



Technology, the climate saviour?

The potential for technology to reduce energy related CO₂ emissions

Introduction and table of contents

The challenge: To limit global warming

In December 2015 the [Paris Agreement](#) was born. The agreement aims to hold global warming well below 2°C and pursues efforts to limit it to 1.5°C. A rigorous reduction of greenhouse gas emissions is key, notably in energy-related emissions. Significant increases have been seen in energy-related emissions globally and are brought about, and can be reduced, by human activity. The key drivers in terms of impact and uncertainty with regards meeting the Paris Agreement targets are policy developments to speed up energy transition and technological progress.

Will technology be the saviour for energy-related CO₂ emissions?

This report focuses on technology. It analyses to what extent technology can reduce energy-related CO₂ emissions by lowering fossil fuel demand up to 2050.

Rapid technological progress coupled with sharp price declines for renewables and batteries may lead to an overly optimistic belief that technology can provide all of the solutions to climate change. In reality, effective government policies are required in tandem with technological developments to implement meaningful climate change, but the coordination of policies across the globe has proven extremely challenging, given vested interests and politics placing insufficient emphasis on the environment.

In our analysis of technological progress in energy intensive sectors, we question to what extent technology can be the solution to climate change. We focus on technologies for energy efficiency, electrification and renewables. We present our **Positive Tech Scenario**, which we see as a positive, but realistic, outlook to 2050.

Report structure

Chapter 1 describes the CO₂ emission targets required in order to reach the Paris Agreement goals and introduces our Positive Tech Scenario. **Chapter 2** describes and quantifies technologies that are being developed to reduce energy-related CO₂ emissions. **Chapter 3** presents the outcomes of technological developments and their implications and the part that government policies need to play.

In conducting this research we gained invaluable insight into the technological change that is underway within sectors and the impact technology could have on climate change.

Summary

1 | The challenge and ING's Positive Tech Scenario

The challenge; to radically reduce greenhouse gas emissions
Energy intensive sectors play a pivotal role
Growth makes reducing emissions even more challenging
Increasing energy efficiency, electrification and renewable power are the essence of the energy transition

2 | How technology can help: inputs Positive Tech Scenario

Improving energy efficiency

Technologies to boost energy efficiency
Efficiency gains largely offset demand growth

Shifting of energy source

Electrification dominates biofuels and LNG in transportation
Gradual electrification in manufacturing and real estate sectors
Power demand increases 160% by 2050 in our Positive Tech scenario

Shifting the power mix

Currently two-thirds of electricity comes from fossil fuels
Wind and solar to provide two-thirds of electricity in 2050

3 | Where technology can lead us: outcomes Positive Tech Scenario

CO₂ emissions reduced by 64% by 2050, but limited reduction towards 2030
Carbon capture usage and storage could partially close the gap
Lack of policy would limit technology's ability to reduce emissions
The world in our Positive Tech Scenario

Footnotes

Sources

Would you like to know more?

3

4

5

6

7

8

9

10

11

12

13

14

15

16

17

18

19

20

21

21

22

23

Technology can reduce CO₂ emissions by 64% by 2050, but needs effective policies to combat rebound effects

In ING's Positive Tech Scenario technology brings CO₂ emissions close to 2050 climate targets, but misses 2030 targets

This report concludes that energy-related CO₂ emissions can be reduced by 64% in a scenario that is optimistic but realistic, encompassing improvements in energy efficiency, electrification and renewables. This is close to the emissions reduction targets of 2050, but the 2030 targets are missed. It will take time for new technologies to be implemented, while the global economy continues to grow.

Energy efficiency and renewables are key

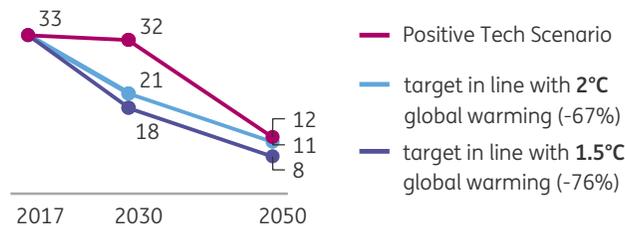
Energy transition to reduce CO₂ emissions is dependent on increasing energy efficiency gains and a shift to electrification and renewable power. Efficiency gains offset global demand growth in terms of CO₂ emissions in our Positive Tech Scenario. Our scenario expects electrification in transport, industrials and real estate to strongly increase power demand, which is predominantly generated by renewables. As a result, energy-related emissions fall from 33 gigatons today to 12 gigatons in 2050. Carbon capture use and storage should reduce emissions further and sooner.

Technology has significant potential, but will need effective government policies

Our Positive Tech Scenario allows for continued economic growth, absorbs increases in the global population and aspirational middle classes and relies less on nuclear energy to meet the climate goals. However, many technologies initially require government policies to become cost competitive and achieve scale. A less emphasised need for policy is to correct unintended feedback loops. For instance, while the switch to electric vehicles is expected to reduce demand for oil, this could cause the oil price to fall and spur demand from shipping and aviation. Strong policy (regulation, subsidies and most of all carbon pricing) is required to eliminate these side-effects. Policy coordination at a global level is most effective.

Positive Tech Scenario: slow start but huge reductions towards 2050

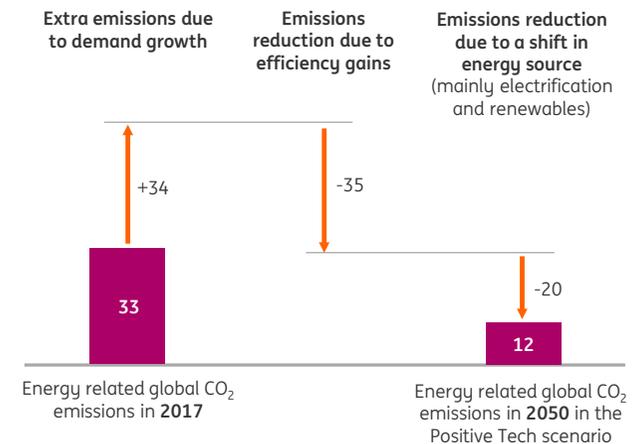
Global energy related CO₂ emissions (gigatons)



Source: ING Economics Department

Positive Tech Scenario: efficiency gains and a shift to renewables are key

Drivers and impact on global energy-related CO₂ emissions (in gigatons, 2017-2050)



Source: ING Economics Department

Key developments in our Positive Tech Scenario (2050)

- Fully electric car fleet, 65% of truck fleet and 10% (including hybrid) of shipping fleet
- Electricity dominant energy source in real estate and industrials
- Power demand increases from 20,000 TWh in 2017 to 52,000 TWh
- Wind and solar to account for 33% of power generation each, coal power (38% now) eliminated
- Other shifts: 10% of ships using LNG, 14% of aviation using biofuels



Chapter 1 | The challenge and ING's Positive Tech Scenario

The challenge: to radically reduce greenhouse gas emissions	5
Energy intensive sectors play a pivotal role	6
Growth makes reducing emissions even more challenging	7
Increasing energy efficiency, electrification and renewable power are the essence of the energy transition	8

1.1 The challenge: to radically reduce greenhouse gas emissions

Energy-related CO₂ accounts for two-thirds of greenhouse gas emissions

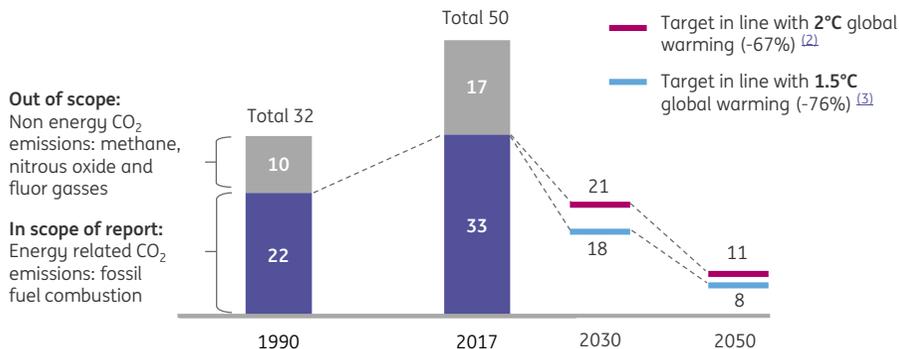
The root cause of global warming is an increasing concentration of greenhouse gasses in the atmosphere. In addition to CO₂, methane and fluor gasses contribute to global warming. It is not easy to compare these gasses due to differences in their atmospheric characteristics and lifespans. This report focuses on energy-related CO₂ emissions, which account for two-thirds of total emissions.

Upward trend in emissions needs to take a U-turn

The Paris Agreement quantifies the requirement to mitigate greenhouse gases through a [carbon budget](#) approach that equates cumulative CO₂ emissions to temperature increase. These translate into target values for CO₂ emissions in 2030 and 2050. The target values expose the significant challenge posed by the Paris Agreement goals. Limiting global warming to 2.0°C will require energy-related CO₂ emissions [to be reduced](#) by almost 67% up to 2050, or by 76% up to 2050 if the 1.5°C target is to be met ⁽¹⁾.

Upward trend in emissions needs to be reversed

Global greenhouse gas emissions (gigatons CO₂-equivalents)



Source: ING Economics Department based on IPCC for target values and IEA for past and current values

Introducing ING's Positive Tech Scenario

This study analyses to what extent technological progress in energy efficiency, electrification and renewables can reduce fossil fuel consumption, thereby reducing energy-related CO₂ emissions. Our conclusions are presented in our Positive Tech Scenario, which:

- assumes a commitment by countries to the Paris Agreement goals and a continuation of policies that aim to make green technology cost competitive. As such ING's Positive Tech Scenario is not a 'tech only scenario',
- assumes active government policies that tackle so-called 'rebound effects'. Rapid technological progress can spur demand and emissions by raising economic growth and/or lowering prices of fossil fuels. For more detail see 3.3,
- does not reduce emissions by shrinking the economy or through radical lifestyle changes, such as less flying, or less heating or cooling of buildings. For more detail see 1.3,
- does not rely on highly uncertain technologies such as [nuclear fusion](#) or technologies that are not focused on reducing fossil fuel consumption, such as carbon capture and use ([CCS and CCU](#)), or [direct air capture](#),
- is not a forecast; rather it presents a possible outcome of future energy-related CO₂ emissions if energy efficiency, electrification and renewables experience accelerates technological progress.

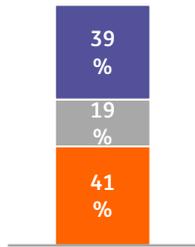
1.2 Energy intensive sectors play a pivotal role

Fossil fuel type makes a difference

With respective shares of 41% and 39% in total energy-related CO₂ emissions, coal and oil are currently the largest sources of CO₂ emissions. A relevant aspect here is that coal has the highest climate impact per unit of energy.

Coal and oil largest sources of CO₂ emissions

Share in total energy related CO₂ emissions, 2017



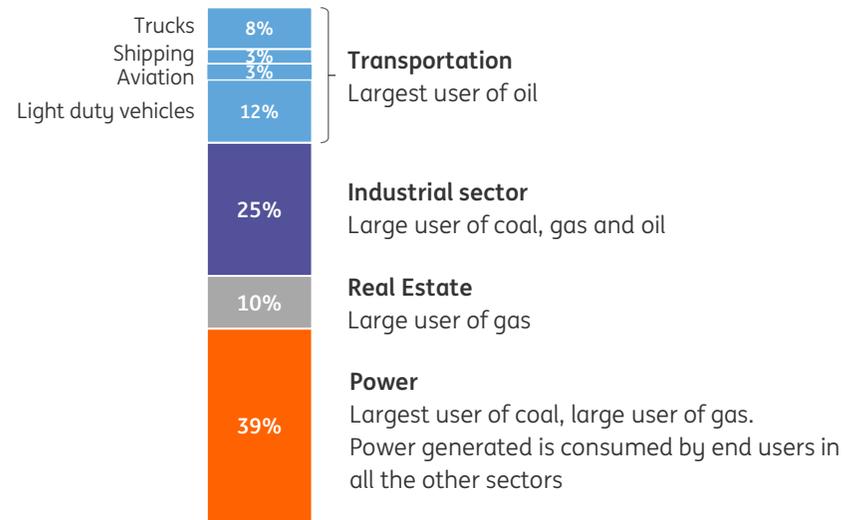
Source: ING calculations based on IEA

Power sector responsible for majority of CO₂ emissions

This report takes a sectoral perspective throughout. It focuses on energy-related CO₂ emissions from fossil fuels across seven sectors: power, industrials, real estate, light duty vehicles (LDVs), trucks, shipping and aviation. With a share of 39% the power sector is currently the largest emitter. However, the electricity it produces is consumed by end users in the other sectors (see chart below).

Power and industrial sectors make up almost two-thirds of direct emissions

Share in total energy related CO₂ emissions, 2017



Source: ING calculations based on IEA

1.3 Growth makes reducing emissions even more challenging

Demand for energy-intensive products and services will continue to grow

Radically reducing energy-related CO₂ emissions is an even bigger challenge in the light of a growing world population striving for higher welfare levels. Our economic and population growth forecasts to 2050 follow base projections from leading institutes ⁽⁴⁾. This leads to an expected growth in all energy-intensive sectors over the coming decades, with aviation currently standing out in terms of growth.

+34
gigatons CO₂

With current energy efficiency levels, demand growth will increase CO₂ emissions by 34 gigatons by 2050 (+2.2% annually) in our Positive Tech Scenario

Continued growth increases demand for energy intensive products and services ^(5,6)

Assumed growth up to 2050 in Positive Tech Scenario (index 2017=100)

Global annual economic growth

+2.8%



Global annual population growth

+0.7%



Now:

7.4 billion

2050:

9.8 billion

Industrial sector



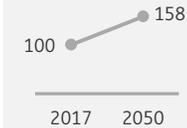
Production: +88%, 1.9% annually
A rising middle class will increase demand for industrial products. Growth is lower than economic growth as the economy shifts from industrial products towards services..

Real estate



Energy demand: +146%, 2.8% annually
Driven by population growth, a rising middle class and more households getting access to energy at the [bottom of the pyramid](#). Strong growth for appliances, heating and cooling.

Light duty vehicles



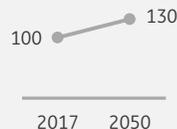
Car fleet: +58%, 1.4% annually
Number of cars is assumed to increase from around 1.1 to 1.8 billion globally as car sharing and autonomous driving does not fully compensate for population and income growth.

Trucks



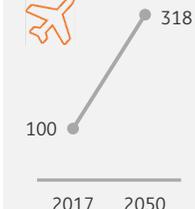
Truck fleet: +53%, 1.3% annually
Consumption growth and e-commerce will lead to an assumed increase of fleet size from 59 to 88 million. Scaling of trucks limits fleet growth.

Shipping



Shipping fleet: +30%, 0.8% annually
Global trade increases despite deglobalisation trends (including 3D printing) and increased local energy systems. The fleet is assumed to grow from 95,000 to 121,000 ships. Ship scaling limits fleet growth.

Aviation



Passenger kilometres: +218%, 3.6% annually
Rising welfare levels and trade spur demand for flying. Internal flights in large countries such as India and China dominate growth.

Sources: ING Economics Department, UN, OECD, Oxford Economics, IEA, DNV-GL, Clarksons and Bloomberg CAGRs are rounded

1.4 Increasing energy efficiency, electrification and renewable power are the essence of the energy transition

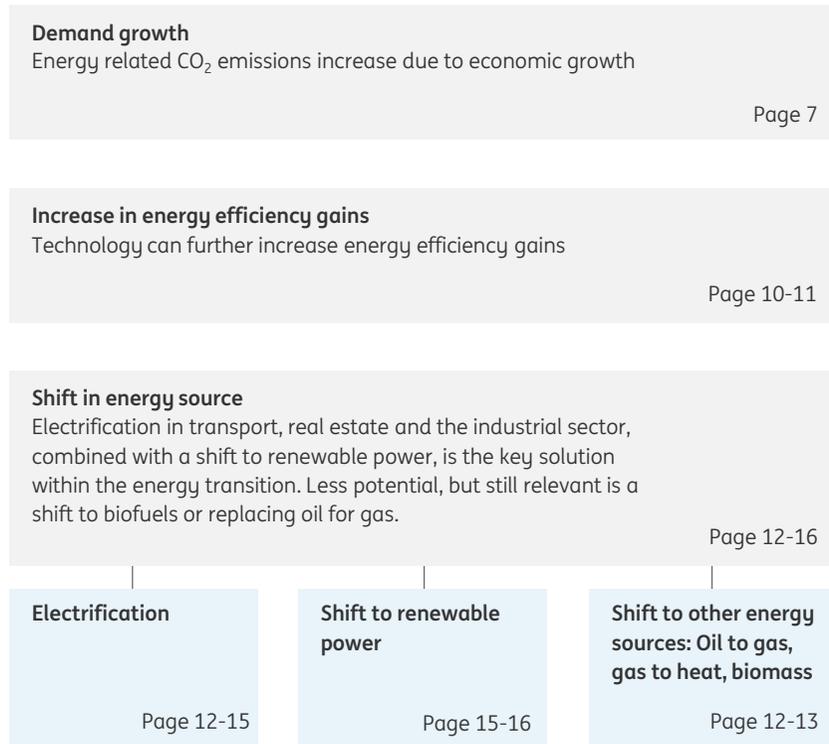
Energy transition is about increasing efficiency, electrification and renewable power

Economic growth is a key driver of energy-related CO₂ emissions. Reducing emissions needs to be driven by, notably:

- Increased energy efficiency
- A shift to cleaner energy sources, in particular electrification at end users combined with renewable power.

This, in essence, is the energy transition. It forms the basis of our calculations in the Positive Tech Scenario as presented in this report (see visual). The next chapter describes the potential of technology in speeding up the energy transition via these three pillars.

Positive Tech Scenario: Drivers of energy-related CO₂ emissions





Chapter 2 | How technology can help: scenario inputs

Technologies to boost energy efficiency	10
Efficiency gains largely offset demand growth	11
Electrification dominates biofuels and LNG in transportation	12
Gradual electrification in manufacturing and real estate sectors	13
Power demand increases 160% by 2050 in our Positive Tech scenario	14
Currently two-thirds of electricity comes from fossil fuels	15
Wind and solar to provide two-thirds of electricity in 2050	16

2.1 Technologies to boost energy efficiency

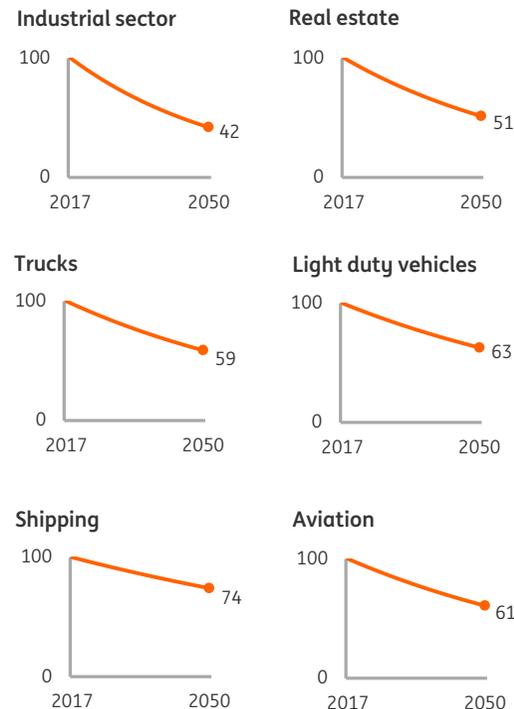
Every sector can further increase energy efficiency

The first 'pillar' in limiting energy demand growth is via energy efficiency measures.

Historically, energy efficiency within the various sectors increased between 1 and 2% annually (see table). In every sector there is technology available to structurally increase this rate (see examples). It is however extremely difficult to quantify the increase for every sector and to come up with an exact number. Our Positive Tech Scenario takes a generic approach by assuming that technology will increase annual efficiency gains with an additional 35% in every sector (see table). A 35% increase in energy efficiency gains would be quite an achievement compared to historical changes in energy efficiency and is slightly more ambitious than the IEA Efficient World Scenario which assumes a 30% efficiency improvement ⁽⁷⁾.

Continued efficiency gains add up in the longer run

Energy demand per unit in Positive Tech Scenario (index 2017=100)



Source: ING Economics estimates based on IEA. Historic trend for aviation based on ICCT

Energy efficiency trends and examples



- Better insulation and the redesign of processes
- Improved energy efficiency standards for machinery
- Increased recycling rates making use of more [efficient techniques](#)



- [Better insulation](#) materials
- Use of LED lighting, more efficient appliances and air conditioning
- Use of energy information and management systems



- Continued engine downsizing, use of turbos, improved car design
- Application of [48 Volt batteries](#) in non electric cars improve fuel efficiency by taking over engine tasks



- Higher energy efficiency standards for new trucks
- Increased aerodynamics and better tyres
- [Truck platooning](#) and smart technology which could even involve [driverless trucks](#) increase fuel efficiency



- Innovative design reducing friction, which improves fuel efficiency
- Improved engine efficiency on new ships



- New airplanes with better aerodynamics and engine efficiency
- Freight in the belly of passenger aircrafts

Average annual efficiency gains

	Past 15 years	Positive Tech Scenario
Industrial sector	1.9%	2.6%
Real estate	1.5%	2.0%
Light duty vehicles	1,0%	1.4%
Trucks ⁽⁸⁾	1.2%	1.6%
Shipping ^(8, 9)	0.7%	0.9%
Aviation ⁽⁹⁾	1.1%	1.5%

Improving energy efficiency

2.2 Efficiency gains largely offset demand growth

Energy efficiency curbs energy demand

Energy efficiency is an important driver to curb energy demand, but our Positive Tech Scenario suggests it will not be enough to (radically) reduce energy use and resulting emissions. A large part of any efficiency gains will be offset by growing demand.

It is clear that bringing the various sectors in line with the Paris Agreement goals will require more than improvements in energy efficiency. A major shift in energy sources brought about by **electrification** and **renewables** will also be key.

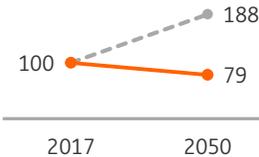
-35
gigatons CO₂

Energy efficiency improvements will reduce CO₂ emissions by 35 gigatons by 2050 (-2.2% annually) in our Positive Tech Scenario

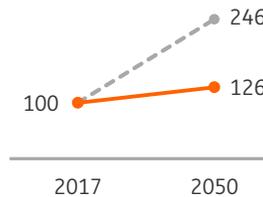
For most sectors energy demand growth and efficiency gains more or less cancel out

Energy demand in Positive Tech Scenario up to 2050 (index 2017=100)

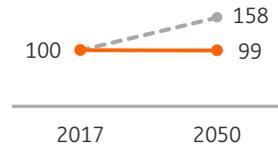
Industrial sector



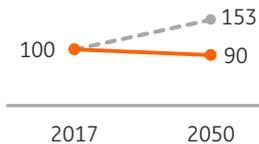
Real estate



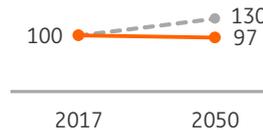
Light duty vehicles



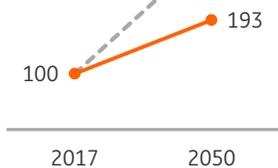
Trucks



Shipping



Aviation



--- Energy demand excluding efficiency gains in our Positive Tech Scenario
— Energy demand including efficiency gains in our Positive Tech Scenario

2.3 Electrification dominates biofuels & LNG in transportation

Electrification: road transport leads the way

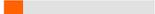
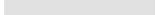
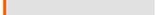
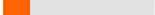
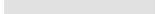
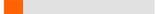
Energy efficiency can make a significant contribution to counterbalancing increased demand and subsequent emissions, but much more is needed to reach the reduction target. Therefore, a shift away from the use of fossil fuel is the key to reducing emissions. Electrification has the greatest potential and disruptive change is expected to have the most impact on light duty vehicles. In our Positive Tech Scenario we assume 990 million electric vehicles will be on the road in 2040, compared to around 330 million as assumed by the IEA New Policies Scenario* and 950 million in the IEA 'Future is Electric Scenario'. The truck fleet will also be largely electrified in the Positive Tech Scenario, albeit at a slower pace.

Shift towards LNG and biofuels in shipping and aviation

The possibilities for electrification in shipping and in particular aviation are expected to be limited up to 2050. Fully electric ships will be operating in inland shipping but not for deep sea shipping, which is the vast majority of the shipping sector globally. Biofuels and LNG are assumed to also play a substantial role. In aviation, our Positive Tech Scenario assumes a modest role for bio kerosene (14%). The potential of bio fuels is limited, because in a world with a growing population it will increasingly compete with food.

Main electrification trends in transportation

Assumptions in our Positive Tech Scenario

		2017 actual	2030 Positive Tech	2050 Positive Tech
 <ul style="list-style-type: none"> Electric vehicles are expected to be cost competitive around 2024 in Europe.* Range anxiety will no longer be a major problem and charging infrastructure will be sufficient in the EU, US and parts of Asia. 	Share of EV's in global car sales	 1.2%	 50%	 100%
	Share of EV's in global car fleet	 0.3%	 14%	 98%
 <ul style="list-style-type: none"> Rapid improvements and cost declines in battery technology LNG acts as a bridge technology between fully electric or hydrogen powered trucks. For a part of the fleet hydrogen technology, requiring electricity for production, is used. 	Share of LNG trucks in sales	 3%	 14%	 0%
	Share of LNG trucks in fleet	 0.3%	 8%	 5%
	Share of electric trucks in sales ⁽¹⁰⁾	 0%	 27%	 100%
	Share of electric trucks in fleet ⁽¹⁰⁾	 0%	 8%	 65%
 <ul style="list-style-type: none"> Electrification for deep sea shipping is limited to the use of shore power, batteries or solar panes that provide electricity for on board processes instead of generators and the use of hybrid engines. Electric vessels will be used in inland shipping. LNG vessels and synthetic fuels substitute oil use. 	Share of LNG vessels in fleet	 0.1%	 3%	 10%
	Share of hybrid vessels in fleet	 0%	 0.7%	 12%
	Share of electric/hydrogen vessels in fleet	 0%	 0%	 10%
 <ul style="list-style-type: none"> Electrification will be limited as batteries are heavy, electric planes need extensive testing and models are typically introduced in 10 year cycles ⁽¹¹⁾ The use of biofuels increases, but is limited as it competes with food consumption. 	Share of biofuels in oil consumption	 0.1%	 9%	 14%

Source: ING Economics Department. * The IEA only provides numbers to 2040, not 2050.

2.4 Gradual electrification in manufacturing and real estate sectors

Multiple drivers for increased electrification

In the manufacturing sector, electrification is mainly driven by increased recycling rates ⁽¹²⁾, electric steam production to produce heat at low temperatures and, to a lesser extent, the production of hydrogen. Electricity is increasingly used as the main energy source in production processes for recycling. In our Positive Tech Scenario the electricity share increases to 45% in 2040* compared to 29% in the IEA New Policies Scenario.

Multiple drivers for increased electrification

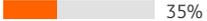
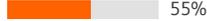
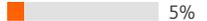
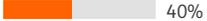
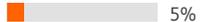
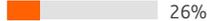
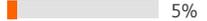
In the real estate sector, the increased share of electricity in the energy mix is driven by:

- 1) faster electricity demand growth for appliances and space cooling;
- 2) increased use of [heat pumps](#) for space heating;
- 3) a shift away from bioenergy (burning wood) to electricity in developing countries.

In our Positive Tech Scenario electricity provides half of the energy in real estate in 2040* (52%) compared to 43% in the IEA New Policies Scenario. If the electricity is generated by renewable sources, it reduces CO₂ emissions.

Main shifts in energy sources in manufacturing and real estate

Assumptions in our Positive Tech Scenario

Sector	Share in energy mix	2017 actual	2030 Positive Tech	2050 Positive Tech
 <ul style="list-style-type: none"> Decarbonisation generally means increased electrification, supporting a move towards electricity in the mix. In the Positive Tech Scenario, we are assuming that electricity will become the main source of power for industry in 2050, compared to coal currently. 	Electricity	 24%	 35%	 55%
	Biomass	 5%	 8%	 10%
 <ul style="list-style-type: none"> Decarbonisation means increased use of heat pumps and district heating. District heating is increasingly used, especially in densely populated cities with nearby industrial clusters where residual heat from factories can be used to heat houses. Use of biomass is reduced as the bottom of the pyramid gains access to energy sources and more people live in cities 	Electricity	 31%	 40%	 62%
	District heating	 5%	 6%	 10%
	Biomass	 26%	 20%	 5%

Source: ING Economics Department. * The IEA only provides numbers to 2040, not 2050.

Shifting of energy source

2.5 Power demand increases 160% by 2050 in our Positive Tech scenario

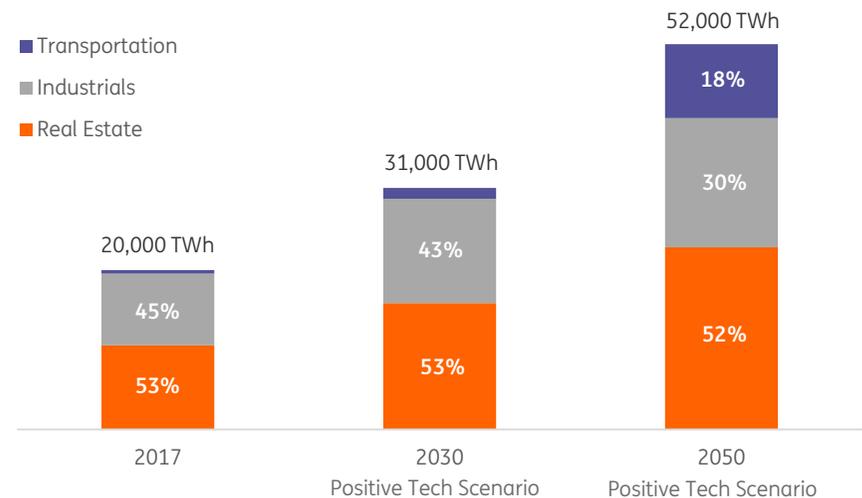
Power demand rises to 52,000 TWh by 2050

If our Positive Tech Scenario assumptions on energy efficiency and the shift in energy sources materialise, electricity demand is set to increase by almost 160% from approximately 20,000 TWh to 52,000 TWh in 2050. Electrification of cars and trucks leads to a share of 18% for transportation by 2050 versus a marginal role currently.

Our Positive Tech Scenario is more bullish on electrification compared to IEA scenarios, leading to a larger uptake of power demand (+103%). Up to 2040*, the IEA's New Policies Scenario delivers a 60% increase in power demand, while its Future is Electric Scenario sees a 90% increase. However, there are more extreme scenarios that anticipate power demand increases of up to [100,000 TWh](#) by 2050.

Electricity demand in the Positive Tech Scenario

Global power demand in TWh



Source: ING Economics Department.

* The IEA only provides numbers to 2040, not 2050.

2.6 Currently two-thirds of electricity comes from fossil fuels

Increased electrification needs to go hand in hand with a shift towards more renewables

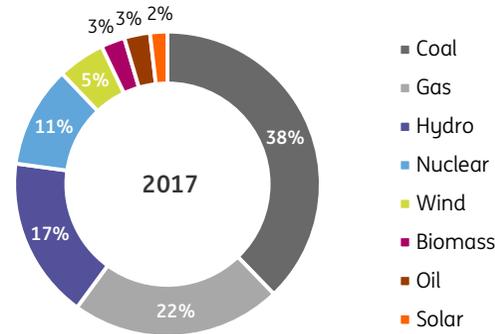
Currently, 63% of electricity globally is generated by fossil fuels, with coal providing the largest share. Electrification most of all benefits the climate if power generation comes from renewables.

Huge differences in energy transition challenge per country

The carbon intensity of the power sector differs widely across countries. In countries like India and China the vast majority of power is generated by coal fired power plants. At the other end of the spectrum, Germany and the United Kingdom are countries with high solar and wind penetration, but still the majority of power generation is fossil based.

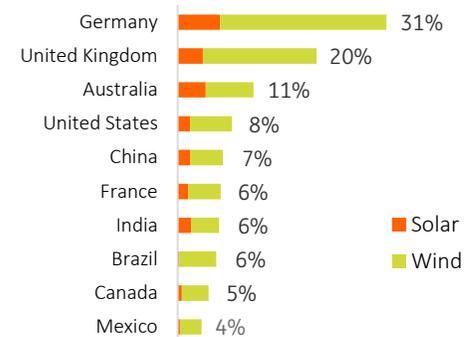
Two-thirds of current electricity use is provided by fossil fuels

2017 global power mix



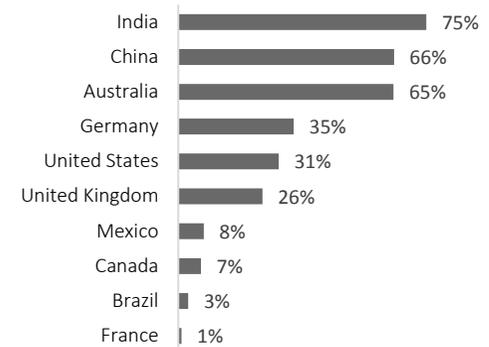
Solar and wind generation across countries

Share of solar and wind in 2017 power mix, %



Coal generation across countries

Share of coal in 2017 power mix, %



Source: ING Economics Department, based on Bloomberg

Shifting the power mix

2.7 Wind and solar to provide two-thirds of electricity in 2050

Rapidly declining costs of solar and wind energy

Solar and wind energy are the main drivers behind the shift in the power mix in our Positive Tech Scenario. Solar and wind energy have already seen rapid cost declines. For example, the price of solar panels has fallen by 29% annually over since the seventies of the past century. As a result, installing solar and wind capacity is already cheaper today compared to building new coal and gas fired power plants in countries with favourable conditions, such as India, China, US, Germany and Australia.

Power predominantly, but not fully, generated by sun and wind by 2050

The power sector moves from around two-thirds of fossil fuels today to two-thirds of solar and wind energy by 2050 in our Positive Tech Scenario. Including hydro, geothermal and biomass the share of renewables reaches 82%. Our Positive Tech Scenario assumes a stronger uptake of 60% in renewables by 2040 compared with the IEA Sustainable Development Scenario's uptake assumption of 51%.

The Positive Tech Scenario does not anticipate 100% renewables in 2050 and needs to be considered against the background of a 160% increase in total electricity demand. Wind and solar are intermittent energy sources that are too unpredictable to meet demand at all times. Breakthroughs in storage solutions need to be realised and implemented on a large scale.

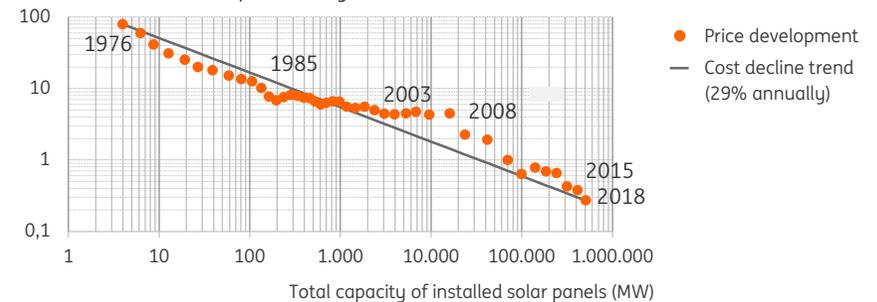
-20
gigatons CO₂

The shift to renewables reduces CO₂ emissions by 23 gigatons in the Positive Tech Scenario by 2050.

Decades of rapid cost declines for solar panels

Module price solar panel in US\$/W, in 2018 real prices

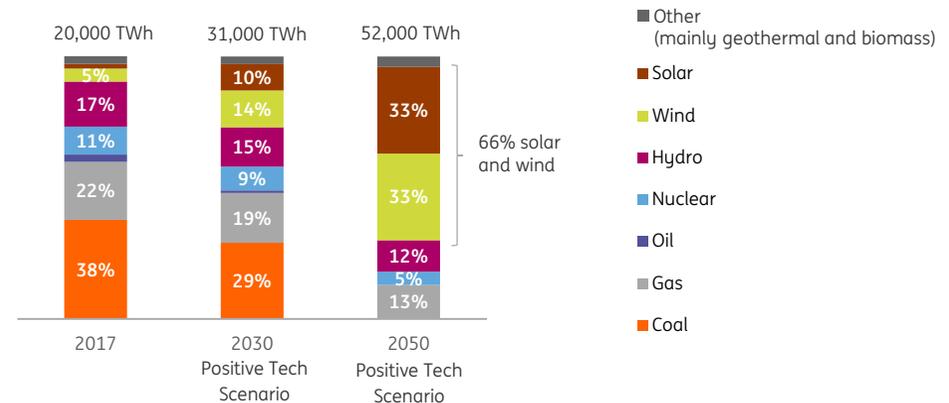
Note that costs are for panels only, so exclude installation and maintenance costs



Source: Bloomberg

Positive Tech Scenario sees rapid shift towards solar and wind energy

Global power mix by source, % of power generation



Sources: ING Economics Department on the basis of Bloomberg, IEA and other sources



Chapter 3 | Where technology can lead us: scenario outputs

CO ₂ emissions reduced by 64% by 2050, but limited reduction towards 2030	18
Carbon capture usage and storage could partially close the gap	19
Lack of policy would limit technology's ability to reduce emissions	20
The world in our Positive Tech Scenario	21

Outcome

3.1 CO₂ emissions reduced by 64% by 2050, but limited reduction towards 2030

Positive Tech Scenario hits the 2050 target, but misses 2030 checkpoint

The developments in energy efficiency, electrification and renewables as assumed in our Positive Tech Scenario would reduce energy-related CO₂ emissions from 33 gigatons in 2017 to approximately 12 gigatons in 2050; a reduction of 64%. This is close to the 2°C reduction target for 2050, but emissions remain considerably higher in earlier years. So, in the long term, we believe a low carbon economy is feasible. However, it will take time for new technologies to be implemented, while the global economy continues to grow.

Power sector remains largest emitter, aviation gains importance

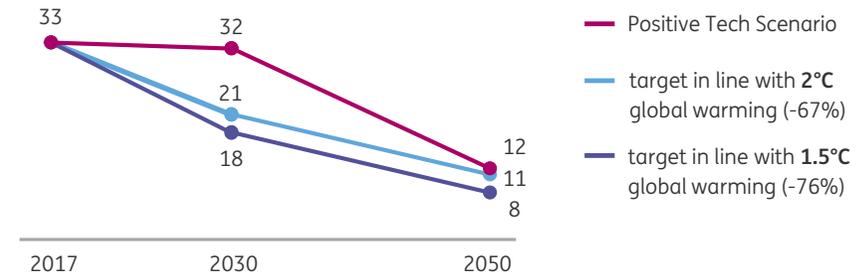
The largest emitter remains the power sector with a share of 30%, due to gas power plants still being active in 2050. The industrial sector comes second. Aviation should see the highest growth in emissions, with its share in global CO₂ emissions rising from 3% to 16%.

Bridging the remaining gap

The CO₂ emissions reduction to 12 gigatons in our Positive Tech Scenario is linked entirely to lower fossil fuel consumption. There are also technologies available that limit the environmental impact of fossil fuel use. We explore these so-called 'post combustion' or 'end of pipe' technologies on the next page.

Positive Tech Scenario: close but not close enough

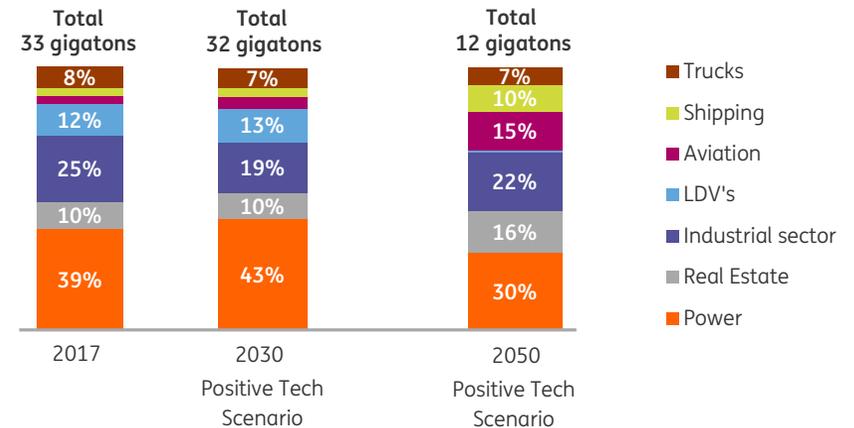
Global energy related CO₂ emissions (gigatons CO₂ equivalents)



Source: ING Economics Department

Power sector and aviation gain importance

Global energy related CO₂ emissions, share by sector



Source: ING Economics Department

3.2 Carbon capture usage and storage could partially close the gap

CCU and CCS could potentially correct an early emissions miss

There is potential to [capture CO₂](#) once it has been emitted (without lowering fossil fuel consumption). Captured CO₂ can be either **stored** (carbon capture and storage, CCS) or **used** (carbon capture and usage, CCU, for instance as feedstock for the chemical industry). For both the power and industrial sectors there is a significant opportunity here:

- 1) The power and manufacturing sectors remain the largest emitters in our Positive Tech Scenario (see previous page), providing ample scope to capture CO₂ on a large scale.
- 2) Carbon is an important resource for the industrial sector so there are multiple uses for captured CO₂.
- 3) If remaining CO₂ needs to be stored, there is sufficient [storage capacity](#) (for example in empty gas fields) with global estimates ranging from 1,600 gigatons to 10,000 gigatons.

Globally, there are only [18 large scale CCS projects](#) currently in operation with five under construction. Examples of large scale CCU are even more scarce. The steel and chemical industries are undertaking pilots for carbon capture and usage that show great potential for [emission reduction](#).

Taking CO₂ out of the atmosphere is not likely to happen soon

Carbon capture and storage can also be applied to biomass. Plants take CO₂ out of the atmosphere as they grow and CCS processes can prevent the CO₂ from returning into the atmosphere if the biomass is burned in a biomass power plant. Many climate scenarios rely heavily on these so-called BECCS processes (Bio Energy combined with CCS), especially after 2050 when early misses of carbon emission targets need to be corrected.

[Machines](#), rather than plants, can also take CO₂ out of the atmosphere. However, these technologies are still at an early stage and relying on them now turns fighting global warming into more of a gamble rather than a deliberate strategy.

Engineering the climate remains a bridge too far

[Geoengineering](#) technologies limit global warming by reducing the amount of sunlight that reaches the earth. These technologies are as yet unproven and highly uncertain. They also pose ethical dilemmas in relation to who is to manage global temperatures on earth and who would be to blame if they get it wrong. Furthermore, relying on geoengineering technologies for the future could reduce the urgency to reduce emissions today.

3.3 Lack of policy would limit technology's ability to reduce emissions

Technology, the climate saviour?

Technology holds significant potential to reduce energy-related CO₂ emissions, but government policy will play an essential role for a number of reasons. In practice there will be many technology induced [feedback loops](#) that will need to be addressed. The five examples we give below play a pivotal role and have received little attention in scenario analyses.

A world rich in technology is a world rich in policies

Policies are vital to reap the emissions reduction potential offered by technology. First, policies can help green technologies to become financially feasible. Second, the five examples we give below clearly show that strong policies (regulation, subsidies and most of all carbon pricing) are needed to prevent and correct unintended side effects. Policy coordination at a global level would be most effective, but also most difficult to achieve.

Why technology needs strong policies: five examples of feedback loops that limit technology's ability to reduce emissions

Price effects trigger new demand

Technologies that reduce the demand for fossil fuels result in lower fossil fuel prices. This will trigger additional demand and raise emissions again (the [Jevons paradox](#)). For example, the rapid take up of electric cars and trucks reduce oil demand. Without any additional policy, aviation becomes cheaper encouraging people to fly more.

Price effects impact speed of transition

Technologies that reduce the demand for fossil fuels result in lower fossil fuel prices. This makes the business case for cleantech the more challenging. In addition price declines of fossil fuel might trigger oil producers to extract oil much faster in a race against the bottom (the [green paradox](#)).

Part of the potential effect will be mitigated

It is quite common that green technology triggers behaviour that reduces its impact. Think of LED lighting that has brought down the cost of lighting and energy use but increased its application for example by encouraging more and larger neon signs on buildings ([rebound effect](#)).

Technological progress can also be dirty

Green innovations do not come in isolation. It is more likely that they are discovered in a world with strong progress in all kind of innovations. Some will not be so environmental friendly. Think of the huge amount of energy required to mine bitcoins or to produce and upload vlogs, let alone innovations such as commercial [space travelling](#).

Technology increases economic growth

A world with strong progress in all kind of innovations could increase productivity and economic growth. Higher demand will raise CO₂ emissions. Our Positive Tech Scenario assumes 'base case' economic growth ⁽⁴⁾.

3.4 The world in our Positive Tech Scenario

Positive Tech world allows for continued growth, but climate concerns not taken away

Strong technological progress can help to make the climate transition less painful economically. Even with continued population and economic growth, emissions are reduced by almost two-thirds compared to current levels. Behaviour would have to be restricted less in comparison with a world characterised by slow technological progress. Policy is still crucial. Firstly, to induce technological progress, for instance by ensuring a return on investment. Secondly, by preventing countervailing feedback loops, such as rebound effects. Technology will however be too slow to meet the 2030 goals. The implementation of technologies - even in our Positive Tech scenario - will be gradual, while meeting the agreed goals requires a larger reduction of emissions in the short run.

Comparing two worlds that strive to meet the Paris goals

The world in our Positive Tech Scenario differs from a world with less technological progress and more restrictive policies

Welfare and lifestyle

In terms of welfare and lifestyle, a world as envisioned by the Positive Tech Scenario:

- allows for more growth in energy-related activities,
- allows for less distortions of consumption patterns,
- reduces the need for income policies. Fast technological progress would prevent strong increases in energy prices. Since energy is a basic necessity it prevents low income households to spend increasing shares of their income on energy.

Climate and environment

In terms of the climate and environment, a world as envisioned by the Positive Tech Scenario:

- continues to emit amounts of CO₂ that remain above the Paris Agreement targets for the next one to two decades, so needs other measures that lead to quick reductions of emissions,
- is a world in which nuclear energy is less of a necessity to limit global warming,
- will lead to the necessary 'low to zero carbon economy', but needs further (technology) solutions after 2050 to reach net negative emissions to limit global warming below 2°C,
- creates new environmental challenges with regard to the disposal of clean technologies like used [solar panels](#), [car batteries](#) and [wind turbines](#). Circular concepts can reduce this impact.

Footnotes

Chapter 1.1

- 1) Numbers represent gross emissions. 2030 and 2050 figures have been adjusted to match levels for energy-related CO₂ emissions as IPCC reports total fossil fuel & industry related CO₂ emissions. Note that IPCC scenarios assume increased take up of CO₂ by nature resulting in lower net emissions. Source: [IPCC 2018, chapter 2](#).
- 2) Midpoint from IPCC scenarios limiting peak warming to below 2°C during the entire 21st Century with greater than 66% likelihood.
- 3) Midpoint from IPCC scenarios limiting warming to below 1.5°C in 2100 and with a 50-67% probability of temporarily missing that level earlier.

Chapter 1.3

- 4) While the Positive Tech Scenario contains optimistic assumptions on technology for energy efficiency, electrification and renewables, assumptions on economic and population growth are more 'basecase', in line with projections of institutes such as UN, OECD, IMF. This is in line with scientific literature which concludes that green growth is possible but most likely will not exceed 'grey growth'.
- 5) Trains, motorcycles and electric bicycles are not included as their impact on fossil fuels and emissions is small compared to other transport modes.
- 6) Due to data availability and modelling choices we focus on fleet developments for cars, trucks and ships. However, in aviation fleet data is less available compared to data on travel distances (like revenue passenger kilometres).

Chapter 2.1

- 7) It is difficult to compare our improvements in energy efficiency with other scenarios as past and future efficiency gains are often not published in detail for every sector.
- 8) Energy efficiency numbers for heavy duty vehicles and shipping are corrected for the trend towards larger trucks and ships (scale effect).
- 9) Developments such as electric taxiing, hybrid airplanes, hybrid vessels and use of shore power represent a shift in energy source (from fossil fuel to electricity). However, this is taken into account as energy efficiency improvements as electric taxiing and hybrid engines that are applied to planes predominantly use fossil fuels.

Chapter 2.3

- 10) Both electric and hydrogen powered trucks hold promise for the future. It is not clear yet which technology will dominate towards 2050. Since the production of hydrogen through electrolysis requires large amounts of electricity, we categorise it as electrification until technology trends become more clear. So the reported shares of electric trucks represent a mixture of electric and hydrogen trucks.
- 11) The impact of electrification in aviation is relatively small and therefore not modelled under electrification. Rather, trends like electric taxiing and hybrid engines are captured through improved energy efficiency growth rates. See also footnote 9.

Chapter 2.4

- 12) Recycling improves energy efficiency and also leads to more electricity use compared to fossil fuels. Hence it is mentioned in the paragraphs on energy efficiency as well as electrification.

Literature

Bloomberg; New Energy Outlook, 2018

DNV-GI; Energy Transition Outlook, 2018

Ecofys; Energy Transition within 1.5°C – a disruptive approach to 100% decarbonisation of the global energy system by 2050, 2018

Energy Transitions Commission; Mission Possible: Reaching net-zero carbon emissions from harder-to-abate sectors by mid-century, 2018

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IPCC; Global warming of 1.5°C, 2018

KVS; Preadviezen klimaatbeleid: kosten, kansen en keuzes, 2018 (in Dutch only)

OECD; Effective Carbon Rates, 2018

PBL; Trends in global CO₂ and total greenhouse gas emissions, 2017

UN; Emissions Gap Report, 2018

This may also be of interest

Focus on the Dutch climate challenge: insights in targets, certainties and uncertainties



Breakthrough of electric vehicles threatens European car industry



Circular construction: most opportunities for demolishers and wholesalers



Less is more; circular economy solutions to water shortages



ING will steer portfolio towards two-degree goal: the Terra approach



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