SHELL ENERGY SCENARIOS GERMANY

Royal Dutch Shell plc

The Hague, 28 April 2017

Note: "The New Lens Scenarios" and "A Better Life with a Healthy Planet" are part of an ongoing process – scenario-building – used in Shell for more than 40 years to challenge executives' perspectives on the future business environment. We base them on plausible assumptions and quantification, and they are designed to stretch management thinking and even to consider events that may only be remotely possible. Scenarios, therefore, are not intended to be predictions of likely future events or outcomes, and investors should not rely on them when making an investment decision with regard to Royal Dutch Shell plc securities.

It is important to note that Shell's existing portfolio has been decades in development. While we believe our portfolio is resilient under a wide range of outlooks, including the IEA's 450 scenario, it includes assets across a spectrum of energy intensities, including some with above-average intensity. While we seek to enhance our operations' average energy intensity through both the development of new projects and divestments, we have no immediate plans to move to a net-zero emissions portfolio over our investment horizon of 10 to 20 years. Net-zero emissions, as discussed in this document, is a collective ambition that is applied in the aggregate, with technical and other considerations determining the net-positive or net-negative emissions for any individual industry sector or company. It must be driven by society, governments and industry through an effective overall policy framework for the energy system as a whole, integrating consumption and production. We believe the Paris Agreement is a start towards creating such a framework, and we look forward to playing a role as society embarks on this very important journey.

INDEX

SHELL ENERGY SCENARIOS FOR GERMANY

Shell has long recognised the importance of the climate challenge, along with the critical role energy plays in enabling a decent quality of life for people across the world. We see the need for transformation of the global energy system towards providing more energy globally, while at the same time responding to environmental stresses.

The pace of transformation will differ from region to region and sector to sector, either for political and economic reasons, population density and associated land-use constraints on the availability of renewables, high infrastructure costs, transport needs, affordability or availability of viable substitutes.

Shell has started looking into individual country dynamics to better understand the specific regional or local opportunities and challenges. The *Energiewende* puts Germany in "pole position" for this transformational journey.

The Shell Energy Scenarios for Germany look at potential opportunities and challenges in the various sectors of the German economy in light of the politically agreed CO_2 reduction targets. They go on to identify high-level drivers that may have the largest impact on how those sectors may evolve between now and 2050. The scenarios are not "predictions" or likely outcomes. They rather ask "what if" type questions and apply Shell's 40 years of scenario experience to explore where those plausible assumptions and quantifications may lead.

GERMANY'S "ENERGIEWENDE"

The German government's political long-term target is to reduce greenhouse gas (GHG) emissions by 80%-95% by 2050 compared to 1990, i.e. from approximately 1,250 million tonnes CO_2 equivalent (in 1990) to less than 250 million tonnes CO_2 equivalent (in 2050). Specific intermediate goals have also been defined in the "Energiekonzept" (energy concept): 40% by 2020, 55% by 2030 and 70% by 2040. And for the first time, the latest Climate Action Plan for 2050 proposes sector-specific targets for 2030 (see Appendix).

The challenge is immense. In 2014 Germany was still the sixth biggest CO_2 country in the world, behind China, the US, India, Russia and Japan. Its per capita CO_2 emissions totalled 8.9 tonnes, whereas the global average remains close to 4.5 tonnes.

So far the *Energiewende* (energy transition) has been focusing primarily on the power sector and renewables on the supply side, and on efficiency gains on the demand side. Although these are necessary areas on which to place attention, the focus needs to be broader as all sectors of the economy shape energy needs. In addition, consumer choices coupled with the societal acceptance of socio-economic change (including, but not limited to cost) will be crucial success factors on the "demand side" of the *Energiewende*: What products are customers willing to pay

for? What energy use behaviours and patterns are they willing to change? How will policy arenas like job security, social security or foreign policy be balanced against far-reaching decarbonisation of the energy system? In a nutshell, what will be seen as affordable and acceptable to society?

While ultimately *technical* factors will determine the potential to which different sectors of the economy can be decarbonised, the level of actual progress will be determined primarily by *non-technical* factors. These include factors such as regulation, cost, societal acceptance and consumer choices.

The greatest progress to date has been made in the power sector. However, similar progress in decarbonising the real end-use consumption sectors of the energy system – mobility, buildings and industry – will at least be equally important for achieving the overall goals. Although agriculture and forestry also impact the overall greenhouse gas balance, primary energy conversion and final energy consumption account for most of man-made greenhouse gas emissions.

Each sector presents its own technical and non-technical challenges as well as specific characteristics. Some economic sectors will inevitably prove more challenging to decarbonise than others. And over time, novel applications and customer choices will drive energy solutions that stretch across various sectors, such as micro- or mini-cogeneration engines to produce both heat and power for private homes.

POWER

Currently, according to the Federal Environment Agency, the **power** sector accounts for more than two fifth of German energy-related CO_2 emissions. In contrast to the other sectors, it is "intermediate": the power sector converts primary energy into electricity, which is then used in end-user sectors.

There are three fundamental ways to decarbonise the power sector: through the use of nuclear power, through renewables and through Carbon Capture and Storage or Use (CCS/U). The government has decided to exit nuclear by 2022, and CCS/U is facing societal concerns in Germany. The focus to date has been on the deployment of renewable energies.

Since the 1990s, renewable energies in Germany have grown at a tremendous rate. The Renewable Energies Act in 2000 (EEG) established a platform for investments in renewables, especially for wind and PV solar, and formed the basis for year-on-year growth thereafter. In 2016, renewables met 32.3% of German gross power demand (according to the latest estimate of AG Energiebilanzen, as of 16 December 2016), up from around 3% in 1990. CO_2 emissions in the German power sector have fallen by about a fifth, despite both the exit initiated from nuclear and the strong role of coal in the German power mix. Coal is outperforming gas due to the lower coal price.

Looking ahead, phasing in more renewables will require better integration within the power sector, extending transmission infrastructure and developing storage technologies to cope with the needs to bridge the intermittency of renewables.

MOBILITY

The **mobility** sector currently accounts for about one fifth of German energy-related CO_2 emissions. Despite efficiency gains, it is the only sector that has not contributed to falling emissions in absolute terms since 1990. However, this is expected to change as fuel consumption by the biggest contributor, i.e. passenger cars, decreases as total vehicle mileage stops increasing and vehicles become more energy efficient. Moreover, the fleet's drivetrain composition changes will also have an impact.

So far, biofuels have been a valuable part of the energy mix as a lower-cost way to reduce CO_2 emissions in the transport sector, provided that their production is managed in a responsible way. For the future, advanced biofuels from non-edible plants and waste materials are needed, and the blending wall will have to be overcome – i.e. the amount of biofuel that can be blended into gasoline or diesel without harming car engines.

Even higher expectations are being set for the electrification of transport, especially with more power coming from "green" renewable sources. Electric vehicles – either FCEVs (fuel cell electric vehicles based on hydrogen), BEVs (battery electric vehicles) or PHEVs (plug-in hybrid electric vehicles) – could contribute to reducing CO_2 emissions in the transport sector. By the end of 2016, 34,022 BEVs and 165,405 hybrid vehicles were registered in Germany. In the first three months in 2017, 17,236 hybrids and 5,060 BEVs were added, out of a total passenger car population of 45.8 million. However, these numbers are growing and with it the need for charging and power infrastructure.

Fuel cell electric vehicles have the potential to be an important part of a future low-carbon transport system. If renewable electricity is used to make the hydrogen, the vehicle can effectively be driven without generating any carbon emissions and provide storage for excess renewable energy.

Heavy duty road transport faces bigger challenges. This segment of the economy has fewer options available to replace efficient (i.e. high energy-density) diesel engines with alternative fuels, especially in the long haul heavy duty segment. Over time, LNG and hydrogen may become an alternative. The same goes for **marine** and especially **aviation** applications, which are both substantial liquid fuel consumers. LNG has the potential to play an increasingly important role for marine and biofuels for aviation. For **rail** transport, hydrogen may become an alternative to electrifying tracks currently served by diesel-powered locomotives.

INDUSTRY

The German **industrial** sector accounts for around 15% of energy-related emissions; non-combustion industrial processes cause another 7% of total GHG emissions in the country. Combustion-related emissions have been reduced by one-third since 1990, and process emissions by 40%. Whether – and how quickly – an industrial sector can decarbonise depends on whether its fundamental processes require high temperatures and whether particular chemical reactions are involved.

For example, heavy industries such as steelmaking rely on intense heat of above 1,200°C in furnaces and depend on hydrocarbons as thermal fuels to provide those high temperatures. While there is ongoing research, it is hard to see any near-term technology breakthroughs that will radically reduce or eliminate the need for thermal fuels and carbon in these basic industrial processes at scale in the foreseeable future.

Current options to decarbonise include recycling of carbon-intensive materials, switching to lower-carbon fuels such as gas or biomass, zero-carbon (hydrogen) thermal fuels and carbon capture and storage (CCS/U).

However, despite further gains in energy efficiency, large industrial plants and processes will continue to emit significant volumes of CO_2 from existing operations for a considerable time to come.

BUILDINGS

The buildings sector includes **the private households and small business consumers.** It accounts for more than 15% of direct energy-related CO_2 emissions. Since 1990, these have been reduced by one-third. In addition, through the use of electricity, the sector is a significant contributor to indirect emissions via power generation.

As an initial step, modernising existing heating boilers to the best-available technology permits substantial energy savings. In the short- and medium-term, there will be more diversification in heating technologies and energy sources (e.g. hybridisation, heat pumps, micro- and mini-cogeneration plants), and another possible perspective is the integration of home heating and power generation (smart grids or smart homes).

As more than 12% of homes will be newly built in the period up to 2030, employing the latest energy-saving standards, energy-efficient modernisation of buildings and heating systems will be key factors for energy and GHG savings.

COPING WITH UNCERTAINTIES

The challenges in the various sectors are significant. And we are living in a connected world in which the future can unfold in many ways. Ultimately, reality will be shaped by individual and collective choices made now and in the future.

To cope with these uncertainties, Shell has been developing and using scenarios for more than 40 years. Shell scenarios ask "what if?" type of questions and aim at helping to understand the possibilities and uncertainties ahead.

Scenarios are based on plausible assumptions and quantifications. They are designed to stretch our thinking so we can take more informed decisions – they are not intended to be detailed predictions of likely future events or outcomes.

In developing them, we look at pressing trends and issues. We use them as "lenses" through which we view a particular landscape and its possible future evolution.

SCENARIOS FOR GERMANY

In addition to the global Shell scenarios, Shell Germany has produced specific national passenger car, commercial road transport and home heating studies for many years (www.shell.de/studien). These look in-depth into particular sectors of the energy system.

For the first time, the Shell Group's Scenario Team, Shell Germany and external experts from institutes and think tanks have teamed up to develop a holistic scenario outlook for Germany to 2050.

The results are two "Energy Transition and Climate Challenge" scenarios: ***"Winning the Marathon"*** and ***"Slowing Momentum".*** They are consistent views on how Germany's future energy pathways could evolve in response to societal, economic, political, geopolitical and technological changes – or "drivers".

Based on these key drivers and additional input from respected third parties, Shell used its in-house World Energy Model (WEM) to analyse progress towards politically defined CO_2 reduction goals for Germany. The scenarios look at trade-offs, opportunities and risks, as well as general societal implications and decisions facing decision-makers in Germany in the coming years.

SCENARIO DRIVERS

Five high-level drivers likely have the largest impact on how the key sectors in Germany may evolve between now, 2025 and 2050.

DEMOGRAPHICS AND IMMIGRATION CHALLENGE

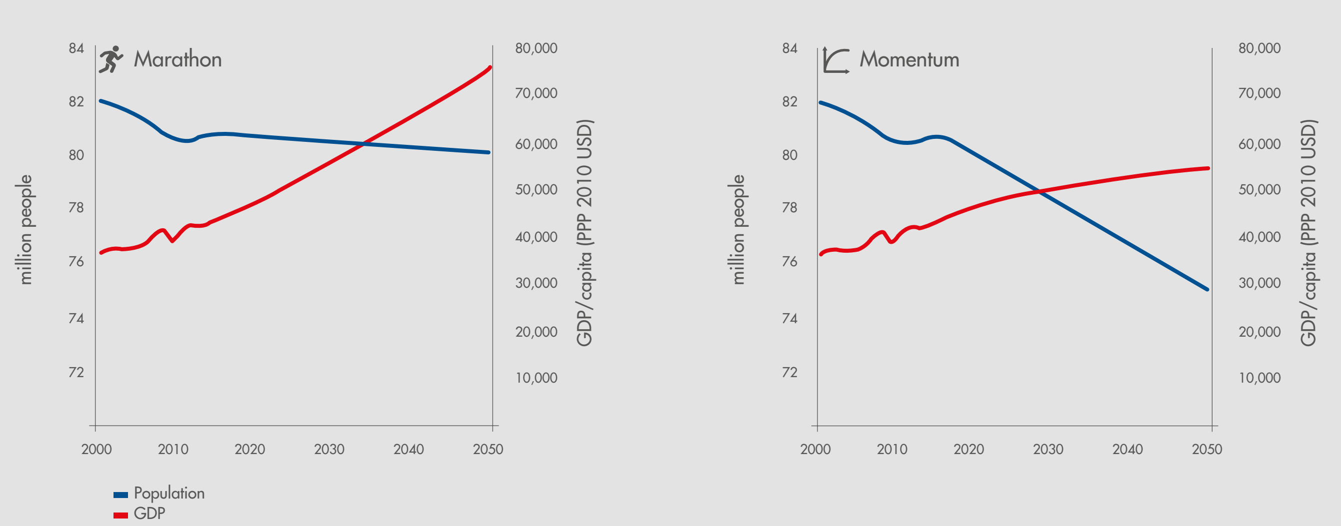
Firstly, we looked at demographic trends for Germany. Societal demographics are usually determined by long-term factors. Germany has one of the lowest birth rates in Europe. At the same time, people are living longer. This makes Germany an ageing society, raising questions around future productivity and economic growth.

Immigration is one of the factors that could slow down this trend, but it doesn't come without social and cultural challenges. Integration is the critical question. In the past, Germany has integrated large numbers of immigrants. But how will German society react in the event of continuous migration flows over the course of the 21st century, as population growth will impact energy demand?

In principle, energy ladders assume that more people as well as wealthier people will lead to a higher demand for energy.

For our scenarios, we have assumed two different levels of immigration. In *Winning the Marathon*, Germany successfully manages to stabilise declining demographics and to keep the population stable by 2050. In *Slowing Momentum*, we have assumed greater challenges to counterbalancing the decline in population through immigration, resulting in a decline in the population. Economic growth is therefore also slower, so government tax income will decrease while social payments increase, leading to less "free" government money available to meet ambitious decarbonisation targets.

Germany - Population & GDP
million people, PPP 2010 USD



In Marathon the population in Germany stays at around 80 mln due to immigration whereas in Momentum it drops to around 75 mln to reflect an ageing society. In Marathon the GDP grows by around 1.6% p.a. whereas in Momentum this stays at around 0.7% p.a.

ECONOMY

The health of the German economy is highly dependent on exports. The German economic record has proven to be flexible and responsive to shocks in the past.

However, the global economy is seeing new forces at work, including opposition to globalisation. The economic model may need to be re-framed as the nature of globalisation changes. The German economy is highly competitive, but faces increased pressure, particularly in new frontier areas such as in the uptake of electric mobility or in information technology.

At the same time, new technologies have the potential to change production processes, economic comparative advantages and also labour requirements. For example, manufacturing in the future may require smaller but more highly skilled work forces.

A key question will be how flexible the German economy will be in coping with new challenges from international competition, and how automation will play into demographics as technology impacts the share of labour in production. "Industry 4.0", or the willingness to invest in education and infrastructure, will also influence how resilient Germany remains in a globalised world and how quickly "established industries" adapt to new business models, growing digitalisation and fast-changing consumer preferences.

GERMAN POLITICS (REGULATIONS/LEGISLATION)

Germany's deeply rooted consensus model – e.g. income redistribution and intergenerational transfers – has supported social cohesion and collective responsibility. But if social pressures mount, society will be forced to make economic choices about how best to respond, and social strain and political volatility may increase.

Will parties agree to promote the wider good? Or would a likely trajectory be more ad hoc political coalitions that focus temporarily on specific policy goals, with more tactical and short-term objectives at the expense of institutional stability and long-term thinking? The answers may translate into different impacts for energy transition, which will require a longer-term, sustainable implementation plan.

TECHNOLOGY CHALLENGE AND HOW THIS WILL SHAPE PRODUCTIVITY

New technologies can have a significant impact across society. And meeting the staged German CO_2 reduction targets for 2030 and 2050 will require the maturation, customer acceptance and market penetration of new technologies, including technologies that are not yet proven or known.

A key technology trend is digitalisation. Coupled with an enormous growth of data volumes, rapidly improving data processing and analytics capabilities, increased connectivity between not only human beings but also machines ("Internet of Things"), and the ability to translate digital data in novel applications, such as 3-D printing or robotics, digitalisation transforms our personal lives, economic processes and consumption patterns.

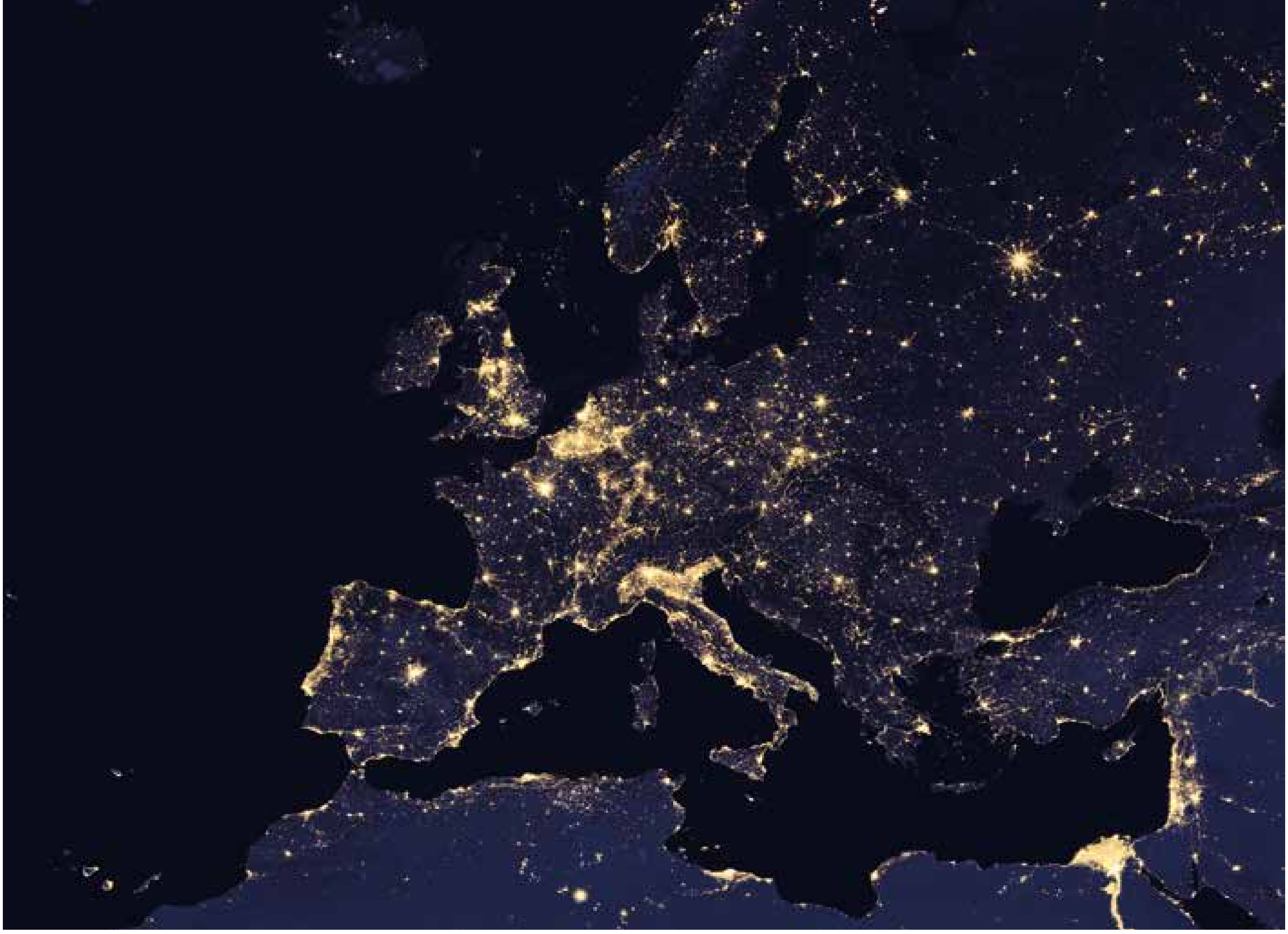
Technology already drives a falling share of labour in production. The penetration of mobile devices or other means of modern telecommunication allows us to stay connected without physically travelling to see each other. Smart metering can accelerate the transition from a centralised energy system dominated by large power plants to a decentralised system with smart homes or other small-scale power generation. And these are just a few examples.

But societal acceptance of new technologies cannot be taken as a given. On the other hand, Germany's response to developing and being a test ground for new technologies will be an important factor in determining whether it remains an innovation frontrunner or will have to surrender its position to other nations able (and willing) to be more flexible and fast-moving – with the consequence that such new industries potentially move to these more flexible, vibrant places.

EXTERNAL DEVELOPMENTS (GLOBAL POLITICS AND GLOBAL ECONOMY)

The fifth driver is Germany's possible response to external developments in geopolitics and the global economy, or more broadly: what will be Germany's place, for example, in the Eurozone or geopolitically in the world?

The EU accounted for 58% of Germany's exports in 2015. In the light of Brexit, the "Euro crisis" and Germany's huge current account surplus with its EU partners, will the European partners make the EU stronger and act together? And how will Europe stand its ground against other trading blocs and evolving geographical areas like China, India and the US? How will the Euro-zone develop? And what will be Germany's future role in the EU? Germany's economy is export-driven and depends on global demand. Changes to the balance of trade and collaboration with other EU member states could trigger a re-framing of the economic model away from exports. A more balanced German economy could be a positive gain.



SCENARIO OVERVIEW

For both scenarios, assumptions (see overview in "Energy developments" table) have been made for the five key drivers.

"Winning The Marathon" is a normative scenario. This means that we have focused on how the energy system and energy mix in Germany could develop over time specifically to deliver the GHG reduction target of at least 80% by 2050 (versus 1990). This scenario reveals that the target could be reached by pulling all possible levers and stretching them to the maximum. In this scenario, the transition plays out like a long race with many hurdles to overcome. Some of these will be easier to leap, while others will prove more difficult, and one or two may lead to stumbles. But ultimately Germany will complete the "marathon hurdle race" by successfully reaching its goals.

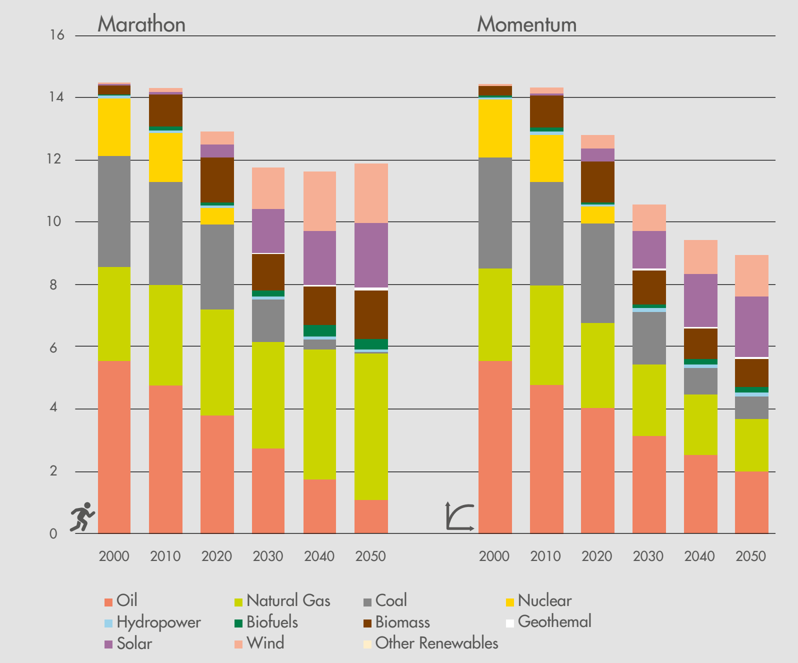
"Slowing Momentum" builds on the same drivers, but with different quantifications. It assumes that the speed of overall change will be slower, with population and GDP growth also smaller. This scenario starts with high momentum in energy transition by the German government and in society based on proven successes of the last 10-20 years. Germany has ambitious targets, but due to internal and/or external factors, unexpected roadblocks will arise, delaying further implementation, slowing the momentum and therefore changing the trend. This will ultimately result in below-target decarbonisation of 70% by 2050. As the world around Germany continues to move fast, its lead position in exports will be challenged.

DRIVERS OF ENERGY DEVELOPMENT

The following overview represents the assumptions and views taken for the key drivers in the two scenarios determining future energy developments up until 2050.

Scenario Drivers	Winning The Marathon	Slowing Momentum
Demographics / immigration	■ Successful integration of immigrants stabilising the declining demographics ■ Around 350,000 immigrants p.a. net inflow ■ Population stays constant at around 80 million by 2050	■ Stumbles over the integration of immigrants ■ Resistance to immigration, job and social issues ■ Low immigrant net inflow of around 100,000 p.a. ■ Population drops to around 75 million by 2050
Economy	■ Germany remains resilient despite set-backs ■ Strong investment in education and infrastructure ■ Germany launches 4th industrial revolution ■ Trade and exports are given a push ■ Automotive industry remains highly competitive and can maintain high export share in future low/net-zero emissions world ■ New industries (smart solutions) emerge as end of productivity in traditional industry is reached ■ GDP growth increases to 2% by 2030, averaging 1.6% p.a. over period up to 2050	■ Traditional manufacturing becomes less competitive, while end of productivity is reached ■ Reduced investment in education and infrastructure leads to less competitive industrial environment ■ Disparities between regions (expensive cities vs. cheap countryside) result in lower urbanisation ■ Economy flatlines and Germany needs to re-invent itself and is struggling to grow ■ GDP grows at 0.5% p.a.; as the population declines, GDP per capita grows by 0.7% p.a.
Politics	■ Strong governments with clear majorities will stay in place for a long time ■ Key parties agree for the wider good ■ Long-term government plan on energy transition will prevail and be followed through and supported by the public and industry ■ Energy transition decisions are taken to reach the ambitious CO_2 targets ■ Coal is phased out by around 2040 and CCS/U is applied such that 0.9 GT of CO_2/year is captured by 2050.	■ Immediate government response needs over-shadow the implementation of a long-term plan ■ Further diversification of the parties; more parties trying to represent mixed populations views ■ Parties fail to agree to ensure re-election ■ Difficult to come to joint decisions / consensus ■ Very slow pace in new legislation / regulation ■ Some limited coal is still in the system by 2050, and no CCS/U is assumed.
External environment	■ European consolidation makes Europe stronger and act together ■ Rise of China gives Germany strong position, having invested heavily in trade in Asia ■ EU becomes a "smaller" geographical area vs. China, India, US but joined-up ■ International institutions become important	■ Germany at heart of a multi-track EU with less alignment across all EU states ■ Global EU cooperation less aligned leading to less global influence ■ More focus on domestic and EU markets ■ Varying relationships between various EU partners and US, China and Russia
Technology challenge	■ Climate change is felt globally and drives policy, business and consumer decisions ■ German new skills from 4th industrial revolution and climate change allow Germany to play key role ■ Germany responds and becomes "testing playground" for new technologies ■ Emerging disruptive technologies bear fruit more broadly	■ Increased resistance to new technology as the economic / social benefit of investment in new technologies does not outweigh the cost ■ Development of new technologies moves to other vibrant places like the US or China, which are "more flexible" and fast-moving

Germany - Total Primary Energy - By Source
EJ/year (Energy source)

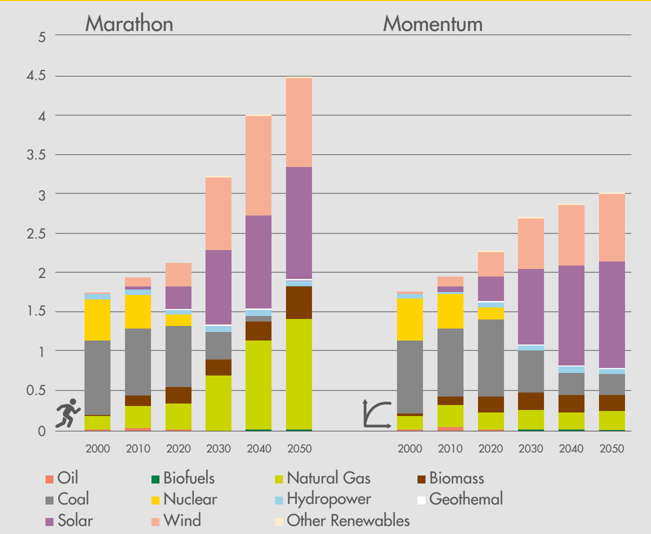


Both scenarios assume that nuclear will be phased out by 2021 with similar breakdown and levels of energy until 2020s. After this point primary energy demand in Marathon remains high whereas in Momentum it decreases steadily by 30% from 2020 to 2050 (less people, less GDP). Marathon assumes all coal to be phased out around 2040. For contrast, coal remains a part of the mix in Momentum. Both see large growth in Solar PV and Wind. Marathon uses less oil due to its rapid transition in the transport sector.

RESULTS

Scenario Drivers	Winning The Marathon	Slowing Momentum
POWER	■ About 2.5 times more electricity demand is expected by 2050 compared to today ■ Renewables (RE), especially onshore and offshore wind and solar PV, will grow to more than 50% of total energy consumption, up from about 20% today ■ Nuclear exit happens as planned by 2022 ■ Societal pressure leads to phased accelerated coal exit and managed social impact of job losses, high public acceptance of a power price increase for private households and exemption of industry to ensure competitiveness ■ Power transmission system can be transformed smoothly to meet the new requirements with an increasing public acceptance of interstate transmission systems ■ Storage / back-up solutions for intermittent RE are found, allowing RE to grow well beyond 50% in the power sector ■ More decentralised generation is built, e.g. mini-CHP starts to penetrate and existing district heating systems are fully utilised ■ Ultimately, the German power system switches to RE with a stable back-up system, and runs smoothly at a low electricity price due to low variable costs in a fully integrated decentralised and centralised power system ■ Falling power prices make traditional oil & gas users (e.g. residential heating) consider switching to electrical heating, simplifying utility installations and using existing synergies ■ Society will initially feel pain of high household costs for the transition, job security and high global competition but impacts are well managed ■ 60% of fossil-based power plants and some heavy industry will need to be fitted with CCS/U, assuming social acceptance for the technology post-2030	■ Electricity demand increases by nearly 50% by 2050 compared to today ■ Slower growth of RE as oversupply of power is becoming an issue with zero value/prices; public discussion focuses on guaranteed RE payments. Due to lower power demand compared to Marathon, RE make up almost 90% of domestic power generation by 2050 ■ Nuclear exit happens as planned, but utilities cannot cope with higher-than-anticipated costs. Government steps in, triggering another large public debate about the cost of the energy transition ■ Coal exit takes much longer as debate slows to a standstill due to implications of higher power prices, job losses and survival of power utilities, with populists' parties exploiting the issue ■ Slowdown of interstate transmission systems expansion caused by public resistance (NIMBY = "Not In My Back Yard") and delay to permits ■ Acceptable low-cost options for storage/back-up systems and low-carbon alternatives fail to emerge. Coal plants continue to operate, gas is pushed back ■ Decentralisation still continues at a slower pace and results in diverse island solutions, e.g. CHP and heat pumps ■ Harsh efficiency measures required, which drive life style changes that are not widely accepted by society ■ Public resistance to CCS/U prevents any deployment in the country

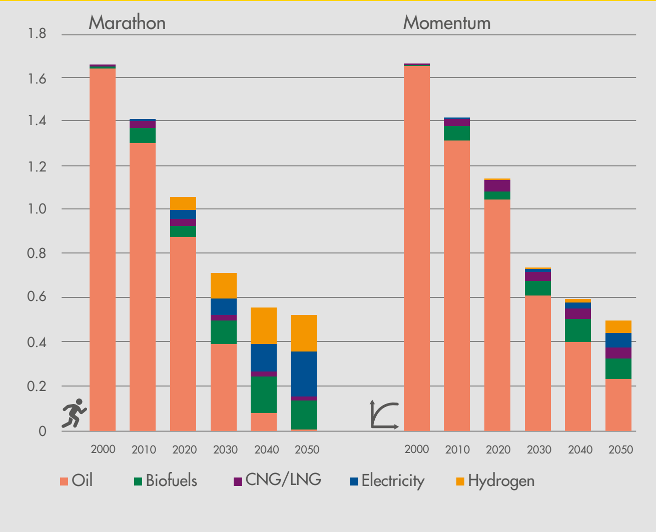
Germany - Total Electricity Consumption - By Source
Total Electricity - EJ/year (Energy carrier)



In Marathon maximum electrification is being implemented with the power demand more than doubling (by 2050) and reaching a 50% share of total final energy consumption. In Momentum power demand increases by only around 50%, reaching around 40% of the total energy consumed. Both scenarios see a strong growth in renewables with around 9-12 GW newly installed annual capacity from Wind and PV Solar.

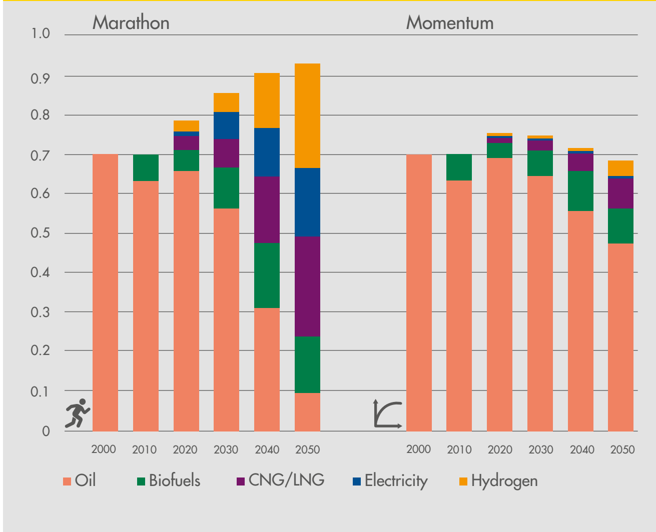
Scenario Drivers	Winning The Marathon	Slowing Momentum
MOBILITY	■ E-mobility flourishes due to attractive vehicle offers and renewable penetration leading to cheaper power at certain times, either via charging at home (PV solar home systems) or the free market ■ Growing demand for EVs (BEVs, plug-in hybrids and FCEVs) leads to more offerings, advanced battery solutions with falling costs and smart system offerings developing. Initially starting with a "second car" or the "car sharing" model (in larger cities), the evolving infrastructure will allow people to use EVs for longer journeys. Other market segments may include the SUV/premium segment allowing better recovery of high e-component costs. EV market will double every year, reaching ~1 million EVs by 2020, and around 75% EV penetration by 2050 ■ Alternative modes of transport as well as societal support for the establishment of emission-free zones with restrictions for diesel cars exist ■ New, cleaner solutions for heavy duty vehicles (HDV) are deployed, e.g. with LNG or hydrogen-propelled vehicles, as governments also look to address air quality issues. The same applies to other special applications (e.g. for public bus transport) ■ Biofuels will continue to grow as the "simplest" replacement, especially for heavy duty vehicles ■ Public emission-free transport and driverless vehicles start to dominate in larger cities, with Germany becoming a frontier player on connected and electric cars. Market growth in emission-free vehicles will also lead to cheap fuel cells ■ Beyond 2030, the majority of new passenger cars are required to be BEVs or FCEVs ■ Marine and aviation are more difficult to decarbonise, and liquid fossil fuels will continue to play the leading role in these segments. On the marine side, gaseous fuels (e.g. LNG) will diversify supply ■ Hydrogen is becoming an alternative to (grid-) electrification of train tracks ■ Both 2030 and 2050 targets can be met	■ Government incentives for EVs do not lead to an accelerated uptake; sparse (fast-) charging infrastructure; cost of EVs still high and limited reach of EVs still seen as major barrier ■ EV penetration takes more time; the shift to e-mobility is less radical ■ Slow cost improvements in battery technology make customers continue to buy efficient conventional ICE cars. This also supports car sharing offerings in larger cities ■ Disparities between regions (expensive cities vs cheap countryside); slower pace of urbanisation, less people move into the cities, less uptake of e.g. "car sharing" or special "city solutions", aspiring private car ownerships is more attractive due to larger distances to drive ■ Low global EV acceptance, especially in US and China, contributes to a slower than desired transition in the mobility sector, allowing other alternative technologies like LNG and hydrogen to pick up, once embraced and made cost-effective in vehicles by the global automotive industry ■ This all results in co-existence of a large mix of various liquid fuels and e-mobility, with a flexible but expensive infrastructure investment ■ 2030 targets can be met; however, the sector will not meet the 2050 target

Germany - Total Final Consumption - By Carrier
Passenger Transport Road - EJ / year (Energy carrier)



In Marathon cars will get highly fuel-efficient and annual mileage will drop. Biofuels will replace conventional fuels while electric (BEV, PHEV) and hydrogen (FCEV) cars will increasingly replace internal combustion engines. In Momentum cars will also continue to become more fuel-efficient. Biofuels continues to grow while electric (BEV, PHEV) and hydrogen (FCEV) cars will only grow visibly after 2030.

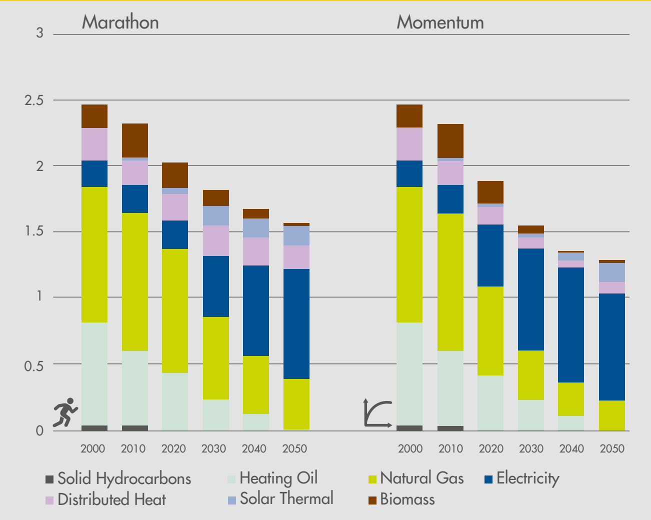
Germany - Total Final Consumption - By Carrier
Freight Transport Road - EJ / year (Energy carrier)



In Marathon the overall road freight transport grows. Biofuels continues to grow, LNG takes a strong position for heavy duty vehicles (HDV) and Electricity and Hydrogen for medium duty vehicles (MDV). In Momentum the road freight transport will be stable. Biofuels continues to grow and LNG takes a share for specific customers and Hydrogen comes in late, overall it will be a slower transition.

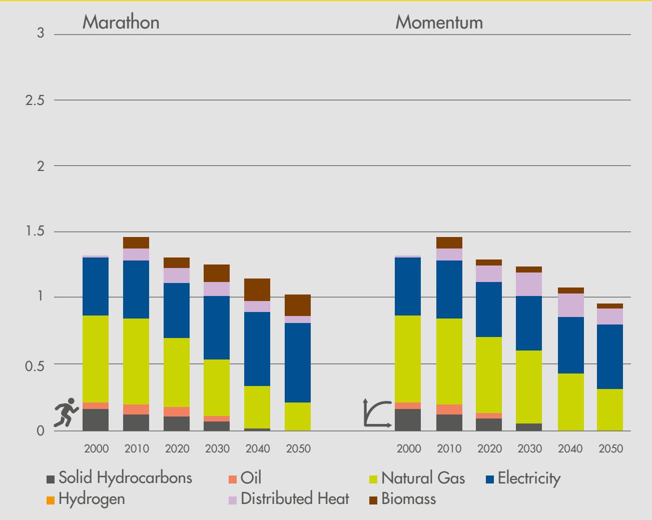
Scenario Drivers	Winning The Marathon	Slowing Momentum
RESIDENTIAL HEATING	■ Demographic development will lead to more, but smaller households with higher average per capita square meters ■ Heating systems start to shift from gas to solar to heat pumps or distributed geothermal ■ High investment in more efficient building, transition of more than 1% p.a. to new energy standards, i.e. continuation of replacement of heating systems with conventional oil & gas systems, complemented by increased insulation and some heat pumps ■ After 2030, as power prices fall, new heating systems for new houses / renovations start to shift from gas/oil systems to electric heating ■ Overall, CO_2 emissions from the housing sector with a substantial growth in housing units can be reduced by 80% by 2050 vs. today	■ The current trend of increasing amount of living space (m^2) per person continues; however, due to the smaller population, fewer housing units are needed ■ Less overall demand for heating. Higher living space needs per person are balanced by efficiency gains ■ Limited investment in renovation, insulation and more efficient heating system ■ Business as usual with limited conversions (0.5-1% p.a.); replacement of existing systems with more efficient gas & oil systems, complemented by increased insulation and heat pumps ■ Compared to Winning the Marathon, CO_2 emissions from the housing sector could be reduced by 90% in 2050 vs. today due to the smaller population and a smaller number of housing units vs. "Winning the Marathon"
INDUSTRY	■ The German government will need to keep the industry globally competitive to retain jobs, making it increasingly difficult to contribute further to the significant GHG emission reductions already achieved ■ Primary focus will be on improving energy efficiency with a "best in class" approach while maintaining global competitiveness ■ Electrification will continue to grow in the industry until maximum productivity is reached ■ As fewer manufacturing jobs will be required, new clean industries will emerge, building on new energy integration skills, new software and new smart systems ■ Ultimately, beyond 2030, only CCS (or another new CO_2 removal technology) will offer sufficient potential to further decarbonise the remaining carbon-intense, heavy industry	■ Primary focus on energy efficiency will go as far as possible with "best in class" while keeping the industry competitive ■ Industry will remain exempt from *Erneuerbare Energien Gesetz* (EEG) charges to keep it globally competitive to ensure job security ■ There is no political consensus on CCS/U, and it therefore does not provide mitigations to industrial GHG emissions ■ Overall productivity continues to grow in manufacturing ■ Few jobs emerge in the high-value service sector

Germany - Total Final Consumption - By Carrier
Residential Heating - EJ / year (Energy carrier)



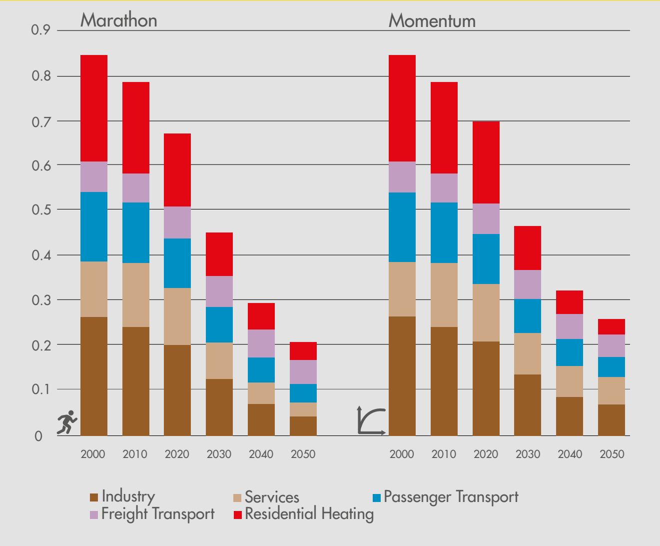
In both scenarios the fuel for heating is increasingly shifting from oil to gas to electricity. In Marathon the shift towards electricity starts earlier and happens faster than in Momentum.

Germany - Total Final Consumption - By Carrier
Heavy Industry - EJ / year (Energy carrier)



In Marathon efficiency improves, solids and liquids are being replaced over time by cheap electricity; CCS or an equivalent is required after 2030 to meet the CO_2 reduction targets. In Momentum there will be a slower improvement of the efficiency with also a lower electricity penetration. CCS will remain rejected.

Germany - CO_2 Emissions from fossil energy - By Sector
Gt CO_2/year (Energy source)



In Marathon the 80% reduction target (2050 vs 1990) will be met. It comes with maximum electrification in all sectors, strong growth in renewables and extreme efficiency improvements in Heavy Industry and Road Transport. Post-2030 CCS or a similar technology will be required. In Momentum a 70% CO_2 reduction will be achieved, driven by a shrinking population, slower GDP growth and continued growth in renewables, while CCS remains rejected.

The CO_2 emissions displayed per consumer group show direct emissions (e.g. from combustion) as well as indirect emissions from use of electrical power in each group. The mobility groups aggregate road, rail, ship, and air transport. "Residential Heating" covers private households, whereas "Services" refers to small business users.

In Marathon, the CO_2 emissions from power generation drop from 0.29 Gt/a in 2000 to 0.17 Gt/a. 0.09 Gt/a will need to be compensated through CCS/U or alternative new technologies coming in after 2030 to reach 0.08 Gt/a CO_2 emissions while meeting the overall 80% CO2 reduction target. In Momentum the emissions from power generation will drop to 0.09 Gt/a in 2050 without CCS because energy demand is significantly lower than in Marathon.

SUMMARY

Both scenarios assume that nuclear power will be phased out by 2022, with a similar energy mix breakdown until the 2020s. After that point, the energy demand in ***Winning the Marathon*** will continue to remain high, whereas in ***Slowing Momentum*** it decreases steadily by 30% from 2020 to 2050, due to a smaller population and lower GDP growth.

Winning the Marathon assumes all coal is phased out by around 2040. In contrast, coal remains a part of the mix in ***Slowing Momentum***. Both scenarios have high growth in solar PV and wind. ***Winning the Marathon*** requires less oil due to a rapid transition toward electrification in passenger transport.

By 2050, about half of primary energy demand in ***Winning the Marathon*** is supplied by renewable energy sources (solar, wind, biomass), with the other half supplied by oil and gas. Overall, gas accounts for about 40% of primary energy needs, e.g. gas serves as primary backup fuel in the power sector to meet overall energy demand of about 11.5 EJ/a (about 15% less than today). Decarbonisation of the energy mix will be largely driven by a strong move towards electrification, the exit from nuclear and coal, and the backup to the intermittency of renewables provided by gas. CCS or similar CO_2 reduction technologies will need to be taken up after 2030 and overall, the 80% CO_2 reduction target vs. 1990 will be achieved by 2050.

In ***Slowing Momentum***, a smaller population and lower GDP growth causes total primary energy demand of about 8.5 EJ/a (almost 40% less than today). Due to lower penetration of electrification in the mobility sector, oil demand remains higher than in *Winning the Marathon* though fewer backup fossil fuels will be required for the power sector. Oil, gas and coal will cover more than 50% of primary energy needs, which are substantially reduced. After the nuclear exit, this includes a strong shift from coal to renewables and from oil to electricity, biofuels and hydrogen. Despite the high growth in renewables (solar, wind and biomass), these will stay below 50% in the primary energy mix while the overall CO_2 footprint will reduce by only 70% vs. 1990 without CCS.

Winning the Marathon assumes the highest rates of electrification in all sectors. By 2050, electricity will account for more than half of total final energy consumed – compared to about 20% today. Electricity demand will more than double compared to its 2015 level. To meet this increase in demand, the generation capacity in renewable energy installed will need to increase six-fold with some 11-12 GW newly installed capacity per annum; in solar from 40 GW today about seven-fold (in average about 7 GW per annum); and in wind from 50 GW today about four-fold (in average about 4.5 GW per annum).

Slowing Momentum also assumes high rates of electrification, but its smaller population as well as lower GDP lead to lower overall demand for energy and thus electricity. By 2050, electricity will account for more than 40% of total final energy consumed in Germany. The energy provided by electricity will increase by almost 50% vs. 2015. To meet this increase in demand, the capacity in renewable energy installed will need to increase about five-fold (some 9-10 GW per annum), in solar from 40 GW today about seven-fold (in average about 7 GW per annum) and in wind from 50 GW today about three-fold (in average about 2.5 GW per annum).

CONCLUDING REMARKS

This scenario work builds on Shell's expertise in scenario development and the views on how Germany's specific energy system could evolve, given the targets and international statements made by its government.

It attempts to describe some of the most important shifts and transformations in the energy system that will be required in Germany over the coming years to support the transition towards the targets set for 2030 and 2050. It further attempts to give a view on the interplay between demographics, the immigration challenge, the overall economy, German politics and regulations, the technology challenge and how this will shape productivity, and external developments that could influence the scale and speed of energy transitions in Germany. It sheds light on the dimension of the task ahead and the political stability and consensus in the German society that is likely required to reach these ambitious targets.

Our hope is that this work will help to build insights and shared perspectives among businesses, the German federal and state governments and civil society more broadly. A shared understanding would recognise not only the continuation in the forthcoming years of the transition journey in the power sector – with the respective roles of renewables, gas, coal and nuclear – but also the increasing need to understand the decarbonisation pathways for key sectors, i.e. mobility, heating of buildings and energy-intensive heavy industry, and the corresponding interconnectivities and complexities involved. There are no simple answers for the deep structural transformation required while also sustaining economic growth and meeting all the needs and expectations of a demanding, mature society.

An aim of the scenario approach in strategic planning is to assist in better seeing challenges, opportunities and patterns of behaviour that may differ from a conventional view of the world. They help us appreciate the most significant features and uncertainties in the future environment and recognise that there may be a breadth of possible outcomes to events that cannot be fully controlled, or ignored, but may be influenced. We hope that this work will help inform and inspire leaders to influence developments constructively.

We would like to thank the external experts for providing their time, expertise and valuable in-depth insights on a variety of aspects, such as technological progress, energy cost developments and societal change. We have also drawn on the talents of the many specialists inside our company, particularly our technical, economic, social-political and energy-modelling teams, and on our own expertise on Germany, gathered through the many activities related to new energy technologies by Shell in Germany over many years.

APPENDIX

Proposed sector targets, Klimaschutzplan 2050

The Climate Action Plan 2050 (Klimaschutzplan 2050) addresses the sectors energy, buildings, transport, industry, agriculture, land use and forestry. The guiding principle presents a 2050 vision for each sector while milestones and measures focus on 2030.

Emissions from areas of action set out in definition of the target:				
Area of action	**1990 (in million tonnes of CO_2 equivalent)**	**2014 (in million tonnes of CO_2 equivalent)**	**2030 (in million tonnes of CO_2 equivalent)**	**2030 (reduction in % compared to 1990)**
Energy Sector	466	358	175 - 183	62 - 61%
Buildings	209	119	70 - 72	67 - 66%
Transport	163	160	95 - 98	42 - 40%
Industry	283	181	140 - 143	51 - 49%
Agriculture	88	72	58 - 61	34 - 31%
Subtotal	1209	890	538 - 557	56 - 54%
Other	39	12	5	87%
Total	1248	902	543 - 562	56 - 55%

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CAUTIONARY NOTES TO INVESTORS

All views presented in this booklet represent only those of Shell and not necessarily a consensus or those of individual partners.

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