Ecofys 2016).

The LCT scenario thus assumes a similar shortage of free CO_2 allowances across regions and countries with a linear extrapolation to 2040. The ACT scenario assumes that the proportion of CO_2 certificates is significantly increased beginning in 2030 with emission trading schemes or similar policies being implemented in all countries in scope, including Brazil. This roll-out of emission trading schemes to major steel producing countries reduces the carbon leakage risk and the need for free CO_2 allowances.

Results. In the LCT scenario, the annual shortage of free CO_2 allowances for direct emissions increases linearly from 32% in 2020 to 66% in 2040. Brazil, with no emission trading scheme in place according to IEA 2016, is an exception and has thus no shortage. In the ACT scenario, the emission trading scheme is rolled out to all regions in scope with no free CO_2 allowances after 2030.

TABLE 4.7 ANNUAL SHORTAGE OF FREE CO_2 ALLOWANCES FOR DIRECT EMISSIONS (% OF TOTAL CO_2 DIRECT EMISSIONS) IN THE ACT AND LCT SCENARIOS (SOURCE: AUTHORS, BASED ON ECOFYS 2016)

Year	EU		Brazil		Mexico		USA	
	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT
2020	32%	32%	32%	0%	32%	32%	32%	32%
2030	100%	49%	100%	0%	100%	49%	100%	49%
2040	100%	66%	100%	0%	100%	66%	100%	66%

5 CEMENT SECTOR

GENERAL OVERVIEW

The cement industry is responsible for about 5% of global anthropogenic carbon emissions, not only caused by combustion related emissions but also a result of process emissions (Mikulcic et al. 2013). The transition risk story for the sector articulates itself along a few trends:

- **Increasing demand for cement.** The demand for cement is largely influenced by economic developments and population growth as it is mostly used in form of concrete by the building industry. Demand is expected to remain stable in developed countries until 2030 and set to continue to increase in emerging economies.

- **Fade out of wet cement production routes.** Cement can be manufactured through four different routes: dry, semi-dry, semi-wet and wet process. The dry or wet state of its raw materials determines the use of the routes. Wet processes consume more energy and are therefore expected to fade out stepwise until 2030. Wet cement routes only play a minor role for the six countries in scope, therefore, this trend won't be considered in detail.

- **Declining clinker-to-cement-ratio.** The production of clinker is highly carbon-intensive. It emits on average about 60% of total CO_2 emissions in the production process (Moya et al. 2010). The demand for specialised cement has risen continuously during the last decades with more composite materials and additives currently being used. Thus, the clinker-to-cement-ratio is declining. This trend is expected to increase further in the future.

- **Shift from coal to less carbon-intensive fuels for cement kilns.** The shift from coal to secondary raw materials (e.g. biomass, waste and waste-related materials such as tyres, sludge and slag) could allow a substitution rate of about 80% from a technical point of view. In addition, the share of renewables in the electricity supply can cause a significant emission reduction.

The scenario involves the following parameters:

PRODUCTION & TECHNOLOGY

Cement production (Mt)
Clinker to cement ratio (%)
Energy intensity clinker production (GJ/t clinker)
CCS deployment (%)
CO_2 Intensity (t CO_2 / t cement)
Share of Alternative fuel use (%)

MARKET PRICING

Secondary fuel prices (USD/ton)

POLICY MANDATES, INCENTIVES & TAXES

Allocation of free CO_2 allowances (%)

5 THINGS BEFORE GETTING STARTED

1. **Demand vs. population growth.** Cement is one of the major building blocks of modern society and is general, correlated with population growth. Over the last 25 years, the global cement production has increased by roughly 400%, in particularly in emerging countries like China, Brazil and India. In industrialized countries like Germany and France cement production is stagnating or decreasing. With increasing global population, the demand for cement is expected to continue to increase unevenly across the globe. This relationship is also known as the cement frown or scowl, as demand increases and then decreases with GDP per capita growth.

2. **Abatement potential.** The production of cement is one of the largest CO_2 sources of all industries. Global cement production is responsible for more than 3% of all anthropogenic CO_2 emissions. Besides the utilization of a range of fossil fuels such as coal and lignite, further process-related CO_2 emissions occur during the calcination from limestone to clinker which is the main ingredient in cement. Calcination is responsible for 50 to 75% of the total CO_2 emissions of cement production. Abating process-related CO_2 emissions is generally perceived as more challenging compared to energy-related CO_2 emissions, as major process changes or CCS retrofitting is required.

3. **Efficiency gains.** A comparatively high energy use combined with low prices for raw materials (e.g. limestone) and products result in one of the highest energy cost intensities in industry. Energy costs compose one third of the total production cost. Increasing the energy efficiency is often a viable option for cement producers to gain a competitive advantage as most of the production inputs like coal are commodities for which main competitors are likely to have similar raw material prices.

4. **Market size.** Cement is among the bulk commodities with the lowest value per weight or volume ratio. With the exception of some high-value white clinker cements, individual transportation of cement over distances longer than 200 km is usually not economically viable. Thus, the supply and demand for cement is regional and international trade intensity is very low.

5. **Carbon leakage risks.** Although cement is considered to be a regional product due to low value per weight ratio, making it unfavorable for imports, cement producers can be exposed to carbon leakage risks. In particular, in areas in close proximity to the sea or major rivers, transportation of the carbon-intensive clinker in bulk carrier ships from countries with no emission trading scheme or similar CO_2 taxes can be become economically viable. Thus, the imported clinker can be ground and mixed with additives in the destination country to produce the desired type of cement with no direct CO_2 emissions involved.

5.1 CEMENT PRODUCTION

Overview. Cement is one of the major building blocks of modern society. It is needed for buildings and infrastructure. Thus, cement demand can be correlated with population growth. Over the last 25 years, the global cement production has increased by roughly 400%. With increasing global population, the demand for cement is expected to continue to increase which implies more ambitious CO_2 intensity reductions to meet climate targets.

Risk pass-through mechanism. Due to a low share of product value to weight, cement is a locally traded product. Cement producers' revenues depend on local demand and supply. While in developing countries like India the demand for cement is steadily increasing, in developed countries like Germany, France and Italy demand has slightly decreased over the last 25 years. Here, overcapacities have put a lot of stress on revenue margins and sales volumes of cement producers. In areas with cement overcapacity, the utilization rate tends to be lower which has a negative effect on the energy intensity and on the specific production costs.

Sources. Scenarios generally present inputs around cement demand at macro-level (e.g. IEA 2016a, Green peace 2015). As an example, IEA (2016a, 2015) give cement production on a highly regional level for the OECD and non-OECD as a whole. The low demand scenario is comparable with IEA 2016a global cement production until 2050. Most sources correlate future cement demand with population growth.

Method. In line with the IEA Energy Technology Perspectives, it is assumed the same global cement demand and production under both climate scenarios. Historic crude steel production on a global level and for the countries in scope is taken from (WBSCD 2014). Country-specific demand for cement is forecasted by computing per capita production multiplied with the future population growth according to the United Nations (UN 2016). Historic per capita production is calculated similarly using UN data 2015, as well as information from the World Business Council on Sustainable Development 2014.

Results. Cement production is expected to increase steadily by 0.3% per on average over the next 35 years at global level. This is a significant reduction in growth compared to the more than 10% average cement production over the last 25 years. The countries in focus cover only about 5% of the global cement production in 2015. For the developed countries in focus, cement production is stagnating or will continue to slightly decrease over time. The USA, with an increase of more than 18% until 2040 in comparison to 2015, is an exception due to anticipated population growth. In contrast, Brazil and Mexico will roughly double their production during the same period, a trend driven by stronger population growth.

TABLE 5.1 GLOBAL AND COUNTRY-SPECIFIC CEMENT PRODUCTION (MT) FOR BOTH SCENARIOS (SOURCE: AUTHORS, BASED ON IEA ETP 2016a, WBCSD 2014, UN 2015)

Country	2015	2020	2025	2030	2035	2040
World	4 074	4 318	4 357	4 387	4 394	4 520
Brazil	53	59	65	71	76	80
France	17	17	18	18	18	18
Germany	34	33	33	32	32	31
Italy	18	18	17	17	17	17
Mexico	40	45	51	56	61	65
USA	56	58	61	64	65	66

5.2 CLINKER TO CEMENT RATIO

Overview. Standard cements like Portland Cement consists of more than 90% clinker. In any kind of cement type, clinker is the major ingredient. The production of clinker is energy and carbon intensive. Over time, cement producers substitute some part of the clinker with cheap by-products like fly ash and granulated blast furnace slag to improve cement properties, but also to reduce production costs. These clinker substitutes are generally accounted as carbon neutral for cement producers, as their CO_2 emissions have already occurred elsewhere during their production e.g. in coal fired power plants and blast furnaces for steel production. Thus, a higher share could reduce the direct CO_2 emissions. However, some of the clinker substitutes require a higher grinding effort, which increases electricity intensity and indirect CO_2 emissions.

Risk pass-through mechanism. The production of cement is regarded as the industrial process with the highest CO_2-intensity, when referencing intensity to product value. In the light of rising CO_2 certificates, failing to increase clinker to cement ratio could lead to higher production cost in comparison to competitors and loss in margins and sales volumes. Furthermore, cement types with a lower clinker ratio tend to be of higher quality (e.g. acid-resistance, quicker drying) and value. Having access to clinker substitutes and the knowledge as well as the machinery to produce high quality cements can be a competitive advantage.

Sources. Scenarios generally report the clinker to cement ratios at macro level (e.g. IEA 2016, Greenpeace 2015). As an example, the IEA's Global Cement Roadmap 2050 gives clinker to cement ratios on a regional level (e.g. Latin America, USA and Canada, EU25) for 2030 and 2050 in a low and high demand scenario.

Method. In line with the IEA (2016a, 2015), the same clinker to cement ratio is assumed under different climate targets. World estimates are taken from IEA 2016e. Country estimates are computed as follows:

- Historic ratios are taken from WBSCD 2014. Mexico's ratio is derived from Latin America.
- Ratios are forecasted following their respective regional estimates (e.g. North America for USA) of the IEA 2009 for the low demand scenario in 2030 and 2040. These estimates are comparable to ETP 2DS and 4DS estimates.
- Data between 2015 and 2040 is linearly interpolated.

Results. The clinker to cement ratio does not vary much among the countries in focus (67% to 75%) with the exception of the USA. The USA has a traditional high demand for standard cement. One of the reasons is that customers are not willing to pay the surcharge for high quality cement with lower clinker content. Increasing prices for CO_2 allowances will have a higher impact in standard cements with a higher carbon-intensive clinker content compared to cements with lower carbon-intensive clinker content reducing the surcharge and bringing the average clinker to cement ratio from 84% to 74%. In other countries, the clinker to cement ratio drops by less than seven percentage points due to already low ratios in the starting year.

TABLE 5.2 GLOBAL AND COUNTRY-SPECIFIC RATIO OF CLINKER TO CEMENT FOR BOTH SCENARIOS (SOURCE: AUTHORS, BASED ON IEA 2016A, 2016E, 2015, 2009, WBSCD 2014)

Country	2015	2020	2025	2030	2035	2040
World	65%	67%	68%	68%	68%	67%
Brazil	67%	66%	66%	65%	65%	65%
France	73%	72%	71%	70%	69%	68%
Germany	70%	69%	68%	67%	66%	65%
Italy	75%	74%	73%	72%	71%	70%
Mexico	69%	68%	68%	67%	67%	67%
USA	84%	82%	81%	79%	78%	77%

5.3 ENERGY INTENSITY FOR CLINKER PRODUCTION

Overview. For clinker production, the main ingredient of cement, temperatures of over 1350°C are required over a long period. These temperatures are reached by burning a range of solid fossil fuels like coal and lignite. The high energy use makes the production of cement one of most energy-intensive industries in the world. Energy intensity has improved significantly over time (e.g. change from wet processes to the use of semi-dry and dry kilns). A dry kiln with high heat integration can reach less than half the energy intensity of older semi-wet or wet kilns. The recent trend of bigger cement plants with ten times more the capacity of a typical European plant affects thermal energy intensity positively due to reduced thermal losses.

Risk pass-through mechanism. The high energy use combined with comparatively low raw materials prices (e.g. limestone) and products, results in one of the highest energy cost in industry. Energy costs usually account for one third of the total production cost. Increasing energy efficiency is often a viable option for cement producers to gain a competitive advantage. Failing to decrease energy intensity in relation to local competitors could lead to lower market volumes and revenues.

Sources. Scenarios generally present total final energy consumption and total crude steel production at macro level. For instance, the IEA's Global Cement Road Map 2050 reports thermal energy intensity at regional level (e.g. Latin America, USA and Canada, EU25) for 2030 and 2050 in a low and high demand scenario. Sector specific studies show cost-effective and technical energy efficiency potentials considering mutual interaction with energy efficiency measures in specific geographies (e.g Brunke & Blesl 2014b).

Method. The ACT and LCT scenarios take as basis ETP's global aggregated energy intensity data built from the ratio of total final energy consumption and total cement production and weighting it with the respective clinker to cement ratio until 2040. In the ACT scenario, the ratio of the regional forecast of energy consumption (e.g. Latin America, EU25 and USA and Canada), and 2015's population-production forecast of UN's World Population Prospects for each region is applied to the current energy intensity of the countries in scope. Mexico's energy intensity corresponds to the average intensity of Latin America due to lack of country data. For the LCT, the relationship of 4DS and 2DS energy intensities of IEA is calculated and applied to the country-specific energy intensities of the ACT scenario.

Results. In both scenarios, the energy intensity in clinker production is reduced by 6% until 2040 compared to 2015 levels. While in the ACT scenario, energy intensity steadily decreases by 10% until 2025 compared to 2015, it increases after 2025 due to higher energy requirements of low carbon technologies. In the LCT scenario, energy intensity declines steadily until it reaches the same level of the ACT in 2040. The countries in focus have a consistent higher energy intensity than the global average figures. This can be explained by the vast majority of high capacity greenfield cement plants in India and China which have been installed over the last decade. Plant operators in Germany and France need to reduce energy by 10% and Italy in until 2040 and require additional capital due to higher energy intensity reductions and the high cost of brownfield plants retrofit.

TABLE 5.3 GLOBAL AND COUNTRY-SPECIFIC ENERGY INTENSITY FOR CLINKER PRODUCTION (GJ/T CLINKER) FOR ACT AND LCT SCENARIOS (SOURCE: AUTHORS, BASED ON IEA 2016A, 2015, 2009)

Country	2015	2020		2025		2030		2035		2040	
		ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT
World	3.5	3.3	3.5	3.1	3.4	3.2	3.4	3.2	3.4	3.3	3.3
Brazil	3.5	3.4	3.5	3.3	3.5	3.2	3.4	3.3	3.4	3.4	3.5
France	3.9	3.7	3.9	3.5	3.8	3.4	3.6	3.4	3.5	3.4	3.5
Germany	3.8	3.6	3.8	3.4	3.7	3.3	3.5	3.3	3.4	3.3	3.4
Italy	3.6	3.5	3.6	3.3	3.5	3.1	3.3	3.1	3.3	3.2	3.3
Mexico	4.2	4.1	4.3	4.0	4.2	3.9	4.1	4.0	4.1	4.1	4.2
USA	3.8	3.6	3.7	3.3	3.5	3.1	3.3	3.1	3.2	3.1	3.2

5.4 SHARE OF ALTERNATIVE FUEL

Overview. The production of cement is associated with a high energy usage to reach and maintain high process temperatures required for the calcination of lime to clinker. Cement operators utilize a wide range of solid fossil fuels like coal and lignite. Fossil fuels are responsible for more than 30% of the total CO_2 emissions of cement production. With rising coal prices, cement producers sought for cheaper energy carriers and started to use alternative fuel mixes. The process temperatures of above 1350°C allow the use of a wide range of alternative fuels from wastes (e.g. waste tyres, waste oil and solvents, pre-treated industrial and domestic wastes, plastic, textile and paper wastes) to biomass (e.g. animal meal, waste wood, sawdust and sewage sludge) with a, in general, lower calorific value (CSI 2009).

Risk pass-through mechanism. A higher share of alternative fuel use can reduce production costs for cement operators nowadays and will even more in the future. Alternative fuels tend to have lower specific costs in relation to their calorific value and a lower CO_2 intensity depending on the share of carbon neutral biomass in the fuel mix. However, the use of alternative fuels is limited to the local situation (i.e. prices and availability), additional preparation time to burn the fuel (e.g. drying and homogenization) and the retrofit of clinker kilns to allow for higher shares of alternative fuels. Cement producers, who are not able to utilize higher shares of alternative fuels due to technical or market-related restrictions, can thus lose competitiveness.

Sources. Scenarios generally present alternative fuels share of macro-level (e.g. ETP). IEA's Global Cement Roadmap 2050 reports the share of alternative fuels at regional level (e.g. Latin-America, EU25, USA and Canada) for 2030 and 2050. Sector specific studies consider an increase in the share of alternative fuels in specific geographies (e.g Brunke & Blesl 2014b).

Method. It is assumed that both scenarios have the same development of alternative fuel shares, since an increase of alternative fuels can be economically beneficial even with lower CO_2 certificate prices. World estimates are taken from IEA 2016e. Country estimates are then computed as follows:

- Country-specific historic data on alternative fuel use is taken from of WBSCD 2014. The Latin American average is applied to Mexico. These shares are compared to the global average provided in IEA's Global Cement Roadmap 2050 and it is assumed that countries with a current higher share need to achieve less relative growth.
- Country-specific alternative fuel use is forecasted using the regional shares from IEA's Global Cement Roadmap 2050 for 2030 and 2040.

Results. The share of alternative fuels increases globally from 10% in 2015 to 32% in 2040. Germany and France will have the highest share of alternative fuels in 2040, partly helped by the well-established infrastructure for collection industrial and households wastes in place. Although some cement plants in Germany claimed the possibility to use 100% alternative fuels, the alternative fuel share is limited to 90% as some fossil fuels are required for process control.

TABLE 5.4 GLOBAL AND COUNTRY-SPECIFIC SHARE OF ALTERNATIVE FUELS IN THE PRODUCTION OF CLINKER IN BOTH SCENARIOS (SOURCE: AUTHORS, BASED ON IEA 2016A, 2016E, 2015, 2009, WBSCD 2014)

Country	2015	2020	2025	2030	2035	2040
World	19%	22%	25%	28%	32%	36%
Brazil	19%	23%	27%	30%	35%	39%
France	37%	41%	44%	47%	49%	51%
Germany	65%	68%	72%	76%	80%	83%
Italy	13%	16%	19%	22%	24%	26%
Mexico	15%	18%	21%	23%	27%	30%
USA	15%	19%	23%	26%	29%	31%

5.5 CCS DEPLOYMENT

Overview. Besides the utilization of a range of fossil fuels such as coal and lignite, further process-related CO_2 emissions occur during the calcination from limestone to clinker. Calcination is responsible for 50 to 75% of the total CO_2 emissions of cement production, depending on the clinker to cement ratio. By extension, CO_2 reduction through increased shares of alternative fuels with lower carbon intensity are limited. One option for the cement sector to contribute to climate targets would therefore be CCS.

Risk pass-through mechanism. With the expected increase of CO_2 certificates, cement producers would need to pay 30% of the total production costs for CO_2 certificates in 2050, when continuing to produce with the same carbon intensity (Brunke & Blesl 2014a). Cement producers failing to deploy CCS would therefore risk losing competitiveness which could lead to lower market volumes and revenues.

Sources. Scenarios generally present CCS deployment for cement production at macro-level. In some cases, the amount of CO_2 captured through CCS is listed for the industry as whole, but not for cement individually (IEA 2016a). Furthermore, the cement sector is rather skeptical of CCS and the topic is hardly covered. For instance, CSI 2009 excludes CCS as a CO_2 reduction mechanism due to barriers, such as technological challenges (e.g. availability of the full CCS chain including infrastructure), settlement of legal requirements and public acceptance. In a questionnaire conducted by the authors among experts on industrial efficiency during the Industrial Summer Study 2016 of the European Council for Energy Efficient Economy (ECEEE) in Berlin, 6 out of 9 participants stated that CCS deployment in Europe will develop similar to the IEA's 4DS scenario.

Method. In both, the ACT and LCT scenarios, the assumptions are based on ETP 2016 global aggregated CO_2 captured emissions data for the total industry from 2015 until 2040. The aggregate figures are broken down to regions (i.e. Latin-America, USA and Canada, and EU25) using the Global Cement Roadmap 2050 data on CO_2 captured for the years 2030 and 2040. Country-specific CO_2 emissions estimates under the ACT and LCT scenarios (see next section) are then used to further break-down regional data (e. g. USA and Canada) to country data (e. g. USA).

Results. CCS deployment differs significantly between the scenarios. While in the ACT scenario, 18% of the global CO_2 emissions occurring from cement production are captured by CCS by 2040, in the LCT scenario only 7% are captured. Countries with a higher CO_2-intensity like Mexico, Brazil and the USA should deploy CCS at a higher rate compared to Germany, France and Italy in both scenarios. CCS deployment has, among the CO_2 abatement options, the highest CO_2 abatement costs and can be regarded as a last resort for cement producers. Countries with higher CCS deployment can have less access to cheap and low carbon alternative fuels or to clinker substitutes, or are required to produce cement types with a higher clinker to cement ratio.

TABLE 5.5 GLOBAL AND COUNTRY-SPECIFIC SHARE OF CO_2 CAPTURED IN THE ACT AND LCT SCENARIO (SOURCE: AUTHORS, BASED ON IEA 2016A, 2015, 2009 AND WBSCD 2014)

Country	2015	2020		2025		2030		2035		2040	
		ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT
World	0%	0%	0%	3%	1%	5%	2%	11%	5%	18%	7%
Brazil	0%	0%	0%	3%	1%	7%	3%	15%	6%	24%	8%
France	0%	0%	0%	2%	1%	4%	1%	9%	3%	15%	5%
Germany	0%	0%	0%	2%	1%	4%	1%	9%	3%	15%	5%
Italy	0%	0%	0%	2%	1%	4%	1%	9%	3%	15%	5%
Mexico	0%	0%	0%	3%	1%	7%	3%	15%	6%	24%	8%
USA	0%	0%	0%	3%	1%	5%	2%	11%	4%	17%	6%

5.6 CO_2 INTENSITY

Overview. The production of cement is one of the largest CO_2 sources of all industry. The CO_2-intensity depends on a wide range of factors including thermal energy intensity, capacity, alternative fuel use, clinker to cement ratio and CCS.

Risk pass-through mechanism. Without disruptive adaptive measures, CO_2 certificate costs can make up for 30% of the total production costs in the in 2050. Thus, reducing the CO_2 intensity is a necessary option for cement producers to gain a competitive advantage. Failing to decrease CO_2 intensity in relation to local competitors could lead to lower market volumes and revenues.

Sources. Scenarios generally present CO_2 intensity at macro-level. For instance, the IEA's Global Cement Roadmap 2050 discloses CO_2 intensity of a regional level (i.e. Latin-America, USA and Canada, EU25) for 2030 and 2050 in low and high demand scenario. Sector specific studies show the cost-effective reduction potential of CO_2 intensity when considering mutual interaction with CO_2 reduction measures and no disruptive innovations for some specific geographies (e.g Brunke & Blesl 2014b).

Method. Both the ACT and LCT scenarios are based on data of ETP 2DS and 4DS scenarios. The global aggregated CO_2 intensity is computed by building the ratio of total cement CO_2 emissions and total cement production for 2010 until 2040. For country-specific data, WBSCD 2014 data is used for each country, except for Mexico, where Latin America data is used. Country-specific CO_2-intensity is forecasted using an carbon intensity factor developed by the authors. This factor has a positive linear relation with energy intensity and the clinker to cement ratio, and a negative relation to share of alternative fuels in the fuel mix and share of CO_2 captured to total CO_2 emissions.

Results. In contrast to energy intensity, the CO_2 intensity in the ACT and the LCT scenario decreases by more than 15% until 2040 in comparison to 2015. New quality cement types and higher alternative fuels shares increase the energy intensity and analogously the CO_2 intensity but at a lower rate until 2020. After 2020, the CO_2 intensity decreases steadily until 2040 at a global and country level. Although countries like Brazil, Germany, France and Italy have a higher energy intensity compared to the global average, the actual CO_2 intensity is less or close to the average due to higher shares of alternative fuels and lower clinker to cement ratios. These countries reduce their CO_2-intensity mainly due to higher shares of alternative fuels in the fuel mix.

TABLE 5.6 GLOBAL AND COUNTRY-SPECIFIC RATIO OF CO_2 INTENSITY FOR BOTH SCENARIOS (SOURCE: AUTHORS, BASED ON IEA 2016A, 2015, 2009, WBSCD 2014)

Country	2015	2020		2025		2030		2035		2040	
		ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT
World	0.6	0.6	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5
Brazil	0.6	0.5	0.6	0.5	0.5	0.5	0.5	0.4	0.5	0.4	0.5
France	0.6	0.6	0.6	0.5	0.6	0.5	0.5	0.4	0.5	0.4	0.5
Germany	0.6	0.5	0.6	0.5	0.5	0.4	0.5	0.4	0.5	0.4	0.4
Italy	0.7	0.6	0.7	0.6	0.6	0.5	0.6	0.5	0.5	0.5	0.5
Mexico	0.6	0.6	0.6	0.5	0.6	0.5	0.5	0.4	0.5	0.4	0.5
USA	0.7	0.7	0.7	0.6	0.7	0.5	0.6	0.5	0.5	0.4	0.5

5.7 SECONDARY FUEL PRICES

Overview. Secondary fuel prices vary between the regional markets. Differences are primarily due to transportation costs, infrastructure constraints, local demand, fossil fuel prices and composition of secondary fuels. Secondary fuel for the cement industry comprises wastes (e.g. waste tyres, waste oil and solvents, pre-treated industrial and domestic wastes, plastic, textile and paper wastes) and biomasses (e.g. animal meat, waste wood, sawdust and sewage sludge). The types of wastes and biomasses vary greatly regarding caloric heating value, CO_2 emissions and price. Depending on the type of fuels, transportation costs make a significant share of the total price. Due to the increasing demand for waste fuels, e.g. cement plants and district heating, industrial and domestic waste is traded internationally. The burning of some types of wastes, e.g. hazardous waste from hospitals or industry, can provide additional monetary benefits for cement producers.

Risk pass-through mechanism. Secondary fuel usage provides a significant reduction of operating costs for cement producers in comparison to fossil fuel usage. Even more important in the future, secondary fuels can have significantly lower CO_2 intensity compared to fossil fuels which reduces costs for CO_2 allowances.

Sources. To derive one secondary fuel price for a nation is generally a challenging task. First, prices vary significantly depending on the composition as high caloric wastes such as waste oil or waste tyres as they tend to be of more value than low caloric wastes such as municipality waste. Second, a significant part of the price depends on regional infrastructure for collecting, transporting and sorting. Third, the competition for secondary fuels or wastes depend on local district heating and cement plants. To the knowledge of the authors, there is no comprehensive listing of regional secondary fuel prices available. McKinsey 2008 states a global long-term price for secondary fuels in relation the primary fuel costs in their report on the impact of emissions trading in Germany.

Method. From an economic perspective, the price of secondary fuel should relate to the respective caloric value of the secondary fuel in relation to the displaced fossil fuel, i.e. coal. The caloric value of secondary fuel ranges widely from 25% to 125% of the caloric value of coal. Additionally, solid waste has on average less than a half of the caloric value of coal (EC 2013). Thus, for achieving the same energy content, twice the amount of secondary fuel compared to coal is required. Additionally, some retrofitting is required to use the inhomogeneous fuel type in cement kiln which increases opportunity costs. McKinsey 2008 states a price of 7% for 2010, 15% for 2015 and a long-term price of 40% in relation to the primary fuel, which is coal. A gradual increase from 40% to 50% until 2040 is expected due to an increasing demand together with increasing CO_2 allowance prices.

Results. With increasing demand of secondary fuels, the secondary fuel price in relation to the coal price increases from 25% in 2015, to 40% in 2020 and 46% in 2040. The secondary fuel share in the energy mix is identical for both scenarios since CO_2-induced incentives through reduced CO_2-intensity are considerably lower than the incentive from the lower energy carrier price.

TABLE 5.7 SECONDARY FUEL PRICE AS A PERCENTAGE OF COAL PRICES (USD/TON) FOR LCT AND ACT (SOURCE: AUTHORS, BASED ON MCKINSEY 2008)

	2010	2015	2020	2025	2030	2035	2040
World	7%	25%	40%	40%	42%	44%	46%

5.8 ALLOCATION OF FREE CO_2 ALLOWANCES

Overview. The combination of high production volumes and high carbon intensity groups the cement industry among the highest CO_2 emitters of all industries. In addition, cement is a bulk commodity with the lowest value and a value-added in relation to its CO_2 emissions. Energy costs are close to 50% of the value-added which indicates a carbon leakage risk (Brunke & Blesl 2014b). As for the steel sector, in Europe, cement producers are granted a volume of free CO_2 allowances which are allocated according to CO_2 intensity benchmarks to minimize carbon leakage risk and their negative impact on the national economics.

Risk pass-through mechanism. Cement production emits 0.5 to 0.8 ton CO_2 per ton of cement nowadays. An increase of CO_2 allowance price to 50 EUR/t CO_2 could lead to more than 30% of CO_2 costs in relation to the sector's typical value-added (Brunke & Blesl 2014b).

Sources. Neither IEA's Energy Technology Perspective nor its World Energy Outlook give detailed information on future CO_2 emission trading schemes or free CO_2 allowances. No source on how free CO_2 allowances for the cement sector could evolve was found during the literature review carried out in this study.

Method. The forecast of the cement sector is aligned to that of the steel sector due to the lack of information of free CO_2 allowances post-2020 for the cement industry. This assumption is based on the similar share the steel and cement sectors have in the overall EU ETS emissions from and allocations allowances to the industrial sector in 2015 (Sandbag 2016). The estimates of free CO_2 allocation allowances from Ecofys 2016 (see page 51) are taken as base and it is assumed that future emissions trading schemes in USA, Mexico and Brazil will follow the EU trend. Ecofys 2016 suggest that the European steel industry will face an annual shortage of free CO_2 allowances for direct emissions increasing from 32% in 2020 to 49% in 2030 based on the proposed ETS revision. Thus, in the LCT scenario a similar shortage of free CO_2 allowances across the regions will occur. Values until 2040 are extrapolated. In the ACT scenario, CO_2 certificates are significantly increased beginning of 2030 and emission trading schemes or similar policies are implemented in all region in scope, including Brazil.

Results. In the LCT scenario, the annual shortage of free CO_2 allowances for direct emissions increases linearly from 32% in 2020 to 66% in 2040. Brazil with no emissions trading scheme in place according to IEA 2016 is an exception and has thus no shortage. In ACT scenario, the emission trading scheme is rolled out to all regions in focus with no free CO_2 allowances after 2030.

TABLE 5.8 ANNUAL SHORTAGE OF FREE CO_2 ALLOWANCES FOR DIRECT EMISSIONS IN CEMENT PRODUCTION (% OF TOTAL CO_2 DIRECT EMISSIONS) (SOURCE: AUTHORS, BASED ON IEA ETP 2016, 2015, ECOFYS 2016)

Year	Brazil		EU		Mexico		USA	
	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT
2020	32%	0%	32%	32%	32%	32%	32%	32%
2025	66%	0%	66%	41%	66%	41%	66%	41%
2030	100%	0%	100%	49%	100%	49%	100%	49%
2035	100%	0%	100%	58%	100%	58%	100%	58%
2040	100%	0%	100%	66%	100%	66%	100%	66%

6 AVIATION SECTOR

GENERAL OVERVIEW

The transition risk story for the aviation sector articulates itself through three trends:

- **Changes in volume.** Demand for international flights is expected to grow on average 4%-5% annually in the coming decades (ICAO 2016a). In contrast, a 2°C transition would be associated with a low-demand scenario for air travel as consumers switch to rail, information technology, and local travel. Policy signals (e.g. carbon prices, incentives for rail travel, etc.) are likely to impact this. Modal switch, whether market or consumer driven, may thus play a key role in shifting volume, as well as unexpected macro trends (e.g. terrorism, pandemics, etc.).

- **Scaling of alternative fuels**. The scale up of alternative fuels will respond to evolving market standards (e.g. approval of blends for commercial use), development of country-specific policy goals (e.g. targets on biofuel consumption) and further extension of international organizations and coalition targets (e.g. continuation of IATA's and ICAO's fuel efficiency targets through to 2050).

- **Efficiency gains.** Fuel efficiency gains will come from two main sources: technological improvements related to the airplane itself (e.g. aerodynamics, designs, material substitution) and more sophisticated traffic management and infrastructure use (e.g. satellite navigation, optimization of control centres). The International Civil Aviation Organization (ICAO) has set a medium-term goal to improve fleet-fuel efficiency by 2% per year through 2020. Over the last years, this goal has been surpassed with annual average improvements of 3.9% IEA 2016a.

The scenarios presented here cover passenger aviation.

The scenario involves the following parameters:

PRODUCTION & TECHNOLOGY	
Demand (passenger-kilometres) Fuel efficiency (g fuel/revenue passenger km)	Biofuel Penetration (%)
MARKET PRICING	
Jet fuel prices (USD / gallon)	
POLICY MANDATES, INCENTIVES & TAXES	
Carbon credit mandates (# and Euro/t CO_2) Fuel efficiency standards (kg/km)	

5 THINGS BEFORE GETTING STARTED

1. **International vs. National Aviation.** Distinction between perspectives in international and national aviation are necessary to reduce the uncertainty around the quantification of transition risks. It is estimated that under the ACT Scenario, aviation will be near equally affected by carbon taxes and the shift to rail transport, while the first affects both international and domestic segments, the second is expected to represent a higher risk for domestic aviation (Table 6.1).

2. **Governance.** Governance in the aviation sector follows a two-fold approach. Governments are responsible for setting measures to decrease or control domestic emissions, while international emissions are covered by the measures set by the International Civil Aviation Organization (ICAO). Thus, alignment and coordination between both parties is required to follow an efficient application of the measures.

3. **International Targets.** ICAO has set two main goals: to improve annual fuel efficiency by 2% and to stabilize international aviation emissions at 2020 levels. To achieve this, it has developed a set of measures including, the CO_2 Emissions Certification Standard (see Page 69) targeting technology improvements, a Global Air Navigation Plan targeting operational improvements and a carbon-offsetting program (see Page 68) to compensate those emissions that surpass 2020 levels. ICAO has however not set any targets on the uptake of Sustainable Alternative Fuels (SAF). In the countries in scope, the initiatives come from governments (e.g. US and EU) and the private sector (e.g. Mexico and Germany).

4. **Biofuel Prices.** The price of biofuels will have a major role in increasing the uptake of Sustainable Alternative fuels. Currently there are few scenarios modelling the changes in biofuel prices for aviation. In the US, the Energy Information Administration has estimated that in 2020 prices could be in the range of 1€/L - 1.4€/L, an increase of 0.6€/L and 1€/L respect to jet fuel prices under a low oil price scenario. Recent estimates for Europe suggest that the additional costs could reach 1.20 €/L, representing an increase of 4.3€ per passenger in a 1000 km flight (Insight_E 2015).

5. **Market-based Measures.** The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) is the first scheme regulating international emissions. It applies to all international routes except those to or from Least Developed Countries, Small Island Developing States or Landlocked Developed Countries. The program will start in 2021 in a voluntary basis until 2026. It is currently scheduled to last until 2035. The application of CORSIA is seen as a potential material risk for companies. Changes in three factors will determine the impact of the measure to the company: i.) fuel efficiency; ii.) demand, and iii.) the cost of an offset.

TABLE 6.1 REDUCTION OF WORLD AIR TRANSPORT BY DRIVER (GPKM & SHARE IN TOTAL GPKM) (SOURCE: AUTHORS, BASED ON IEA 2016)

Driver	2020	2025	2030	2035	2040
Carbon tax	162 (2%)	553 (6%)	1 066 (9%)	1 783 (13%)	2 541 (16%)
Rail transport	214 (3%)	566 (6%)	1 024 (9%)	1 588 (12%)	2 335 (14%)

6.1 DEMAND

Overview. ICAO estimates that global passenger traffic is expected to grow from 5 billion to more than 13 billion RPK (Revenue Passenger-Kilometer) over the period 2010-2030 (i.e. average annual growth rate of 4.9%). Under the scenarios developed here, the demand captures changes that could correspond to: i.) Modal shifts from air travel to High-Speed Rail (HSR); and ii.) Changes in the economics of air travel due to carbon pricing or other policy instruments.

Risk pass-through mechanism. A change in demand can be translated to a change in the average load factor of a company, thus having a direct effect on passenger revenues. Companies with long-term ownership of long-term assets purchased under growth assumptions that will not materialize are likely to be the most exposed to changes in volume.

Sources. Demand is generally modelled using external variables such as GDP and population projections, however, long-term changes are generally modelled using assumptions around changes in the connectivity of supply networks (e.g. OECD 2016, Boeing 2016) or substitution of air by rail transport (e.g. IEA 2016a, Greenpeace 2015). Modelling the sector's demand requires considering changes in domestic and international operations as both segments may behave differently in the transition, thus having a different impact at company level. Most scenarios either cover the sector as a whole (e.g. ETP) or one of the segments (e.g. Greenpeace 2015), limiting the analysis of a company's risk.

Method LCT. The LCT takes the estimates of IEA 4DS 2016. It does not model changes in the domestic segment as the scenarios follow the same demand levels under business as usual.

Method ACT. Two models are used, IEA's 2DS scenario which presents general sector changes, and an integrated assessment model developed by the International Centre for Research on Environment and Development (CIRED) which models domestic demand for selected regions. European countries estimates are build based the current country demand share (e.g. number of passengers) reported in EUROSTAT. The share is assumed to be constant across scenarios, in line with the low demand forecast of Eurocontrol 2017 and 2013. Domestic transport estimates for Brazil and Mexico were not built due to the lack of a granular regional breakdown.

Results. Under the ACT scenario demand's annual growth rate will be cut nearly by half compared to the LCT due to the effect of carbon-related policy instruments and the shift to rail transport. Brazil and Mexico are the economies that will experience the highest growth explained by macro-economic factors and the expansion of national and international routes (see Table 6.2). Companies with high domestic operations are the most exposed to the transition as global demand is expect to increase only by 27% through 2035 compared to current levels (see Table 6.3).

TABLE 6.2 AIR TRANSPORT DEMAND IN THE ACT AND LCT SCENARIOS (BILLION PKM) (SOURCE: AUTHORS, BASED ON IEA 2016A)

Year	World		Brazil		France		Germany		Italy		Mexico		US	
	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT
2015	6 290		113		264		201		169		56		1 470	
2020	15%	21%	8%	12%	7%	15%	7%	15%	7%	15%	18%	25%	9%	13%
2025	32%	49%	30%	42%	10%	30%	10%	30%	10%	30%	37%	55%	16%	29%
2030	49%	82%	55%	80%	12%	45%	12%	45%	12%	46%	55%	89%	22%	44%
2035	65%	119%	85%	124%	14%	62%	14%	62%	14%	62%	71%	125%	29%	61%
2040	80%	158%	114%	171%	17%	80%	17%	80%	17%	80%	86%	161%	37%	80%

TABLE 6.3 GROWTH RATE OF AIR DOMESTIC TRANSPORT UNDER ACT (BILLION PKM) (SOURCE: AUTHORS BASED ON AEA 2016, EUROSTAT 2016, IATA 2016, CIRED 2016)

Year	World	France	Germany	Italy	US
2015	2 314	22	18	23	1 018
2020	-41%	-28%	-28%	-28%	-64%
2025	-28%	87%	87%	87%	-81%
2030	0%	179%	179%	179%	-59%
2035	27%	305%	305%	305%	-41%

6.2 FUEL EFFICIENCY

Overview. Fuel efficiency in the aviation sector relates both to policy measures and market trends. As part of the ICAO process, policymakers have agreed to define fuel efficiency standards that will be implemented in the course of the next decade. In parallel, fuel efficiency will also be driven by market forces. These relate to the evolution of aircraft design, the growing demand for efficiency and the expected associated cost benefits.

Risk pass-through mechanism. Fuel efficiency in the aviation sector is generally expressed in terms of fuel used or burned by kilometre travelled. The more fuel is consumed per kilometre travelled, the higher the costs, and therefore, the lower the gross profit margin. According to a study from ICCT, accelerated efficiency gains could save airlines $3 for every $1 invested (ICCT 2016b).

Sources. Scenarios present results around fuel efficiency generally at macro level (e.g. IEA 2016a, Greenpeace 2015). As an example, under IEA's 2DS scenario ICAO's goal of 2% annual reduction in energy use per passenger-kilometre a year is surpassed, the energy intensity decreases annually by 2.6% from 2015 to 2050. Other scenarios present results at a micro level allowing for a bottom-up analysis, but not necessarily solving for a specific climate target (e.g. ICCT 2016). Opting for one or another depends on the granularity of model used to assess financial risks.

Method. Fuel efficiency for both scenarios is taken from the scenarios developeby the ICCT (2016). In line with the philosophy of a 'market optimist' approach, the ACT scenario takes the most ambitious scenario developed by ICCT, which implements "all cutting-edge fuel-saving technologies in development for conventional airframe designs, irrespective of whether they are likely to be economically reasonable." Under a 2°C transition, it is assumed that this aggressive scenario materializes due to changes in the economics that allow for more ambitious fuel savings. This scenario complies with the 2.6% annual fuel efficiency needs estimated in ETP 2DS scenario. The LCT scenario takes a 'moderate' scenario that assumes modest technology improvements driven by policy factors. This scenario slightly exceeds ICAO's annual 2% efficiency target through 2034.

Results. Results are presented in Table 6.4 and apply to new aircraft that come online. The ambitious climate scenario envisions higher fuel savings of around 8 to 10% by 2024 and 4 to 5% by 2034 compare to the limited climate scenario. Years should be interpreted more as 'generations' of fleets rather than specific years given the nature or aircraft development. Values for 2020 and 2030 where interpolated using a polynomial function. To put these results into context, they largely reflect the results of the NASA ERA project (Nickol & Haller 2016).

TABLE 6.4 FUEL BURN (G FUEL BURNED/REVENUE PASSENGER-KM) BY TYPE OF AIRCRAFT UNDER THE ACT AND LCT SCENARIOS (SOURCE: AUTHORS, BASED ON ICCT 2016)

	Single Aisle		Small Twin Aisle		Regional Jet	
Year	ACT	LCT	ACT	LCT	ACT	LCT
2016	20		24		33	
2020	16.1 (-20%)	16.7 (-17%)	18.8 (-21%)	13.7 (-17%)	26.1 (-20%)	27.2 (-17%)
2024	12.1 (-40%)	13.2 (-34%)	13.7 (-43%)	15.9 (-33%)	19.6 (-40%)	21.8 (-33%)
2030	11.4 (-43%)	12.5 (-38%)	13.1 (-45%)	14.3 (-40%)	18.5 (-43%)	20.4 (-37%)
2034	10.9(-46%)	12.0 (-40%)	12.7 (-47%)	13.3 (-44%)	17.7 (-46%)	19.5 (-40%)

6.3 BIOFUEL PENETRATION

Overview. Sustainable Alternative Fuels (SAF) are one of the main sources that will enable the reduction of carbon emissions in the sector. ICAO estimates that to achieve their 2020 net zero emissions target under BAU, alternative fuels could potentially close the emissions gap that cannot not be addressed by technological and operational improvements. This however can only be possible provided 100% of petroleum-based jet fuel is replaced with sustainable alternative jet fuel by 2050. However, such a shift may not be feasible due to technical barriers (e.g. availability of technologies for commercial scale production), limits on feedstock yields and land requirements and pace of capital investment.

Risk pass-through mechanism. The impact of increased biofuels uptake on a company is uncertain. Higher fuel prices will impact costs, however, the emissions associated with the use of polluting fuels will require buying carbon offset credits (see Page 68). Thus, there exists the possibility of a compensation effect.

Sources. Several scenarios model changes in the uptake of biofuels, these are however limited to global estimates and do not disclose changes at regional nor country level. This split is relevant given the importance that the domestic market has in some countries. In general, scenarios estimate that the uptake of biofuels in the sector will start being representative in 2020 (IEA 2016a, Greenpeace 2015).

Method ACT. In designing an ambitious climate transition scenario, the scenario is based on the following assumptions. Countries in scope reach a global estimated biofuels market share of 3% by 2020 (ICAO 2016a). Non-European countries reach the IEA 2DS estimated share of biofuels of 55% by 2050. The final energy demand of biofuels in Europe is 77% by 2050 (Insight_E 2015). Analyst could as well use the IEA 2DS scenario estimated share. 2030 and 2040 values were extrapolated using a linear regression.

Method LCT. The LCT considers the estimates of Energy Technology Perspectives. In its 4DS scenario, ETP 2016 suggest a share of 3% of second generation biofuels by 2050.

Results. Table 6.5 presents the share of biofuels under an ambitious climate transition. The increase in the uptake needed to achieve the targets is substantial and it raises the question of ICAO's and governments role to enable deployment of these technologies. The ACT requires that current national commitments are surpassed, while levels required under an LCT could be reached already in 2020 following ICAO's estimations.

TABLE 6.5 SHARE OF SUSTAINABLE ALTERNATIVE FUELS UNDER AN ACT SCENARIO (SOURCE: AUTHORS, BASED ON EC 2011, IATA 2015, ICAO 2016, IEA 2016A AND INSIGHT_E 2015)

Year	Brazil	France	Germany	Italy	Mexico	USA
2020	3%	3%	3%	3%	3%	3%
2025	12%	16%	16%	16%	12%	12%
2030	20%	28%	28%	28%	20%	20%
2035	29%	40%	40%	40%	29%	29%
2040	38%	52%	52%	52%	38%	38%

6.4 JET FUEL PRICES

Overview. Jet fuel is the main fuel used today in air transport, the expectations around its price will thus be influenced by the decisions on fuel efficiency measures and the uptake of sustainable alternative fuels.

Risk pass-through mechanism. An increase in jet fuel prices will increase the operational expenses related to fuel costs, ceteris paribus, this translates in a decrease of the operating income.

Sources. There are no scenarios modelling the price of jet fuel oil under both an ambitious climate transition scenario nor a limited climate transition scenario.

Method. Jet fuel prices are highly correlated with crude oil Brent prices, thus under the ACT and LCT jet fuel prices are based on oil prices. Using historical correlation, a constant jet-fuel to oil ratio of 0.028 is applied for both scenarios.

Results. Table 6.6 presents the estimates for Jet fuel prices under the ACT and LCT. Under the ACT a decrease in prices is expected, this decrease will be responding to a decrease in jet fuel demand that is expected to halve by 2040 respect to 2030 levels.

TABLE 6.6 JET FUEL PRICE DEVELOPMENT (USD / GALLON) (SOURCE: AUTHORS, BASED ON ETP 2016 AND INDEX MUNDI)

Year	ACT	LCT
2014	2.7	2.7
2020	2.2	2.2
2025	2.4	2.7
2030	2.7	3.2
2035	2.7	3.4
2040	2.7	3.6

6.5 CARBON CREDIT MANDATE

Overview. International aviation emissions, which fall out of the scope of the Kyoto Protocol, are, since 2016, covered by the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) (see Page 63). Several other voluntary instruments exist (e.g. Clean Development Mechanisms, Verified Carbon Standard, the Gold Standard), however, in the aviation sector, as in general in the transport sector, the uptake is rather low.

Risk pass-through mechanism. The application of CORSIA will affect companies' operational expenses in the form of higher costs associated with the purchase of carbon offsets.

Sources. The only scenarios available modelling the effects of a market-based measure such as carbon offsetting programs have been developed by ICAO 2013, ICAO scenarios have however not been adjusted to include recent developments around CORSIA. Moreover, these scenarios do not intend to address the needs under a 2°C policy target but rather model the different avenues needed to reach the sector's targets.

Method. Under CORSIA only those emissions surpassing 2020 levels will be offset. This mean that under an ambitious climate transition scenario companies won't be required to offset their emissions, however, under a limited climate transition scenario companies will have to abide to the scheme. The role of CORSIA in risk assessment is defined then by two situations:

- The sector reaches its international emissions peak around 2020 (see Fig. 6.7). Companies do not have to buy offsets as emissions are under 2020 levels.
- The sector continues emitting over 2020 levels and carbon offsets must be purchased to achieve the sector's carbon neutral goal.

Results. The number of carbon offsets (see Annex 5) to be purchased by a company will depend on the overall total emissions of the countries participating in CORSIA, however, the impact of the measure on the emissions reduction will be conditional upon the cost of an offset. There is still high uncertainty around the cost of each offset and how it will articulate with measures set up at national level. The analysis can be conducted using either the expected carbon prices under the LCT (see page 26), thus reaching a maximum of 50 EUR/tCO_2 in 2040 or the "alternative" low carbon prices (see Table 6.8) that ICAO is currently including in its CORSIA roadshows.

FIGURE 6.7 PROJECTED DEMAND FOR OFFSETS UNDER AN MBM SCHEME (GT CO_2) (2020 - 2035) (SOURCE: AUTHORS, BASED ON ICCT 2013, 2016 AND ENVI 2015)

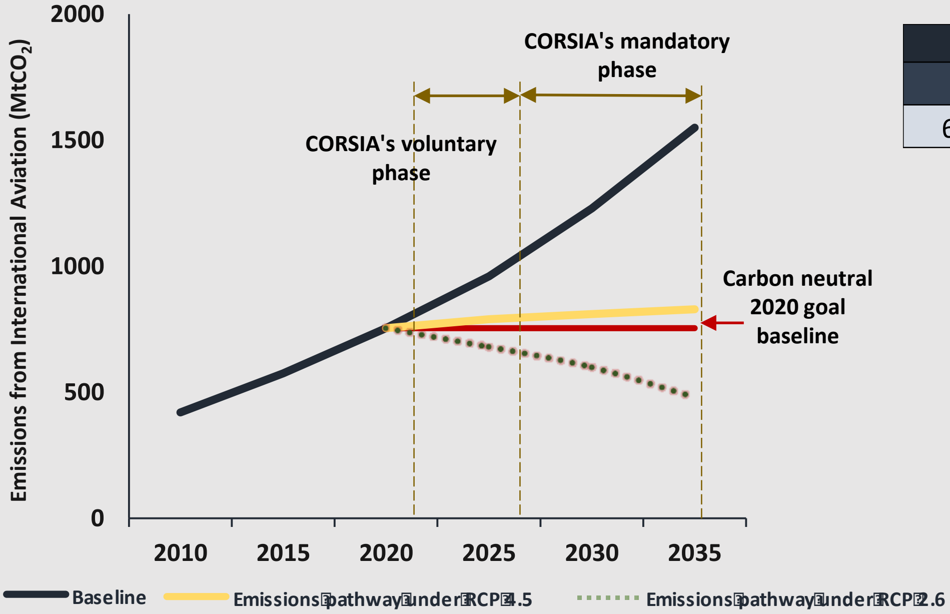


TABLE 6.8 ALTERNATIVE CARBON OFFSET PRICE UNDER CORSIA (USD/TCO$_2$) (SOURCE: AUTHORS, BASED ON ICAO 2016B)

Carbon offset price		
2020	2030	2035
6 \$/tCO_2	10 \$/tCO_2	12 \$/tCO_2

6.6 FUEL EFFICIENCY STANDARDS

Overview. Fuel efficiency standards are mainly based on emissions reduction through technology deployment. Two major standards, namely the non-volatile Particulate Matter (nvPM) standard for engines and the CO_2 Emissions Certification Standard have been recently adopted and will frame aircraft design in the following years. The focus is given to the latter standard, as the direct impact of the nvPM standard on climate change lies on the reduction of black carbon emissions (i.e. emissions from incomplete combustion), which do not fall under the scope of the study.

The ICAO developed in 2016 the first global CO_2 Emissions Certification Standard for new aircraft to support efficiency gains based on the adoption of fuel efficient technologies into airplane system design (e.g. propulsion, aerodynamics and structures). The standard will apply to new type (NT) designs of subsonic jet and turboprop airplanes launched after 2020 and those that will be in-production (InP) from 2023. Airplanes not meeting the standard can no longer be produced from 2028. The standard makes a distinction based on the maximum take-off weight of the aircraft (MTOM) and sitting capacity, it assigns a higher reduction of CO_2 to larger airplanes with a MTOM higher that 60 tonnes.

Risk pass-through mechanism. Compliance with a standard will require in general companies to increase their expenditure in fuel efficient measures. These expenses will most likely have a negative impact in the short run company's net income margins under and ACT. Under an LCT the expenditures will be compensated by the savings. However, since the stringency of the standards is low on average companies won't be affected by it.

Sources. There are currently no scenarios that put into context the application of the CO_2 Emissions Certification Standard. However, the requirements of the standard can be compared to the ICCT estimations on required fuel efficiency under the aggressive and moderate scenarios (see Page 65). ICCT "business as usual scenario" estimates an increase in fuel efficiency of 27% on average for new types in 2024 (ICCT 2016a).

Method. To date, there is no reference on the potential strengthening of the standard. Therefore, estimations around future values are not developed. The description and analysis of the standard is therefore intended to inform on the misalignment of current policy and needs under the scenarios developed.

Results. Under both scenarios companies will be on average already complying to the standard. Considering today's requirements, companies manufacturing and/or having a fleet complying with the minimum threshold won't be contributing to the achievement of either scenario. It is estimated that the standard will contribute to an average increase in fuel efficiency of 4% in 2020 (see Table 6.9), however, to achieve the efficiency levels required under the ACT and the LCT an average increase of 40% and 33% is already needed in 2024 (see Page 65). The standard therefore does not pose additional cost to companies under the selected scenarios – assuming they get implemented by companies.

TABLE 6.9 ESTIMATED METRIC VALUE (KG/KM) REDUCTION REQUIRED FOR NEW IN-PRODUCTION AND NEW TYPES AIRCRAFT BY AIRCRAFT CATEGORY UNDER BOTH SCENARIOS (SOURCE: AUTHORS, BASED ON ICCT 2016)

New in-production						
Aircraft type	Very large aircraft	Twin aisle	Single aisle	Regional jets	Business jets	Freighters
2015 average	2.9	1.7	0.9	0.7	0.6	2.1
2028 target	2.6	1.8	0.9	0.7	0.6	1.9
Reduction	10%	0%	6%	0%	0%	7%
New types						
New design aircraft average[5]	2.8	1.5	0.8	0.6	0.5	-
Required metric value (2020 – 2028)	2.5	1.7	0.8	0.7	0.6	-
Reduction	10%	0%	0%	0%	0%	-

7 SHIPPING SECTOR

GENERAL OVERVIEW

The transition risk story for the shipping sector articulates itself along three trends:

- **Demand increase.** The increasing relevance of global supply chains and the expansion of trade routes will likely drive the increase of the sector's demand (GMT 2013). These factors will however have limited impact on fossil fuel forecasts in scenarios where there is high exposure to transition risks.

- **Energy Efficiency improvements.** Efficiency improvements will come from the implementation of technologies for fuel control, instrumentation and navigation, as well as from operational changes. Efficiency measures will be pushed by the industry itself and by market standards. Both have the potential to reduce 40% of the sector's emissions by 2040.

- **Increase in the emissions control areas and gases in scope.** Currently areas with emission controls are set up in the North and Baltic sea, US, Canada and some regions in China. The International Maritime Organization (IMO) is not only looking towards the increase of control areas and the maximum gas limits allowed but as well to extending the global requirements (e.g. global maximum sulphur content from 3.5% to 0.5% from 2020). Abiding to regulation will thus require manufacturers to implement new reduced pollutant technologies.

The scenarios developed here take the results of UMAS 2016. UMAS develops 10 scenarios of which 4 solved for a carbon budget that follows a 2°C pathway and 1 scenario for a carbon budget that droves to be aligned with a LCT scenario (i.e. scenario 10) when comparing it in the range of calculated[5] carbon budget values of RCP 4.5 and 6.0 pathways. Scenario 10 is however very ambitious in the share of biofuel penetration and allows up to 80% of carbon offset purchase. This scenario is presented to keep consistency among assumptions and allow comparison between scenarios. Analysts can as well refer to the alternative scenarios mentioned in the chapter, but should keep in mind possible inconsistencies.

The scenario involves the following parameters:

PRODUCTION & TECHNOLOGY	Shipping Transport Demand (G tonne-km / year) Fuel efficiency (kJ/tonne-km) Alternative Fuels Penetration (%)
MARKET PRICING	Marine Fuel prices (fraction to 2010 HFO price and USD/GJ)
POLICY MANDATES, INCENTIVES & TAXES	Efficiency Design Standards

5 THINGS BEFORE GETTING STARTED

1. **Sector Segmentation.** In 2012 emissions from international shipping accounted for 85% of the total sector's emissions. The demand analysis is focused on international shipping as the sector is driven mainly by global trade and thus is dependent on the international market behavior.

2. **Split Responsibility.** Shipping cargo transportation occurs under two main types of contracts:[6] the voyage charter contract between ship-owners/operators and the time charter contract with charterers within the freight market. The costs structure for both contacts is different. The voyager charter hires the vessel in a per-ton scheme, where the ship owner pays for energy, crew and port costs. The time charter contract involves hiring the vessel on a daily rate, thus covering energy and port costs, while the ship owner covers crew cost. These arrangements split the responsibility of costs (i.e. split incentives) making the cost pass-through of implementing fuel efficiency and fuel switching measures in the industry complex compared to other industries. Incentives towards implementing measures thus change according to the type of contract.

3. **Economic Viability of Efficiency Measures.** Most of the fuel efficiency technologies and operational measures that are currently available are already economically viable (ICCT 2013). Economic viability of the measures is subject to non-cost driven barriers (i.e. split incentives and operational information reliability) and the learning curve that technologies will take. No scenarios known to the authors models changes in technology costs. Quantifying the costs is thus an important missing piece in the analysis.

4. **Policy Development.** Recent efforts towards enabling data collection on company-related emissions (i.e. SEEMP, EVDI) will benefit policy creation and monitoring by providing a baseline that enables the identification of needs for operational and technology improvements and fuel switching. Consequently, further regulation and developments of standards in the sector is expected.

5. **Effect of Air Pollution Regulation.** Air pollution regulations in NOx and SOx –although they are not part of the GHGs– have an effect in the CO_2 intensity of the vessels. The measures that shippers will adopt (i.e. solar and wind power and biofuels) to comply to current and future regulation will have an important impact in the emissions reduction of the sector.

7.1 SHIPPING TRANSPORT DEMAND

Overview. The analysis of demand for shipping transport considers two transport segments: fossil fuel (i.e. oil and coal) and cargo transportation. Under risk scenarios, the modelling of fossil fuels transport should consider transition drivers that steer oil and coal consumption. Cargo transport can still be modelled based on economic growth assumptions as the operation of this segment is not directly affected by transition risks.

Risk pass-through mechanisms. Changes in demand will have a direct impact on company revenues. In the transition to a low carbon economy, companies whose operations are concentrated in the fossil fuel segment are more exposed and can expect to lose the most.

Sources. Demand for shipping transport is generally modelled on multi-sector scenarios such as the ETP and Greenpeace scenario, however results are often not disclosed (e.g. ETP 2016) or partially presented (e.g. the Greenpeace scenario only discloses results of inland navigation). Other scenarios focusing on transport or specifically on marine shipping base their projections in macroeconomic assumptions (e.g. OECD 2017, 2nd IMO GHG study), integrating in some cases assumptions around environmental policies and carbon prices (GMFT2030 2014). The first sector specific scenarios solving for a climate outcome have recently been published (e.g. 3rd IMO GHG study).

Method. In designing the LCT and ACT scenario, the Third IMO Study is used. This scenario is selected because it models the fossil fuel and cargo segment independently. The fossil fuel segment is modelled considering emission pathways using RCPs,[7] while the cargo segment uses standard population and economic growth assumptions through IPCCs AR 5 socio-economic pathways (SSPs[8]). In the fossil fuel segment, the LCT can be described by RCP6.0 and the ACT by RCP2.6 and RCP4.5, representing respectively a maximum warming increase of 3.1°C, 2.6°C, and 1.7°C in 2100. In the cargo segment, both the LCT and ACT are described by SSP3, a world with slow technology development. This pathway is selected to be in line with UMAS 2016.

Results. Under an ACT, demand for oil and coal transport is expected to reach its peak in 2018 and decline to 2000 levels by 2050. Demand for fossil liquid-bulk will decline by 28% through 2040 compare to 2015 levels. Likewise, bulk-coal transport will decline by 52% through 2040 from 2015 (see Table 7.1). Total demand for cargo transportation is expected to increase by a growth factor of 1.8.

TABLE 7.1 GLOBAL TRANSPORT WORK BY TYPE OF TRANSPORT IN THE ACT AND LCT SCENARIOS (SOURCE: AUTHORS, BASED ON IMO3 2015)

Scenario	Type	2015	2020	2025	2030	2035	2040
ACT (RCP2.6)	Liquid Bulk oil	18 980	18 250	16 425	14 600	14 162	13 724
	Bulk coal	7 300	7 008	6 424	5 840	4 672	3 504
	TOTAL	**26 280**	**25 258**	**22 849**	**20 440**	**18 834**	**17 228**
ACT (RCP4.5)	Liquid Bulk oil	17 520	16 936	17 301	17 666	17 885	18 104
	Bulk coal	7 300	8 176	8 833	9 490	9 709	9 928
	TOTAL	**24 820**	**25 112**	**26 134**	**27 156**	**27 594**	**28 032**
LCT	Liquid Bulk oil	18 688	20 878	22 995	25 112	27 594	29 200
	Bulk coal	7 300	7 227	7 519	7 738	8 030	8 103
	TOTAL	**25 988**	**28 105**	**30 514**	**32 850**	**35 624**	**37 303**
ACT & LCT	Non-coal bulk dry	15 330	18 980	23 214	27 448	30 952	34 456
	Unitized cargo	24 236	33 580	43 435	53 290	64 532	75 774
	TOTAL	**39 566**	**52 560**	**66 649**	**80 738**	**95 484**	**110 230**

7.2 FUEL EFFICIENCY

Overview. Efficiency in the sector is determined by both technical and operational improvements. Technical improvements come from advancements in navigation, design efficiency and materials. Operational improvements relate mainly to speed reduction, weather routing and hull cleaning. The potential reduction in total CO_2 emissions after efficiency measures by 2040 respect to 2015 is of 35 to 40% depending of the type of ship (ICCT 2013).

Risk pass-through mechanism. Fuel efficiency gains result in the reduction of operational expenses via fuel consumption. Efficiency gains from technology improvements impact positively time charterers and could impact positively shipowners under a voyager contract provided the measures are cost effective. It is uncertain how ship-owners expenses could be transferred to time and voyage charterers as tariff changes respond mainly to market forces (i.e. supply vs. demand). Time charterers have higher incentives to implement fuel efficient operational measures as these have a direct impact in their costs.

Sources. Fuel efficiency for marine transportation is usually modelled to provide a ratio of the amount of energy inputed by fuel against the transport work undertaken (i.e. cargo weight unit-distance travelled). However, in the design of forecasts aligned with emission pathways, models often present the CO_2 emissions from the burned fuel compared to the transport work (as the fuels under the scope come from fossil sources) (ICCT 2013). Models considering biofuels can thus report a lower indicator, thus limiting the indicator to a proxy of fuel efficiency for ambitious scenarios. The IEA publishes the total emissions for their 4DS and 2DS scenarios, but as the shipping demand is not disclosed, it is not possible to use their data to build this indicator.

Method ACT. Projections are based on UMAS' scenario 8. This scenario models energy efficiency from technical and operational improvements. The scenario also models efficiency by type of ship. Size and age are not detailed, as they combine these characteristics into factors to calculate the annual shipping activity per year. The scenario assumes: i.) An allowance for purchasing carbon offsets for an up to 20% of the revenue derived from carbon pricing. This MBM starts in 2025; ii.) a 20% of slow steaming is allowed.

Method LCT. Projections for the LCT are based on UMAS' scenario 10. The scenario assumes: i.) An allowance for purchasing carbon offsets for an up to 80% of the revenue derived from carbon pricing, resulting in a lower rate of improvement in energy efficiency. This MBM starts in 2025; ii.) a 1% of slow steaming is allowed. An alternative to this scenario could be the EDDI+ scenario developed in ICCT 2013.

Results. The ACT sees the maximum reduction in fuel consumption for the dry-bulk segment with an average sector abatement of 52% by 2040 from 2010 levels. The lowest abatement comes from the container segment with 26% reduction. In the LCT, the highest improvement in fuel consumption comes as well from the dry-bulk segment with 40% decrease and the lowest from the container segment with a 18% decrease by 2040. Under the LCT, the container segment is projected to have a rebound effect after 2035 as the increase of biofuels allows to operate at higher speeds with a reduced impact in the carbon emissions. This effect is also present in the ACT scenario at a lower scale.

TABLE. 7.2 FUEL EFFICIENCY (MJ/TONNE-KM) PROJECTIONS IN THE ACT AND LCT SCENARIOS (SOURCE: AUTHORS, BASED ON UMAS 2016)

Year	Dry-bulk		Container		Gas		Gen. cargo		Wet Prod. Chem.		Wet crude	
	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT
2010	5.0	5.0	85.5	85.5	15.9	15.9	7.1	7.1	12.1	12.1	14.0	14.0
2015	3.9	3.9	67.4	63.8	14.5	14.5	7.1	7.1	12.1	12.2	16.1	16.1
2020	3.5	3.5	70.3	65.4	13.6	13.2	6.8	6.5	11.1	10.6	15.3	14.9
2025	3.2	3.2	68.0	61.8	12.3	11.8	6.3	6.0	9.9	9.4	13.3	12.4
2030	2.8	3.0	65.7	62.3	10.8	11.1	5.6	5.7	9.2	8.9	11.7	11.7
2035	2.5	2.9	62.7	62.1	9.1	10.7	4.5	5.4	7.5	8.4	9.9	10.7
2040	2.4	3.0	63.6	70.2	8.1	10.9	4.0	5.4	6.5	8.1	8.3	9.7

7.3 ALTERNATIVE FUEL PENETRATION

Overview. Three types of fuels are expected to increase in uptake in the transition to a low carbon economy: LNG and biofuels from 2020, and hydrogen from 2030. Alternative fuels will arise as a cost-efficient option to comply with regulations (i.e. air pollutant emissions control (i.e. NOx, SOx) regulations (LNG) and the CO_2 limits), competing with the usage of traditional fuels (i.e. HFOM MDO) with installation of abatement technologies for emissions reduction (McGill et al. 2013).

Risk pass-through mechanism. The switch to alternative fuels can affect companies' margins and revenues in two ways: increased capital costs and operational expenses. Shipowners may incur in higher capital expenditures to retrofit the infrastructure for adopting alternative fuels. It is uncertain how the costs pass through could impact the tariffs of voyager and time contracts as tariffs respond mainly to market forces. Operational expenses are mainly related to purchase of alternative fuels (see next page).

Sources. Forecasts for fuel mix are generally built around the actual and projected regulations that will directly affect fuel use in the sector, alongside with assumptions on technological development and adoption of potential alternative fuels. For instance, several reports consider penetration of LNG as a measure to comply with the projected new Sulphur limit restrictions (e.g. Kent, et al. 2013, McGill, et al. 2013). Fuel Marine Trends 2030 considers the presence of LNG and introduces hydrogen as a decarbonisation option in their most optimistic scenario by 2030, while IEA considers LNG and biofuels (ETP 2016) for their 2DS and 4DS. UMAS 2016 foresees a higher penetration of hydrogen after 2030. Some other scenarios only breakdown the fuel mix between biofuels and conventional fuels but provide no visibility on the type of fuels considered (e.g. Greenpeace 2016).

Method. The fuel shares presented here follow UMAS 8 (i.e. ACT) and 10 (i.e. LCT) scenarios. The ACT scenario assumes a significant uptake of biofuels and hydrogen as a measure for the decarbonisation of the sector. The LCT scenario assumes an ambitious penetration of biofuels, limited LNG and hydrogen uptake in the fuel mix. Alternatively, users can compute the alternative fuels share using the energy fuel data provided in IEA ETP 2DS and 4DS. In doing so, inconsistencies with other indicators need to be considered.

Results. Table 7.3 provides the fuel mix under an Ambitious Climate Transition and Limited Climate Transition scenario. In the ACT scenario, technological advancements and bio-availability allow the penetration of biofuels starting in 2020 and reaching a share of 20% by 2040. Hydrogen will be used starting in 2030 occupying a share of 6% by 2040 in the ACT and less than 1% in the LCT. Biofuels in the LCT will account for 48% of the total supply by 2040.

TABLE 7.3 FUEL MIX UNDER THE ACT AND LCT SCENARIO (SOURCE: AUTHORS, BASED ON UMAS 2016)

Year	HFO/LSHFO		MDO/MGO		LNG		HYDROGEN		Biofuels	
	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT
2010	93%	94%	4%	5%	2%	2%	0%	0%	0%	0%
2015	82%	82%	17%	18%	0%	1%	0%	0%	0%	0%
2020	76%	69%	18%	15%	0%	0%	0%	0%	7%	15%
2025	70%	58%	18%	14%	3%	0%	0%	0%	9%	28%
2030	64%	48%	19%	12%	3%	0%	1%	1%	14%	38%
2035	58%	44%	19%	10%	4%	1%	2%	1%	17%	45%
2040	50%	44%	17%	8%	8%	1%	6%	1%	20%	48%

7.4 MARINE FUEL PRICES

Overview. Heavy Fuel Oil (HFO) and Marine Diesel (MDO) are the most used fuels in the sector. These are oil-derived fuels; thus, its price is highly correlated with oil-prices. On the other hand, LNG naturally follows the gas price, however, its modelling should include an adjustment factor to contemplate necessary capital investment in the infrastructure required. Hydrogen and methanol can be also modelled following a similar process to that of LNG price estimation or using generate equilibrium models considering different assumptions around oil price projections and decarbonisation pathways (e.g. UMAS 2016b).

Risk pass-through mechanism. As in any other sector, changes in marine fuel prices will have a direct effect on operational expenses for the energy cost payer (i.e. the ship owner under a voyager charter contract or the end-user under a time charter contract). Opting for one type of fuel or another will require a cost-benefit analysis that considers the costs of adopting technologies for emission reduction and the decrease in costs associated to the purchase of less CO_2 emissions allowances.

Sources. In general, scenarios that cover multiple sectors do not disclose their assumptions/forecasts around marine fuel prices. Scenarios modelling exclusively the sector tend to give more visibility on market prices (e.g. GMFT and UMAS).

Method ACT. The prices under the ACT scenario are taken from the “2 degree prices scenario” of UMAS 2016. The scenario assumes that LSHFO (Low Sulphur Heavy Fuel Oil) enters the market by 2020 with a price linked to the MDO price by a factor of 1.28.

Method LCT: Prices for the LCT scenario are based on the estimates of GMFT 2013. The Global Commons model of GMFT considers a scenario with more climate action than a BAU scenario and is less ambitious than a 2°C scenario. Global Commons Scenario demand estimates are similar to those of the LCT demand (see Page 72). The model is limited to 2030 and its indexed to HFO prices.

Results. Figure 7.4 and 7.5 present the results under the ACT and LCT scenarios. Fossil fuel derivatives prices are projected to continue increasing at a constant rate. Marine Gas Oil (MGO) is projected to be the highest price option in both scenarios. In the LCT, the expected increase in its price is 30% by 2030 respect to 2015 levels. HFO will remain as the lowest cost option, but from 2020, its use alongside with emission abatement technologies will be required to comply with emissions regulation.

TABLE. 7.4 MARINE FUEL PRICES UNDER ACT IN (USD/GJ) (SOURCE: AUTHORS, BASED ON UMAS 2016)

Year	HFO	LSHFO	MDO	LNG	Hydrogen
2015	11	-	15	7	-
2020	8	10	12	7	14
2025	9	10	13	9	12
2030	10	11	14	10	12
2035	9	12	15	11	11
2040	7	13	16	12	11

TABLE. 7.5 MARINE FUEL PRICES UNDER LCT, INDEXED TO 2010 HFO PRICE (SOURCE: AUTHORS, BASED ON MFT 2030 2013)

Year	HFO	LSHFO	MDO	LNG	Hydrogen
2010	1.0	1.5	1.5	1.5	2.9
2015	1.4	1.6	2.2	2.3	4.0
2020	1.4	1.6	2.3	2.0	3.6
2025	1.4	1.6	2.5	2.0	3.6
2030	1.5	1.7	2.6	2.0	3.7

7.5 EFFICIENCY STANDARDS – EEDI

Overview. The Energy Efficiency Design Index (EEDI) is a standard adopted in 2011 by the International Maritime Organization (IMO). EEDI sets the mandatory minimum technical efficiency levels per transport work (ton-km) for new ships. Compliance is demonstrated by the issuance of an International Energy Efficiency Certificate (IEEC). Many new build ships are currently outperforming EEDI requirements even compared to future stages of the standard. The implementation of the IMO Roadmap (IMO 2016) will most likely contribute to the increase of the standard's requirements.

Risk pass-through mechanism. Companies non-compliant with EEDI could be exposed to regulatory risks as port state control mechanisms requiring compliance with the standard "under their flag" (i.e. ships registered in the country) may deny the entry of non-compliant ships.

Sources. Few organisations have developed projections of the effects of EEDI in the global fleet, and have challenged its current stipulations as non-aligned with market forces and with a decarbonisation pathway (e.g. ICCT 2013, UMAS 2016). ICCT modelled the effects of EEDI in the reduction of global emissions along with more ambitious scenarios. UMAS 2016 modelled decarbonisation scenarios, along with a BAU with EEDI scenario, concluding that its requirements are outdated policy, as the current EEDI projection could only reduce 3% of the emissions of a non-EEDI world by 2050 (UMAS 2016).

Method. UMAS scenarios are preferred as they modelled how the EEDI index for several ship types will evolve under their decarbonisation scenarios, including a reference scenario of the current policy results.

Results. EEDI compliance at the current values is not sufficient to be aligned in with the ACT nor the LCT. Additional carbon intensity reduction mechanisms are needed (i.e. technical measures, alternative fuels, carbon offsets).

TABLE 7.6 REQUIRED EEDI REDUCTION FACTORS BY SHIP CAPACITY (SOURCE: AUTHORS, BASED ON UMAS 2016)

Type of ship	Size	Phase 0	Phase 1	Phase 2	Phase 3
		1 Jan 2013 - 31 Dec 2014	1 Jan 2015 - 31 Dec 2019	1 Jan 2020 - 31 Dec 2024	1 Jan 2025 - onwards
Bulk Carriers	>20 000 DWT	0%	10%	20%	30%
	10-20 000 DWT	n/a	0-10%*	0-20%*	0-30%*
Gas tankers	>10 000 DWT	0%	10%	20%	30%
	2-10 000 DWT	n/a	0-10%*	0-20%*	0-30%*
Tanker and combination carriers	>20 000 DWT	0%	10%	20%	30%
	4-20 000 DWT	n/a	0-10%*	0-20%*	0-30%*
Container Ships	>15 000 DWT	0%	10%	15%	30%
	10-15 000 DWT	n/a	0-10%*	0-15%*	0-30%*
Refrigerated cargo carriers	>5 000 DWT	0%	10%	15%	30%
	3-5 000 DWT	n/a	0-10%*	0-15%*	0-30%*

*The reduction factor is to be linearly interpolated between the two size values depending on the vessel size. The lower value of the reduction factor

7.6 EFFICIENCY STANDARDS - GHG RATING

Overview. The GHG Emissions Rating (ER) index allows to classify the CO_2 emissions by ship and benchmark performance of vessels with similar characteristics. Calculations are based on the EEDI standard and on the EVDI index. The EVDI index is the equivalent of EEDI but for in-use ships. After the EDVI/EEDI is calculated a formula is applied to obtain a score that allows to assign a GHG ER through peer comparison (Fig. 7.1).

Risk pass-through mechanism. Noncompliance with the minimum levels of the GHG ER could potentially represent revenue losses for shipowners. Charterers, covering over 20% of the global maritime fleet, have started using the rating to create policies in order to exclude lower performing vessels (i.e. F and G levels in Fig 7.1). Some ports have started programs to offer discounted harbour dues based on environmental metrics, such as the GHG Index rating (RightShip, 2017). Charter rates can increase in the long-term as shipowners invest in improving their GHG rating. In the long run, this can be beneficial for ship-owners under a voyager contract and companies under a time charterer contract as they perceive a reduction in fuel costs due to fuel savings.

Sources. Few papers discuss the impact of the GHG ER. A study that aims to assess the impact that the GHG rating has in the energy efficiency of the fleet and the implications for different stakeholders (i.e. charterers, shipowners and operators, financiers and policymakers) was published recently by UCL Energy Institute (UCL 2016). The study concludes that policymakers could benefit from the transparency provided by the index to support the sector's energy efficiency and decarbonisation.

Method. Due to the novelty of the research on the GHG Emissions Rating and its lack of implementation as a policy tool, the analysis of the standard is limited to a description of the current's fleet performance.

Results. Figure 7.2 presents an overview of the current GHG ER index performance of the four main ship categories for the top 30 shipping companies. Container is the leading segment with a higher share of A-class ships (approx. 4%), however, 76% of the fleet is classified as D-and-worse, showing that industry's leading performers have a bigger gap to fill compare to other segment's fleet. The tanker sector has the biggest share of A and B class, with 18% of the fleet allocated in these categories.

FIGURE 7.1 GHG EMISSIONS RATING KEY – NORMAL PEER DISTRIBUTION (SOURCE: AUTHORS, BASED ON RIGHTSHIP 2017)

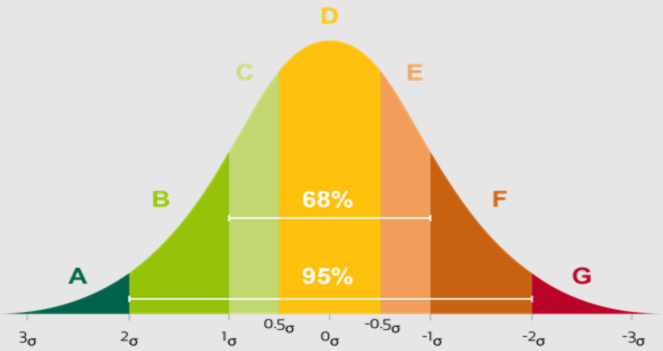
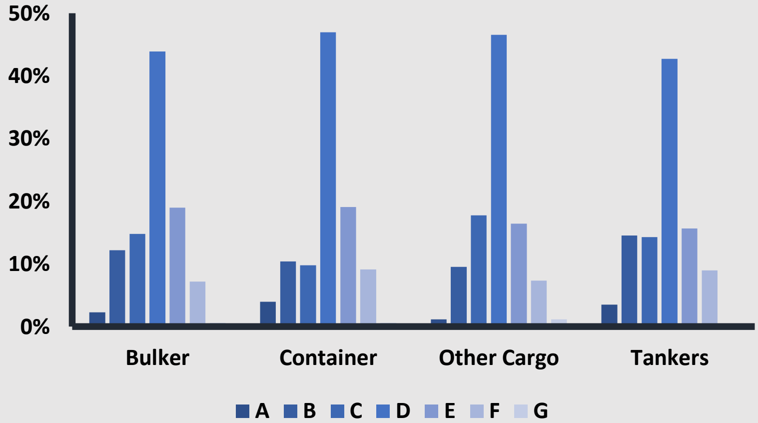


FIGURE 7.2 GHG INDEX BY TYPE OF SHIP (SOURCE: AUTHORS, BASED ON RIGHTSHIP DATA)



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NOTES

1. E.g. Projections on sales of electric vehicles (BNEF 2016)
2. The <5% price increase assumption relates to the 5% electricity price share that is estimated to be due to the renewable energy subsidy under the LCT.
3. This classification does not distinguish plug-in hybrid electric vehicles with hybrid electric vehicles, which may be a crucial difference in terms of deployment.
4. The Global Fuel Economy Initiative (GFEI) is a joint partnership of the IEA, UNEP, ITF, ICCT< ITS-Davis, and the FIA Foundation.
5. Defined as new types certified between 2011 and 2019.
6. The carbon budget for the sector is calculated using the sector's share from the total global CO_2 emissions (2.33%) multiplied by the cumulative CO_2 emissions from 2010-2100 projected under the RCP pathway
7. A third type of contract is also present in the freight market, bareboat charter. It is not used as a contract for the carriage of goods, instead is used for the lease of a vessel. Other hybrid charter contract forms exist but can be reclassified in the first two categories in terms of costs allocation. (Rehmatulla, 2014).
8. The Representative Concentration Pathways (RCPs) consist of 4 GHG concentration scenarios developed to model different climate outcomes.
9. The Shared Socioeconomic Pathways (SSPs) are a collection of pathways that describe alternative futures of socio-economic development (e.g. population, GDP, economic growth) in the absence of climate policy intervention.

ANNEX 1 – ELECTRICTY GENERATION

TABLE 1. GROWTH IN ELECTRICITY GENERATION (TWh) (SOURCE: AUTHORS, BASED ON ETP 2016, EC 2016)

Technology	2015	2020		2025		2030		2035		2040	
		ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT
Brazil											
Total	600.4	670.9	680.4	733.4	772.4	814.0	868.1	925.6	1 002.7	1 004.0	1 090.8
Oil	21.8	9.9	9.9	7.4	7.4	3.0	6.9	3.0	7.0	2.9	6.7
Coal	20.7	17.9	17.9	12.7	25.7	7.7	16.3	0.5	26.6	0.0	32.5
% Coal w/ CCS	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*
Natural gas	61.5	38.1	47.7	7.9	34.5	12.4	46.3	25.9	81.3	26.6	87.7
% Natural Gas w/ CCS	*0%*	*0%*	*0%*	*0%*	*0%*	*10%*	*0%*	*29%*	*0%*	*54%*	*0%*
Nuclear	17.5	24.6	24.6	24.6	24.6	33.6	29.6	39.9	30.0	40.0	30.1
Biomass and waste	43.2	50.1	50.1	54.4	51.5	66.9	63.1	86.9	81.3	90.6	89.2
% Biomass w/ CCS	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*
Hydro*	411.1	461.5	461.5	530.6	536.9	575.0	592.2	619.4	632.2	670.3	674.3
Geothermal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wind	23.0	64.0	64.0	85.5	81.5	99.1	97.7	126.3	121.6	140.2	136.1
% Wind onshore	*100%*	*100%*	*100%*	*94%*	*100%*	*90%*	*100%*	*89%*	*99%*	*88%*	*98%*
Solar	1.4	4.7	4.7	10.4	10.3	16.3	16.0	23.8	22.5	33.4	34.2
% Solar PV	*100%*	*100%*	*100%*	*100%*	*100%*	*95%*	*95%*	*90%*	*89%*	*83%*	*89%*
France											
Total	562.8	621.0	596.1	646.0	599.5	663.3	608.4	683.4	603.9	687.9	609.2
Oil	1.9	0.5	0.0	0.3	0.3	0.2	0.3	0.1	0.2	0.0	0.1
Coal	18.9	7.9	9.1	0.3	0.4	0.0	0.1	0.0	0.0	0.0	0.0
% Coal w/ CCS	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*
Natural gas	20.4	20.2	22.3	18.1	23.7	9.2	12.0	4.8	10.0	10.6	54.0
% Natural Gas w/ CCS	*0%*	*1%*	*0%*	*5%*	*0%*	*14%*	*1%*	*33%*	*1%*	*69%*	*1%*
Nuclear	406.8	431.3	396.2	423.5	385.2	412.0	385.1	411.8	378.9	362.6	299.3
Biomass and waste	9.8	14.7	14.1	19.6	20.1	19.5	20.3	18.9	20.5	22.7	26.3
% Biomass w/ CCS	*0%*	*0%*	*0%*	*0%*	*0%*	*1%*	*0%*	*1%*	*0%*	*2%*	*2%*
Hydro*	68.1	65.1	66.9	66.6	64.1	69.0	64.1	71.7	65.5	76.9	69.5
Geothermal	0.5	0.6	0.8	2.2	1.2	4.5	2.0	8.2	3.3	14.4	5.2
Wind	27.0	54.2	55.1	81.2	65.4	114.1	83.4	129.2	83.6	153.1	103.7
% Wind onshore	*86%*	*83%*	*82%*	*85%*	*83%*	*85%*	*81%*	*82%*	*78%*	*81%*	*77%*
Solar	9.3	26.4	31.6	34.1	39.2	34.6	41.0	38.7	41.9	47.6	51.3
% Solar PV	*95%*	*96%*	*96%*	*91%*	*93%*	*88%*	*91%*	*83%*	*87%*	*79%*	*84%*
Germany											
Total	598.5	621.0	599.2	601.2	603.8	517.0	610.8	436.4	611.6	460.7	617.7
Oil	6.7	1.1	0.9	1.8	2.0	2.0	3.1	1.9	3.4	0.6	3.6
Coal	269.2	240.4	273.8	204.0	267.2	98.6	231.9	21.8	182.9	22.9	160.4
% Coal w/ CCS	*0%*	*1%*	*0%*	*5%*	*0%*	*20%*	*2%*	*90%*	*6%*	*100%*	*12%*
Natural gas	69.6	67.8	74.7	78.0	102.2	83.5	108.8	71.7	150.1	30.4	154.6
% Natural Gas w/ CCS	*0%*	*1%*	*0%*	*5%*	*0%*	*14%*	*1%*	*33%*	*1%*	*69%*	*1%*
Nuclear	76.0	37.5	34.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Biomass and waste	41.3	35.2	33.9	42.5	43.4	51.4	53.4	53.1	57.5	58.8	67.8
% Biomass w/ CCS	*0%*	*0%*	*0%*	*0%*	*0%*	*1%*	*0%*	*1%*	*0%*	*2%*	*2%*
Hydro*	23.2	30.7	22.5	31.1	23.0	29.6	23.8	28.2	25.7	34.1	27.4
Geothermal	0.4	1.1	1.0	2.3	1.0	2.4	1.0	2.4	1.0	3.9	1.0
Wind	75.7	150.6	109.5	183.0	113.2	192.1	128.3	201.1	130.1	240.5	139.0
% Wind onshore	*87%*	*83%*	*82%*	*85%*	*83%*	*85%*	*81%*	*82%*	*78%*	*81%*	*77%*
Solar	36.4	56.7	48.5	58.4	51.8	57.4	60.5	56.3	61.0	69.6	63.9
% Solar PV	*95%*	*96%*	*96%*	*91%*	*93%*	*88%*	*91%*	*83%*	*87%*	*79%*	*84%*
Total	598.5	621.0	599.2	601.2	603.8	517.0	610.8	436.4	611.6	460.7	617.7

*(excl. pumped storage) ** Values in TWh ***Ocean and Other technologies are not included

TABLE 1 (Cont.). GROWTH IN ELECTRICITY GENERATION (TWh) (SOURCE: AUTHORS, BASED ON ETP 2016, EC 2016)

Technology	2015	2020		2025		2030		2035		2040	
		ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT
Italy											
Total	291.0	291.8	316.5	281.8	313.8	283.7	323.1	270.3	351.6	256.8	378.8
Oil	15.3	9.2	7.8	7.4	8.0	5.2	7.8	2.8	5.1	0.7	4.5
Coal	46.6	59.0	67.2	34.4	45.1	19.0	44.7	4.6	38.8	1.4	9.9
% Coal w/ CCS	*0%*	*1%*	*0%*	*5%*	*0%*	*20%*	*2%*	*90%*	*6%*	*100%*	*12%*
Natural gas	119.4	114.4	126.2	94.8	124.2	93.9	122.4	65.1	136.4	32.9	167.6
% Natural Gas w/ CCS	*0%*	*1%*	*0%*	*5%*	*0%*	*14%*	*1%*	*33%*	*1%*	*69%*	*1%*
Nuclear	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Biomass and waste	16.2	22.3	21.4	23.7	24.2	24.6	25.6	40.1	43.4	50.5	58.3
% Biomass w/ CCS	*0%*	*0%*	*0%*	*0%*	*0%*	*1%*	*0%*	*1%*	*0%*	*2%*	*2%*
Hydro*	49.8	46.3	47.5	50.9	49.0	53.5	49.7	56.2	51.3	58.2	52.6
Geothermal	6.4	5.0	6.2	11.5	6.2	14.0	6.2	15.4	6.2	17.3	6.2
Wind	14.9	14.4	14.6	31.8	25.6	44.8	32.7	52.2	33.8	58.7	39.8
% Wind onshore	*89%*	*83%*	*82%*	*85%*	*83%*	*85%*	*81%*	*82%*	*78%*	*81%*	*77%*
Solar	22.4	21.3	25.6	27.3	31.5	28.7	34.0	33.9	36.7	37.1	39.9
% Solar PV	*95%*	*96%*	*96%*	*91%*	*93%*	*88%*	*91%*	*83%*	*87%*	*79%*	*84%*
Mexico											
Total	319.0	372.1	375.3	434.0	455.1	493.4	524.2	556.8	609.1	626.0	690.5
Oil	41.5	24.9	26.1	16.2	12.8	7.5	8.1	5.8	7.3	1.6	1.6
Coal	34.6	27.8	54.9	22.7	54.9	3.0	54.9	3.0	51.8	3.0	48.7
% Coal w/ CCS	*0%*	*0%*	*0%*	*0%*	*0%*	*100%*	*0%*	*100%*	*0%*	*100%*	*0%*
Natural gas	177.4	208.1	204.7	227.4	256.9	236.7	279.1	211.0	338.8	200.4	395.8
% Natural Gas w/ CCS	*0%*	*0%*	*0%*	*1%*	*0%*	*4%*	*0%*	*8%*	*0%*	*13%*	*0%*
Nuclear	11.8	11.9	11.9	14.9	11.9	26.8	18.9	34.7	18.9	46.0	26.8
Biomass and waste	5.7	24.7	8.6	25.9	13.8	27.1	21.4	30.1	19.5	39.9	19.3
% Biomass w/ CCS	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*
Hydro*	30.9	38.0	38.0	45.4	43.9	46.2	45.4	47.3	46.7	48.5	47.9
Geothermal	6.6	8.0	8.0	12.9	11.7	16.5	14.4	20.8	17.1	26.2	20.4
Wind	9.7	26.4	20.9	45.3	34.5	72.2	49.5	102.2	64.2	114.6	74.3
% Wind onshore	*100%*	*100%*	*100%*	*99%*	*100%*	*98%*	*100%*	*98%*	*100%*	*95%*	*98%*
Solar	0.7	2.2	2.2	23.1	14.6	57.4	32.5	101.8	44.8	145.9	55.8
% Solar PV	*97%*	*96%*	*97%*	*45%*	*50%*	*54%*	*56%*	*52%*	*46%*	*49%*	*41%*
United States											
Total	4 319.4	4 286.4	4 515.1	4 224.5	4 615.5	4 179.8	4 708.1	4 189.5	4 762.7	4 178.6	4 839.2
Oil	34.7	17.6	41.3	18.3	41.3	48.6	41.2	28.1	43.9	5.8	5.5
Coal	1 647.4	1 458.8	1 510.7	885.6	1 149.5	179.4	875.9	151.1	804.4	219.2	794.5
% Coal w/ CCS	*0%*	*0%*	*0%*	*4%*	*0%*	*58%*	*3%*	*100%*	*5%*	*100%*	*10%*
Natural gas	1 198.8	1 214.5	1 384.5	1 350.6	1 657.7	1 507.6	1 782.4	1 333.4	1 820.6	870.8	1 755.2
% Natural Gas w/ CCS	*0%*	*0%*	*0%*	*2%*	*0%*	*5%*	*2%*	*13%*	*4%*	*45%*	*4%*
Nuclear	821.2	819.2	819.2	839.6	839.6	888.1	868.4	828.9	804.2	916.0	884.9
Biomass and waste	81.9	92.2	89.9	114.0	102.4	148.2	115.2	185.4	128.1	222.4	139.9
% Biomass w/ CCS	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*
Hydro*	277.0	291.0	294.0	302.0	301.6	322.1	309.3	329.5	316.1	337.2	323.1
Geothermal	19.5	22.1	22.1	45.5	37.8	63.4	48.1	84.6	57.4	113.1	68.7
Wind	200.9	288.0	270.3	447.9	365.2	630.2	480.4	749.1	535.4	822.4	566.8
% Wind onshore	*100%*	*99%*	*99%*	*96%*	*99%*	*95%*	*98%*	*92%*	*97%*	*89%*	*95%*
Solar	34.9	83.1	83.1	220.4	119.6	390.3	185.0	493.2	249.1	653.7	295.7
% Solar PV	*91%*	*90%*	*90%*	*83%*	*89%*	*74%*	*85%*	*62%*	*78%*	*57%*	*78%*

*(excl. pumped storage) ** Values in TWh ***Ocean and Other technologies are not included

ANNEX 2 – ELECTRICTY CAPACITY

TABLE 1. GROWTH IN ELECTRICITY CAPACITY (GW) (SOURCE: AUTHORS, BASED ON ETP 2016, EC 2016)

Technology	2015	2020		2025		2030		2035		2040	
		ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT
Brazil											
Total	144	32%	33%	44%	45%	56%	58%	70%	76%	82%	98%
Oil	9	14%	17%	-1%	7%	-23%	-15%	-38%	-30%	-86%	-57%
Coal	5	25%	29%	19%	25%	17%	32%	11%	36%	-18%	43%
% Coal w/ CCS	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*
Natural gas	13	26%	34%	25%	35%	22%	30%	13%	86%	54%	188%
% Natural Gas w/ CCS	*0%*	*0%*	*0%*	*0%*	*0%*	*1%*	*0%*	*8%*	*0%*	*11%*	*0%*
Nuclear	2	41%	41%	41%	41%	92%	69%	127%	72%	127%	72%
Biomass and waste	11	39%	33%	46%	33%	55%	32%	53%	35%	46%	38%
% Biomass w/ CCS	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0.00%*
Hydro*	93	19%	19%	25%	26%	35%	38%	44%	47%	56%	57%
Geothermal	0	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Wind	10	160%	160%	245%	236%	291%	287%	370%	362%	391%	395%
% Wind onshore	*100%*	*100%*	*100%*	*96%*	*100%*	*93%*	*100%*	*92%*	*99%*	*91%*	*99%*
Solar	1	239%	239%	627%	621%	1020%	997%	1493%	1416%	2111%	2237%
% Solar PV	*100%*	*100%*	*100%*	*100%*	*100%*	*98%*	*98%*	*97%*	*96%*	*91%*	*96%*
France											
Total	119	24%	25%	34%	28%	40%	29%	43%	24%	58%	40%
Oil	1.7	-39%	-100%	-66%	-62%	-75%	-58%	-83%	-78%	-96%	-92%
Coal	4	-51%	-49%	-98%	-98%	-100%	-100%	-100%	-100%	-100%	-100%
% Coal w/ CCS	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*
Natural gas	9	-3%	11%	-16%	-7%	-59%	-59%	-76%	-68%	11%	112%
% Natural Gas w/ CCS	*0%*	*0%*	*0%*	*2%*	*0%*	*5%*	*1%*	*11%*	*1%*	*11%*	*1%*
Nuclear	60	7%	-2%	4%	-5%	0%	-6%	0%	-8%	-14%	-29%
Biomass and waste	3	53%	49%	99%	103%	85%	87%	60%	78%	97%	135%
% Biomass w/ CCS	*0%*	*0%*	*0%*	*0%*	*0%*	*1%*	*0%*	*1%*	*0%*	*2%*	*1%*
Hydro*	21	-2%	0%	-5%	-6%	-1%	-8%	3%	-7%	11%	-1%
Geothermal	0.1	43%	62%	305%	124%	712%	269%	1404%	518%	2529%	849%
Wind	12	93%	100%	182%	128%	291%	182%	331%	174%	402%	232%
% Wind onshore	*91%*	*88%*	*88%*	*90%*	*88%*	*90%*	*87%*	*88%*	*86%*	*88%*	*85%*
Solar	8.4	180%	235%	237%	296%	224%	294%	229%	265%	303%	339%
% Solar PV	*98%*	*98%*	*98%*	*97%*	*97%*	*95%*	*97%*	*94%*	*94%*	*92%*	*93%*
Germany											
Total	193	21%	9%	24%	10%	17%	15%	4%	7%	9%	11%
Oil	6.0	-62%	-68%	-44%	-37%	-37%	4%	-34%	-14%	-56%	-19%
Coal	59	3%	6%	-5%	5%	-30%	3%	-66%	-31%	-87%	-48%
% Coal w/ CCS	*0%*	*1%*	*0%*	*3%*	*0%*	*7%*	*1%*	*14%*	*5%*	*43%*	*10%*
Natural gas	30	-5%	9%	6%	17%	8%	9%	6%	38%	-7%	78%
% Natural Gas w/ CCS	*0%*	*0%*	*0%*	*2%*	*0%*	*5%*	*1%*	*11%*	*1%*	*11%*	*1%*
Nuclear	11	-50%	-54%	-100%	-100%	-100%	-100%	-100%	-100%	-100%	-100%
Biomass and waste	11	-12%	-14%	4%	5%	17%	19%	8%	20%	22%	46%
% Biomass w/ CCS	*0%*	*0%*	*0%*	*0%*	*0%*	*1%*	*0%*	*1%*	*0%*	*2%*	*1%*
Hydro*	7	35%	-1%	31%	-1%	25%	0%	19%	8%	44%	15%
Geothermal	0.1	229%	167%	465%	140%	465%	136%	486%	141%	840%	136%
Wind	35	90%	41%	126%	41%	134%	54%	138%	52%	180%	58%
% Wind onshore	*91%*	*88%*	*88%*	*90%*	*88%*	*90%*	*87%*	*88%*	*86%*	*88%*	*85%*
Solar	34	49%	27%	43%	29%	33%	44%	19%	32%	46%	35%
% Solar PV	*97%*	*98%*	*98%*	*97%*	*97%*	*95%*	*97%*	*94%*	*94%*	*92%*	*93%*

*(excl. pumped storage) ** Values in GW ***Ocean and Other technologies are not included

TABLE 1 (Cont.). GROWTH IN ELECTRICITY CAPACITY (GW) (SOURCE: AUTHORS. BASED ON ETP 2016. EC 2016)

Technology	2015	2020		2025		2030		2035		2040	
		ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT
Italy											
Total	126	2%	9%	-4%	2%	-5%	1%	-11%	-4%	-8%	11%
Oil	16	19%	1%	-14%	-4%	-39%	1%	-62%	-51%	-79%	-62%
Coal	10	44%	48%	-8%	1%	-23%	13%	-59%	-16%	-95%	-82%
% Coal w/ CCS	*0%*	*1%*	*0%*	*3%*	*0%*	*7%*	*1%*	*14%*	*5%*	*43%*	*10%*
Natural gas	52	-7%	7%	-25%	-17%	-29%	-29%	-44%	-27%	-41%	13%
% Natural Gas w/ CCS	*0%*	*0%*	*0%*	*2%*	*0%*	*5%*	*1%*	*11%*	*1%*	*11%*	*1%*
Nuclear	0	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Biomass and waste	4	41%	37%	46%	48%	41%	43%	105%	129%	165%	216%
% Biomass w/ CCS	*0%*	*0%*	*0%*	*0%*	*0%*	*1%*	*0%*	*1%*	*0%*	*2%*	*1%*
Hydro*	15.3	-5%	-3%	0%	-2%	5%	-3%	10%	0%	15%	3%
Geothermal	1	-1%	13%	84%	1%	120%	0%	148%	2%	177%	0%
Wind	7	-9%	-5%	97%	60%	174%	97%	211%	98%	244%	127%
% Wind onshore	*93%*	*88%*	*88%*	*90%*	*88%*	*90%*	*87%*	*88%*	*86%*	*88%*	*85%*
Solar	21.1	-10%	8%	8%	27%	7%	30%	15%	28%	25%	36%
% Solar PV	*97%*	*98%*	*98%*	*97%*	*97%*	*95%*	*97%*	*94%*	*94%*	*92%*	*93%*
Mexico											
Total	75	37%	28%	71%	52%	104%	92%	145%	112%	163%	112%
Oil	16	4%	0%	-1%	-6%	-30%	-35%	-47%	-51%	-62%	-67%
Coal	6	-8%	43%	-24%	43%	-85%	43%	-93%	34%	-94%	24%
% Coal w/ CCS	*0%*	*0%*	*0%*	*0%*	*0%*	*44%*	*0%*	*95%*	*0%*	*100%*	*0%*
Natural gas	31	36%	20%	66%	41%	76%	96%	73%	123%	34%	104%
% Natural Gas w/ CCS	*0%*	*0%*	*0%*	*0%*	*0%*	*2%*	*0%*	*4%*	*0%*	*9%*	*0%*
Nuclear	2	0%	0%	28%	0%	133%	63%	203%	63%	303%	133%
Biomass and waste	1.3	184%	17%	197%	71%	213%	154%	248%	153%	360%	158%
% Biomass w/ CCS	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*
Hydro*	14	46%	46%	46%	46%	46%	46%	45%	45%	45%	45%
Geothermal	1.0	34%	35%	102%	86%	152%	122%	208%	157%	277%	194%
Wind	3.8	171%	117%	364%	259%	634%	415%	936%	566%	1053%	663%
% Wind onshore	*100%*	*100%*	*100%*	*99%*	*100%*	*99%*	*100%*	*98%*	*100%*	*97%*	*99%*
Solar	0.5	193%	192%	2086%	1399%	5780%	3299%	10127%	4044%	14249%	4831%
% Solar PV	*99%*	*99%*	*99%*	*65%*	*66%*	*73%*	*73%*	*74%*	*67%*	*72%*	*63%*
United States											
Total	1 139	3%	4%	8%	2%	13%	5%	10%	7%	17%	11%
Oil	61	-8%	-3%	-38%	-37%	-61%	-63%	-78%	-81%	-84%	-67%
Coal	310	-11%	-8%	-37%	-31%	-61%	-48%	-82%	-58%	-82%	-61%
% Coal w/ CCS	*0%*	*0%*	*0%*	*3%*	*0%*	*13%*	*2%*	*41%*	*5%*	*57%*	*10%*
Natural gas	458	0%	2%	1%	4%	-3%	5%	-11%	9%	-21%	9%
% Natural Gas w/ CCS	*0%*	*0%*	*0%*	*1%*	*0%*	*3%*	*1%*	*6%*	*2%*	*15%*	*2%*
Nuclear	108	0%	0%	2%	2%	8%	6%	2%	-1%	14%	11%
Biomass and waste	18	12%	13%	22%	14%	43%	14%	67%	13%	110%	17%
% Biomass w/ CCS	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*
Hydro*	82	5%	6%	10%	10%	18%	13%	21%	16%	24%	19%
Geothermal	4	24%	20%	89%	63%	150%	97%	223%	123%	335%	154%
Wind	72	47%	37%	132%	88%	228%	149%	290%	180%	329%	199%
% Wind onshore	*100%*	*100%*	*100%*	*97%*	*99%*	*96%*	*99%*	*95%*	*98%*	*93%*	*97%*
Solar	25	112%	112%	426%	197%	756%	345%	877%	458%	1132%	556%
% Solar PV	*93%*	*95%*	*95%*	*91%*	*94%*	*86%*	*91%*	*79%*	*88%*	*76%*	*88%*

*(excl. pumped storage) ** Values in GW ***Ocean and Other technologies are not included

ANNEX 3 – LEVELISED COST OF ELECTRICITY

TABLE 1. LEVELISED COST OF ELECTRICITY (LCOE) UNDER THE AMBITIOUS AND LIMITED CLIMATE TRANSITION SCENARIOS BY COUNTRY (SOURCE: AUTHORS, BASED ON NREL DATA)

Technology	2014	2020		2025		2030		2035		2040	
		ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT
Brazil											
Coal	76	73	77	71	77	70	77	68	77	67	77
Coal with CCS	102	95	95	92	91	89	87	86	85	83	82
Gas	95	76	103	75	97	77	96	73	96	68	95
Gas with CCS	74	60	80	59	75	60	74	56	75	52	74
Nuclear	82	81	81	81	81	80	80	79	79	79	79
Wind onshore 26% CF	79	63	76	55	76	53	76	51	76	50	76
Wind onshore 30% CF	61	49	59	43	59	40	59	39	59	39	59
Solar PV - 14% CF	127	70	122	54	122	46	122	42	122	37	122
Solar PV - 20% CF	89	49	85	38	85	32	85	29	85	26	85
France											
Coal	69	66	69	65	69	63	69	62	69	61	69
Coal with CCS	92	86	86	83	82	80	79	78	77	75	74
Gas	102	81	110	80	104	82	102	78	103	73	102
Gas with CCS	79	64	85	63	80	64	79	60	80	55	79
Nuclear	90	89	89	89	89	88	88	87	87	86	86
Wind onshore 26% CF	102	81	98	71	98	68	98	66	98	65	98
Wind onshore 30% CF	78	63	76	55	76	52	76	51	76	50	76
Solar PV - 14% CF	213	118	205	91	205	78	205	70	205	63	205
Solar PV - 20% CF	149	83	144	64	144	54	144	49	144	44	144
Germany											
Coal	69	66	69	65	69	63	69	62	69	61	69
Coal with CCS	92	86	91	83	92	80	92	78	92	75	92
Gas	107	85	115	84	109	87	107	82	108	76	107
Gas with CCS	83	67	89	66	84	67	83	63	84	58	83
Nuclear	90	89	89	89	89	88	88	87	87	86	86
Wind onshore 26% CF	137	109	132	95	132	91	132	89	132	87	132
Wind onshore 30% CF	105	84	102	74	102	70	102	68	102	67	102
Solar PV - 14% CF	202	112	194	86	194	73	194	66	194	59	194
Solar PV - 20% CF	141	78	136	60	136	51	136	46	136	42	136
Italy											
Coal	69	66	69	65	69	63	69	62	69	61	69
Coal with CCS	92	86	86	83	82	80	79	78	77	75	74
Gas	98	78	105	77	100	79	98	75	99	70	98
Gas with CCS	76	61	82	61	77	62	76	58	77	53	76
Nuclear	90	89	89	89	89	88	88	87	87	86	86
Wind onshore 26% CF	86	69	84	60	84	58	84	56	84	55	84
Wind onshore 30% CF	67	53	64	47	64	44	64	43	64	43	64
Solar PV - 14% CF	228	126	219	97	219	83	219	75	219	67	219
Solar PV - 20% CF	159	88	154	68	154	58	154	52	154	47	154
Mexico											
Coal	76	73	77	71	77	70	77	68	77	67	77
Coal with CCS	102	95	95	92	91	89	87	86	85	83	82
Gas	92	73	99	73	94	75	93	71	93	66	92
Gas with CCS	72	58	77	57	73	58	72	54	72	50	72
Nuclear	82	81	81	81	81	80	80	79	79	79	79
Wind onshore 26% CF	79	63	76	55	76	53	76	51	76	50	76
Wind onshore 30% CF	61	49	59	43	59	40	59	39	59	39	59
Solar PV - 14% CF	127	70	122	54	122	46	122	42	122	37	122
Solar PV - 20% CF	89	49	85	37	85	32	85	29	85	26	85

ANNEX 4 – SUBSIDIES IN POWER GENERATION

TABLE 1. SUBSIDIES IN POWER GENERATION UNDER THE AMBITIOUS AND LIMITED CLIMATE TRANSITION SCENARIOS BY COUNTRY (SOURCE: AUTHORS, BASED ON NREL DATA)

Technology	2014	2020		2025		2030		2035		2040	
		ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT	ACT	LCT
Brazil											
Nuclear	8	21	4	22	6	20	6	23	4	27	5
Wind onshore 26% CF	5	3	0	0	1	0	2	0	1	0	2
Wind onshore 30% CF	0	0	0	0	0	0	0	0	0	0	0
Solar PV - 14% CF	53	10	45	0	47	0	48	0	47	0	48
Solar PV - 20% CF	15	0	8	0	10	0	11	0	10	0	11
France											
Nuclear	21	25	20	26	20	25	19	27	18	31	17
Wind onshore 26% CF	33	17	29	8	29	5	29	6	29	10	29
Wind onshore 30% CF	9	0	7	0	7	0	7	0	7	0	7
Solar PV - 14% CF	144	54	136	28	136	15	136	10	136	8	136
Solar PV - 20% CF	80	19	75	1	75	0	75	0	75	0	75
Germany											
Nuclear	21	23	20	24	20	25	19	25	18	28	17
Wind onshore 26% CF	68	43	63	30	63	28	63	27	63	29	63
Wind onshore 30% CF	36	18	33	9	33	7	33	6	33	9	33
Solar PV - 14% CF	133	46	125	21	125	10	125	4	125	1	125
Solar PV - 20% CF	72	12	67	0	67	0	67	0	67	0	67
Italy											
Nuclear	21	28	20	28	20	26	19	29	18	33	17
Wind onshore 26% CF	17	8	15	0	15	0	15	0	15	2	15
Wind onshore 30% CF	0	0	0	0	0	0	0	0	0	0	0
Solar PV - 14% CF	159	65	150	36	150	21	150	17	150	14	150
Solar PV - 20% CF	90	27	85	7	85	0	85	0	85	0	85
Mexico											
Nuclear	10	23	4	24	8	22	8	25	7	29	7
Wind onshore 26% CF	7	5	0	0	3	0	4	0	4	0	4
Wind onshore 30% CF	0	0	0	0	0	0	0	0	0	0	0
Solar PV - 14% CF	55	12	45	0	49	0	50	0	50	0	50
Solar PV - 20% CF	17	0	8	0	12	0	13	0	13	0	13

ANNEX 5 – CALCULATION OF CORSIA CARBON OFFSETS

CORSIA has been designed as a two-step process. During the first six years of the program companies are called to join in a voluntary basis, period after which, countries that surpass a defined revenue tonne-kilometre threshold must comply with it. The total CO_2 emissions to be offset by a company following CORSIA are computed as follows:

From 2021 to 2029: Companies share the burden of increased sectoral emissions. Thus, the emissions to be offset by the company account as well for those of laggard peers.

$$Emissions\ offset_{202X} = Company\ emissions_{202X} \times Sector\ growth\ factor_{202X}$$

$Company\ emissions_{202X}$: International emissions of the company covered by CORSIA in the year 202X.
$Sector\ growth\ factor_{202X}$: Percentage change of CORSIA member emissions in the year 202X respect to the average of 2019 and 2020 emissions.

From 2030 to 2035: As the emissions growth rate has decreased (but it is still positive), companies account for their emissions "fair share".

$$\begin{aligned} &Emissions\ offset_{202X} \\ &= (1 - fair\ share) \times Company\ emissions_{202X} \times Sector\ growth\ factor_{202X} \\ &+ faire\ share \times Company\ emissions_{202X} \times Company\ growth\ factor_{202X} \end{aligned}$$

$Company\ growth\ factor_{202X}$: Percentage change of company's emissions in the year 202X respect to 2020 emissions.

The $faire\ share$ is set by the company. It is at least 0.2 from 2030 to 2032 and at least 0.7 from 2033 to 2035.

The previous definition of $Company\ emissions_{202X}$ and $Sector\ growth\ factor_{202X}$ is maintained.

MEET THE BUILDERS - ET RISK CONSORTIUM

The ET Risk consortium, funded by the European Commission, is working to develop the key analytical building blocks (Fig. 0.1) needed for Energy Transition risk assessment and bring them to market over the coming two years.

1. TRANSITION SCENARIOS

The consortium will develop and publicly release two transition risk scenarios, the first representing a 'soft' transition extending current and planned policies and technological trends (e.g. an IEA NPS trajectory), and the second representing an ambitious scenario that expands on the data from the IEA 450S /2DS, the project's asset level data work (see Number 2), and relevant third-party literature. The project will also explore more accelerated decarbonization scenarios.

2. COMPANY & FINANCIAL DATA

Oxford Smith School and 2° Investing Initiative will jointly consolidate and analyze asset level information across six energy-relevant sectors (power, automotive, steel, cement, aircraft, shipping), including an assessment of committed emissions and the ability to potentially 'unlock' such emissions (e.g. reducing load factors).

3. VALUATION AND RISK MODELS

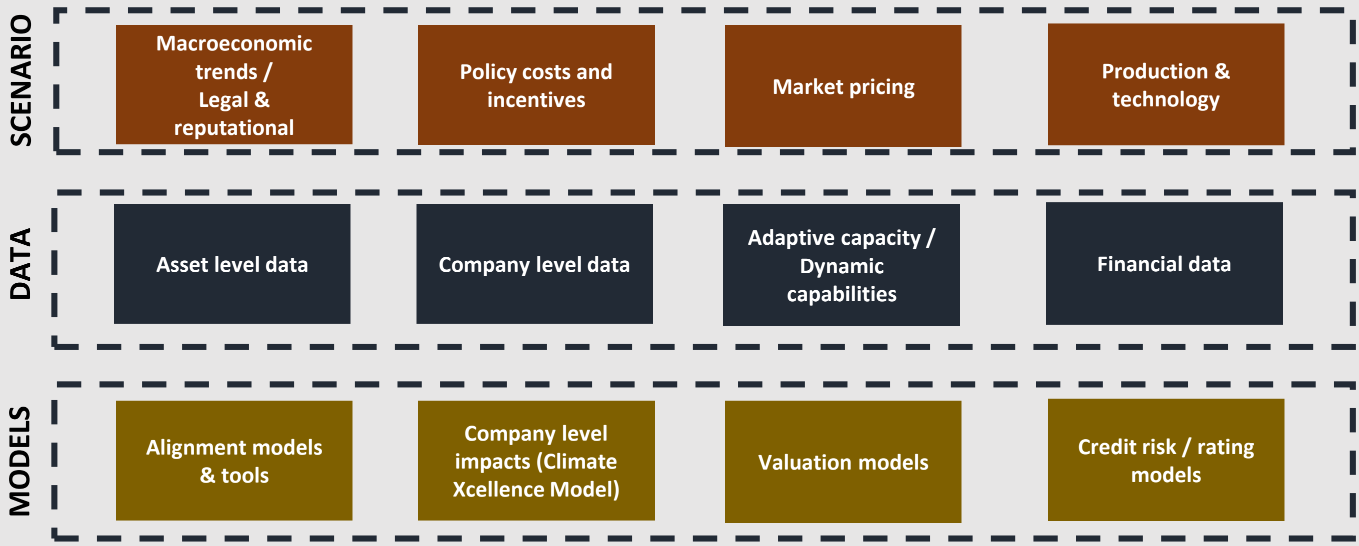
a) **2°C portfolio assessment – 2° Investing Initiative.** 2° Investing Initiative will seek to integrate the project results into their 2°C alignment model and portfolio tool and analytics developed as part of the SEI metrics project.

b) **ClimateXcellence Model – The CO-Firm**. This company risk model comprises detailed modeling steps to assess how risk factors impact margins and capital expenditure viability at the company level.

c) **Valuation models – Kepler Cheuvreux.** The above impact on climate- and energy-related changes to company margins and cash flows can be used to feed discounted cash flow and other valuation models of financial analysts. Kepler Cheuvreux will pilot this application as part of their equity research.

d) **Credit risk rating models – S&P Global.** The results of the project will be used by S&P Global to determine if there is a material impact on a company's creditworthiness. S&P Dow Jones Indices, a S&P Global Division, will explore the potential for developing indices integrating transition risk.

FIG. 0.0: ASSESSING TRANSITION RISK ACROSS THE INVESTMENT CHAIN (SOURCE: AUTHORS)



ABOUT 2° INVESTING INITIATIVE

The 2° Investing Initiative [2° ii] is a multi-stakeholder think tank working to align the financial sector with 2° C climate goals. Our research work seeks to align investment processes of financial institutions with climate goals; develop the metrics and tools to measure the climate friendliness of financial institutions; and mobilize regulatory and policy incentives to shift capital to energy transition financing. The association was founded in 2012 and has offices in Paris, London, Berlin, and New York City.

ABOUT THE CO-FIRM

The CO-Firm GmbH is a boutique consultancy specialized in developing climate and energy strategies for financial services providers, industry, and utilities. Based on financial risk modelling under a range of climate and energy scenarios, the proprietary ClimateXcellence Toolset, and a dataset of more than 200.000 assets and more than 15.000 different technical mitigation measures, The CO-Firm supports its clients in identifying, evaluating and realizing their specific economic opportunities in the national and global climate transition. Specifically, the CO-Firm serves its clients in adjusting their strategies, setting Science Based Targets, creating new business models, and identifying cost savings in their operations and their supply chain. Additionally, the consultancy provides regulatory monitoring services.

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