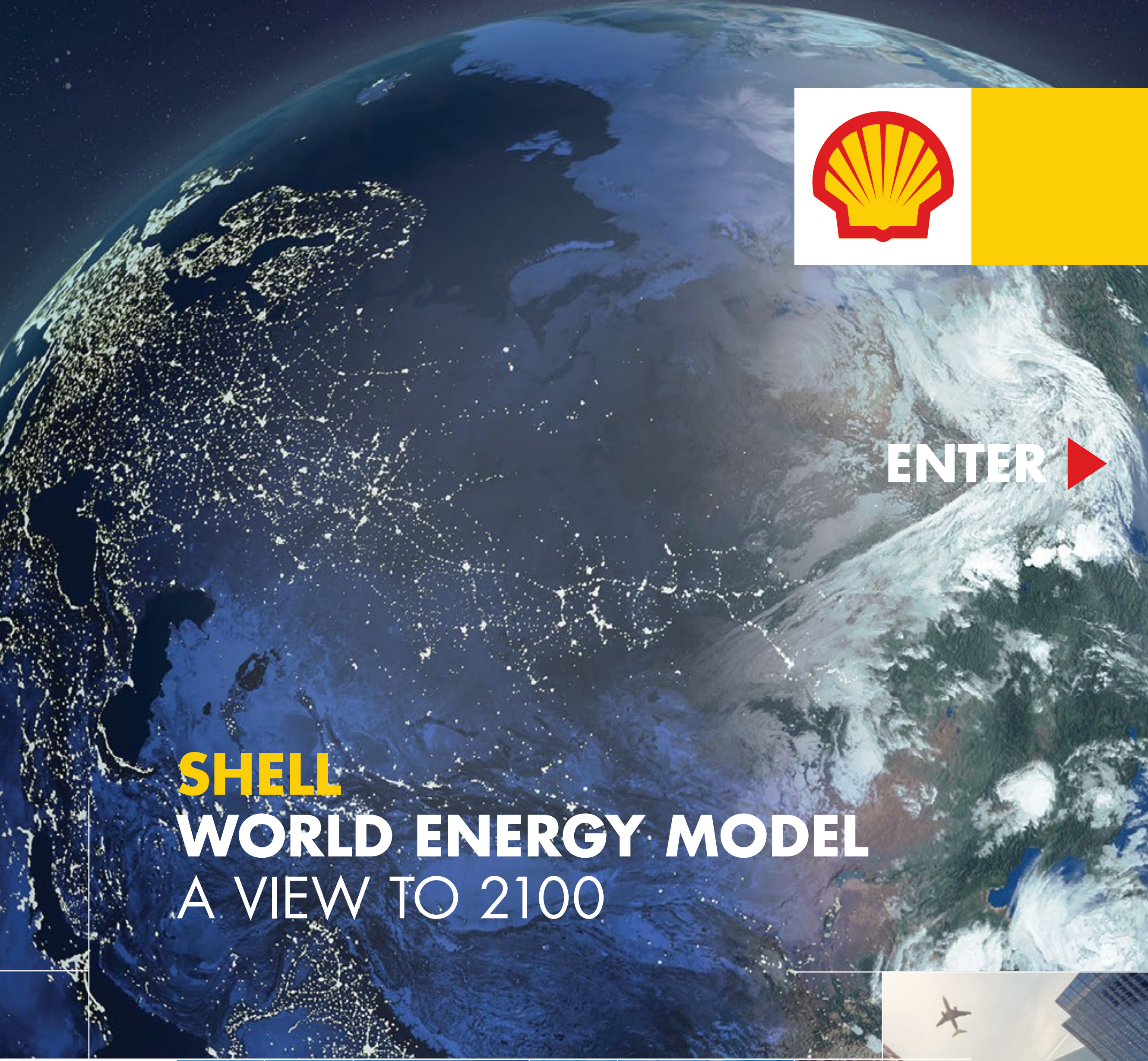

ENTER

SHELL
WORLD ENERGY MODEL
A VIEW TO 2100

TO NAVIGATE

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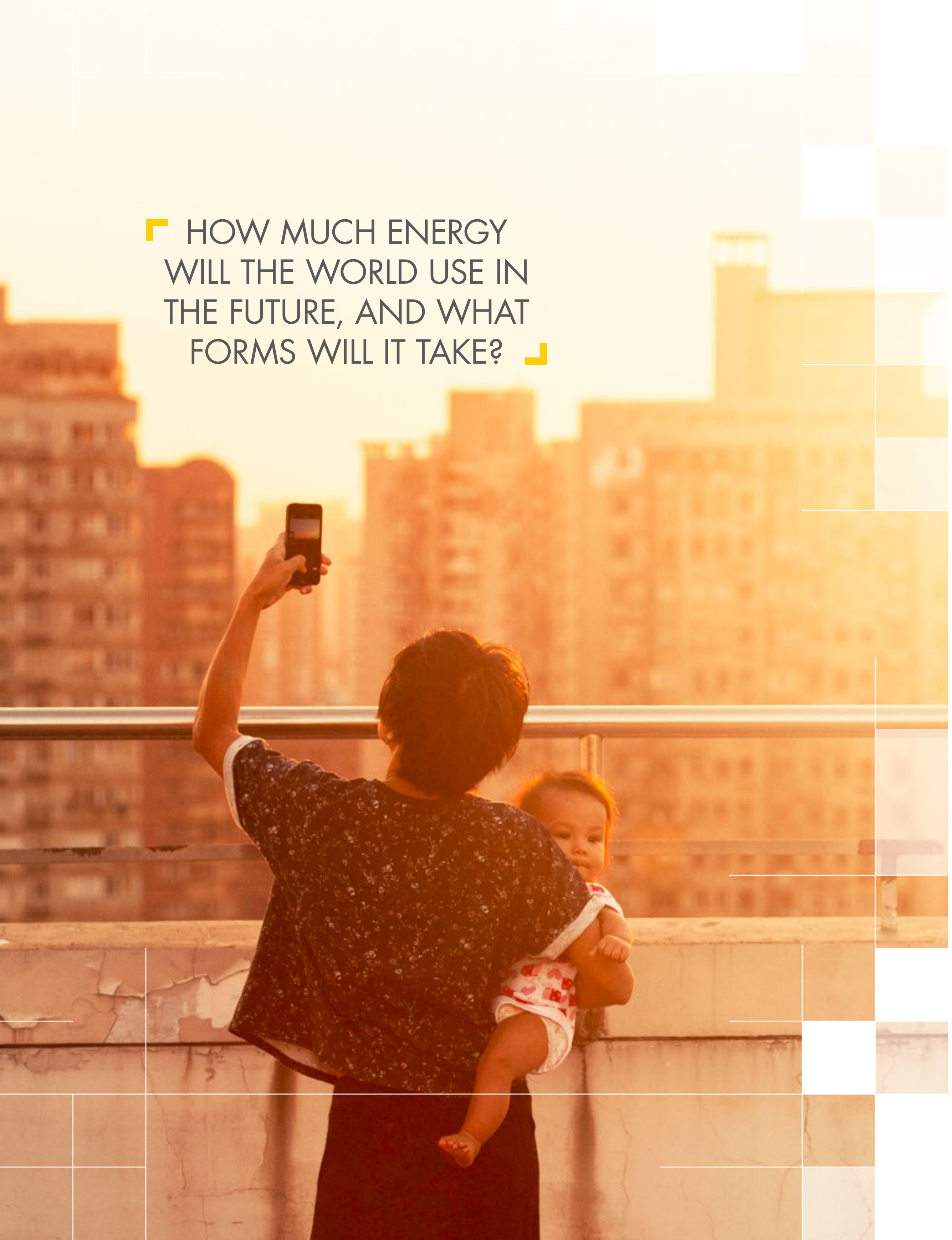


HOW MUCH ENERGY WILL THE WORLD USE IN THE FUTURE, AND WHAT FORMS WILL IT TAKE?

1. INTRODUCTION

Wim Thomas
Chief Energy Advisor

In support of strategy development, Shell has been making scenarios for the last 45 years. At heart, these are stories of how the world and its systems may develop given a number of core drivers and assumptions developing over time. To provide a rigorous quantitative framework to underpin the logic of scenarios, we developed the Shell World Energy Model (WEM). The WEM is a core tool in exploring the evolution of energy demand in different countries and in different sectors, helping us to maintain system consistency, under varying assumptions in policy, economy, technology and consumer choices. Together with Shell's Global Supply Model we can coherently examine the impacts in one part of the world made by changes in another.

In presenting our scenarios, we have been asked by many audiences how our energy modelling works. This guide seeks to help to answer that question.

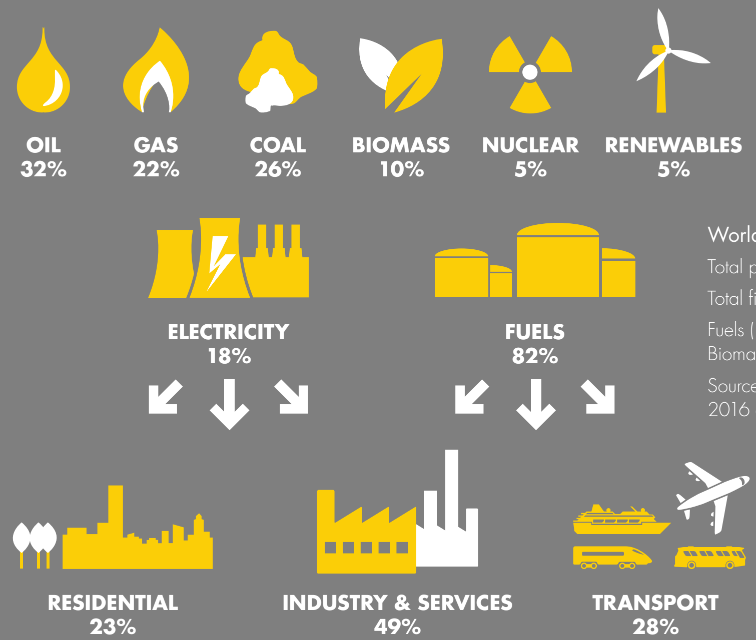
Martin Haigh
Senior Energy Advisor,
Team Leader WEM
and Principal Developer

The WEM is designed to support the Shell approach to scenarios, as a means to explore plausible, alternative futures for the world's energy system. It is unusual amongst long-term energy models for its approach and the level of detail it contains.

It begins with consumers' needs for energy services (such as lighting, or amounts of freight carried on the roads), and translates those into demand spanning all forms of energy. It covers all sectors of the economy together with all foreseeable energy technologies. And this all runs together for the whole world at a detailed country level, out to 2100.

It does this in a dynamic framework – meaning that changes in one place can affect others. A distinctive feature of the WEM is its capability to explore the plausible short-term trends as well as how these might evolve into the long-run transformation of the energy system.

THE ENERGY SYSTEM IN 2016:
HOW TO CALCULATE END-USER ENERGY DEMAND OVER TIME AND WHICH FUELS AND FEEDSTOCKS WILL BE USED?



World Energy Demand, 2016

Total primary energy = 583 EJ/year

Total final consumption = 399 EJ/year

Fuels (82%) comprises Fossil fuels (67%), Biomass (12%) and Commercial Heat (3%)

Sources: IEA Extended Energy Balances 2016 and Shell Scenarios Team 2016

SHELL'S WORLD ENERGY MODEL
COMBINING TOP-DOWN & BOTTOM-UP

100 YEARS

100 COUNTRIES & REGIONS (INCL. 82 COUNTRIES INDIVIDUALLY)

14 SECTORS

10 ENERGY CARRIERS

18 ENERGY SOURCES

Across these dimensions, we cover not only energy, but also other key elements like efficiency and prices, and outcomes like emissions.

2. WHAT IS THE WEM?

Shell's long-term energy system model

- Shell's World Energy Model is designed to put numbers to long-term scenario stories of the transformation of the energy system, at a detailed country level in a consistent and holistic framework.
- The WEM explores the development of aggregate demand based on consumers' needs for energy services. It then charts the energy choices of both consumers and energy producers. The model balances these against supply, using resource constraints, build rates and prices.
- The WEM is a suite of linked Excel spreadsheets, with data handling and model runs governed by Visual Basic. The core engine comprises over 55,000 lines; the output engine is able to produce a wide variety of custom tables and graphs.
- The WEM combines top-down and bottom-up approaches across the three main components (sector demand, choice, supply).
- It has a large repository of historical data from 1960 on both energy demand and the drivers. It runs in yearly time-steps, out to 2100 if required.

Six key drivers of the energy system


POPULATION


ECONOMIC GROWTH


ENVIRONMENTAL PRESSURES


TECHNOLOGY


RESOURCE AVAILABILITY


PEOPLE'S CHOICES

The WEM has 75 different specific scenario-based inputs spanning these six key drivers. These include the traditional techno-economic inputs as well as scenario-driven views of changes in supply and in consumer acceptance of new energy technologies. Assessments typically take into account historic evidence, current trends and plans, user judgement and specialist projections.

The scenario builder needs to maintain consistency across the input assumptions. For example, policies to support development of compact cities can have many effects. Their spread should reduce the need for urban travel, but could also facilitate greater use of public transport and a more rapid electrification of vehicles.

3. HOW DOES THE WEM WORK?

Exploring the plausible ranges for a variety of energy system questions

- Examples of questions supporting our scenarios addressed by the WEM:
  - How might energy demand grow in Asia and the world in total?
  - How fast are markets for oil and gas evolving geographically and in which sectors?
  - Is 100% renewables plausible this century?
  - What is the pathway for CO_2 emissions from energy use?
  - What policy frameworks need to be in place and what needs to be built to achieve the Paris Agreement's aspirations?

A role in company conversations and wider public debates

- Within Shell, the WEM is a key reference model for the corporate centre as well as many Shell businesses.
- Outside the company, the WEM contributes to work on country collaborative engagements, government relations and external communications, including Shell Scenarios publications.

A hybrid of modelling approaches

Combining the strengths of both economic (top-down) and engineering (usually bottom-up) modelling approaches:

- Economic modelling
  - Aggregate energy demand growth
  - Substitution of energy carriers and sources
  - Non-monetary values of different energy forms
  - Connecting the world together, revealing dynamic effects, e.g. the impact on gas and coal demand in Asian countries after Fukushima and success of shale gas and oil in North America on global oil and gas prices
- Engineering modelling
  - Potential supply of energy sources – political and technical
  - Practical constraints on technology build rates and equipment turnover
  - Recognising limits to trend extrapolation and keeping details in plausible bounds

Having a transparent logic is important. When the future seems clear, a common bias is that people often expect it to arrive sooner than it does. The WEM can show what you need to believe to see a particular outcome.

The WEM has 3 principal components

The pricing mechanisms link these three components. As an example, higher prices will curtail total demand, both through the price elasticity and efficiency uptake; they will also change the rates of substitution, reducing the choice of the more expensive energy carriers and sources; but they will also (usually) lead to greater supply.

Linking prices with scenario stories

- The use of prices to balance supply and demand makes the model dynamic. As such, changes in one part of the world or a value chain will affect others. The result can be a "balloon effect" where pressure in one part of the energy system to reduce supply or demand, can lead to growth elsewhere. An example has been expansion of shale gas in North America reducing local coal demand, but leading to greater coal exports to Europe.
- The WEM calculates demand on the basis of both the prices and the independent scenario inputs, like renewables cost assumptions, efficiency improvements or turnover rates.
- The scenario-building process, therefore, means a process of reviewing scenario assumptions with consistency checks with the WEM.
- For example, if a combination of WEM inputs leads to excessively loose (or tightly constrained) market conditions, revealed by very low (or high) prices, then this can prove a valuable input to the scenario-building process. Developing internally consistent scenario stories is nearly always an iterative process. In this case, the iteration would need to consider whether key scenario inputs, seen together in the story, both on supply and demand, would be resilient to these prices.
- For more on the place of the WEM in scenario building, see page 19.

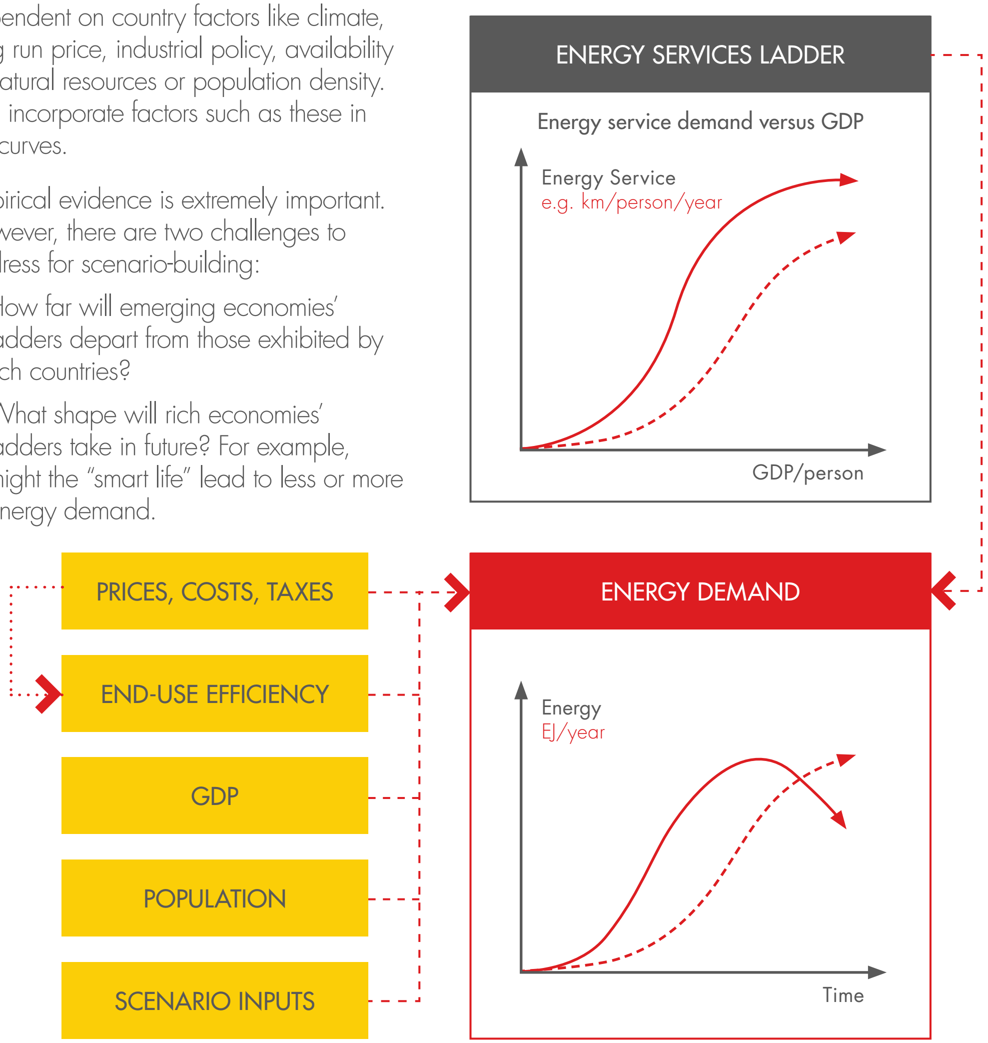
Calculating total energy demand: from energy service, via end-use efficiency, to final energy demand

The WEM incorporates the non-linear structure of energy service demand: the low-then-high-then-low again pattern of elasticity to income, along the development cycle. The levels at which energy service demand matures, however, are more dependent on country factors like climate, long run price, industrial policy, availability of natural resources or population density. We incorporate factors such as these in the curves.

Empirical evidence is extremely important. However, there are two challenges to address for scenario-building:

- How far will emerging economies' ladders depart from those exhibited by rich countries?
- What shape will rich economies' ladders take in future? For example, might the "smart life" lead to less or more energy demand.

A common finding to the analysis is that, on average, developing economies will exhibit lower energy ladders than today's rich countries because of better equipment being available, and, to a lesser extent, country factors like climate, being more supportive of lower energy needs overall.



1. Energy demand through "Energy Ladders"

- The energy ladder represents the way aggregate energy demand responds to changes in prices and incomes (GDP).
- As people get richer they typically use more energy services. However, this relationship between energy service demand and income, also known as the energy ladder, is not linear and it is partially country-specific.
- The efficiency of the end-use of energy (e.g. fuel economy of cars) provides the link from the energy service to final energy demand.
- The demand may saturate and in some sectors may even fall. Yet there are also sectors that have shown no saturation (notably non-energy use, and often freight demand)
- After income, price is often the second most important factor determining long run energy demand in a country. Examining the price effects helps to explain some – although not all – of the differences between countries' paths up the energy ladder.
- In reality, a sector will provide many energy services to customers. For instance, car drivers value speed and comfort as well as simply the distance travelled. However, we represent total activity with one measure, which has three roles in the model. First it scales overall demand growth for the activity. Scenarios involving the creation of new energy services, such as space travel or aeroplane drones, can then be modelled. Second, it allows us to represent end-use efficiency changes. And, third, it allows for substitution of different energy with different relative efficiencies in that sector.

Total primary energy vs total final consumption: the energy ladder is usually drawn using primary energy demand

Total primary energy (TPE) represents the total quantity of energy sources consumed in the country: crude oil, coal, nuclear energy generated, geothermal heat and so on. End-users, for the most part, do not use these energy sources. Instead, they buy energy carriers, including electricity, liquid fuels and – possibly in future - hydrogen.

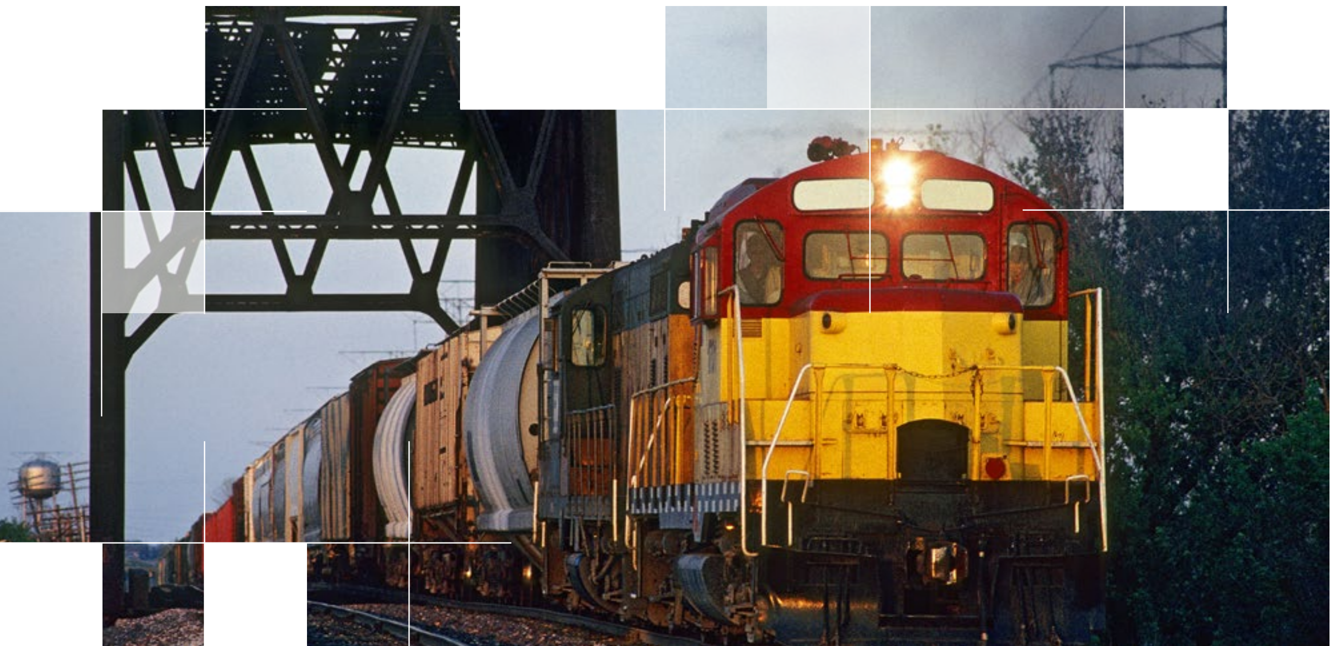
Total final consumption (TFC) is the demand for energy carriers by end-use sectors.

Losses in conversion processes largely account for the differences between TPE and TFC.

The WEM follows the IEA standards of measurement for all energy sources and carriers.

14 END-USE SECTORS

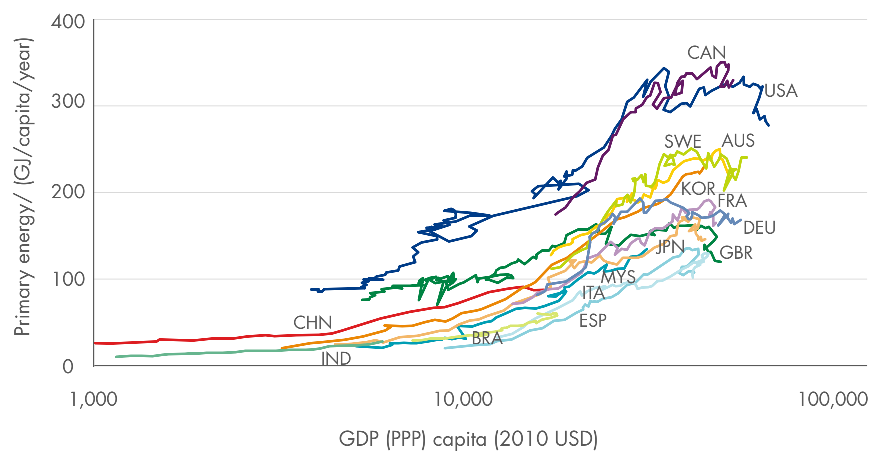
Sector	Unit of Energy Service
Heavy Industry	Tonne of steel equivalent
Agriculture & Other Industry	Heating requirement in buildings
Services	Heating requirement in buildings
Passenger Transport – Ship	Passenger kilometre
Passenger Transport – Rail	
Passenger Transport – Road	
Passenger Transport – Air	
Freight Transport – Ship	Tonne kilometre
Freight Transport – Rail	
Freight Transport – Road	
Freight Transport – Air	
Residential – Heating & Cooking	Heating requirement in buildings
Residential – Lighting & Appliances	Electricity need
Non energy use	Oil equivalent for output



The energy ladder follows an S-curve

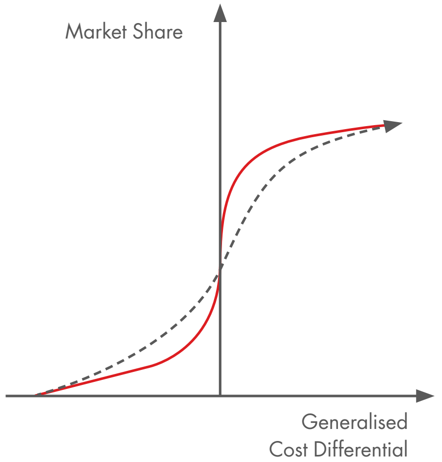
As the very poorest countries start to develop, they tend not to use significantly more energy. When average incomes reach 4,000 USD/person (at Purchasing Power Parity), demand tends to accelerate. In other words, the elasticity rises. At around 15,000 USD/person, demand growth eases, as some uses approach saturation (domestic heating or cooling) and the economy diversifies from industrial to service sector activity. Whilst there is consistency in the overall pattern, there is significant country-specific variation in the exact acceleration point. Similarly, the point when energy demand growth slows varies significantly.

THE ENERGY LADDER 1960-2016*



*UK and USA 1870-2016; Japan 1953-2016; Nom-OECD 1971-2016

ENERGY CHOICE
SCHEMATIC FOR A MARKET WITH TWO CHOICES



- The market share for an energy carrier (e.g. electricity) in a sector (e.g. residential) is determined by its generalised cost compared to competing energy carriers.
- Generalised cost comprises fuel cost, operating cost, capital cost and the fuel convenience factor (i.e. the non-monetary preference for different forms of energy).
- The WEM employs the discrete choice methodology of multinomial logit*.
- The steepness of the S-curve represents the sensitivity of market shares to differentials in cost.
- The approach allows for a range of consumer preferences i.e. it is not an optimisation.

(*) Reference: 'Multinomial logit' is a mathematical model used to estimate odds across discrete choices. In this case the choices are different energy carrier or sources. We apply the odds to represent market shares across the population. Instead of optimising choices (meaning all consumers choosing the cheapest option), our approach will apportion demand across the market, recognising that there are different preferences in the population. For example, some people prefer to cook with natural gas, whilst others prefer to cook with electricity, even if they are facing the same costs.

2. Energy choice

- The Energy Choice is a two-stage process in the WEM to determine the energy mix:
  - End-users' choice of energy carrier (electricity, petroleum products, etc.) for each of the end-use sectors.
  - Producers' choice of energy source (crude oil, wind energy, etc.) for each of the energy carriers.
- The WEM uses a behavioural approach to allocate energy demand to an energy carrier or source, acknowledging that different users have different preferences. Its aim is to represent how people choose between technologies and how they change their choices in response to prices, preferences, energy security or policies. Not all choices will be based on lowest cost options. And different energy choices are not perfect substitutes.

18 ENERGY SOURCES

TRANSPORT: SHIP, RAIL, ROAD, AIR

RESIDENTIAL: HEATING & COOKING, LIGHTING & APPLIANCES

INDUSTRY & SERVICES: HEAVY, OTHER, SERVICES, NON-ENERGY

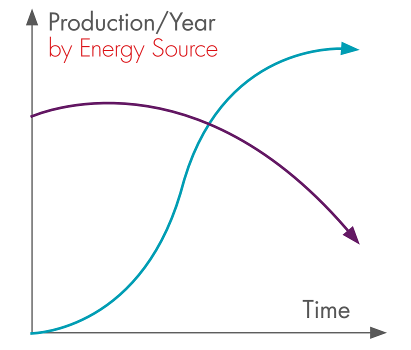
END-USER CHOICES →

ELECTRICITY
LIQUID FUELS
GASEOUS FUELS
SOLID FUELS
BIOMASS
HYDROGEN

PRODUCER CHOICES →

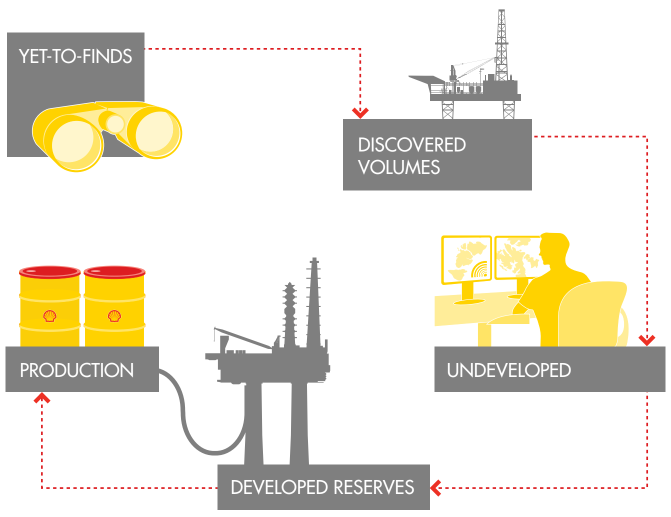
Oil
Natural Gas
Coal
Nuclear
Hydro-electricity
Biofuels – 1st Gen
Biofuels – 2nd Gen
Biofuels – Marine
Biomass – Traditional
Biomass – Commercial
Waste
Geothermal – Hydrothermal
Geothermal – Engineered
Solar – Photovoltaic
Solar – Thermal
Wind
Tidal
Wave

ENERGY SUPPLY
EACH ENERGY SOURCE IS TECHNOLOGY, RESOURCE AND SCENARIO-BASED



- The WEM controls supply in two ways: a maximum annual production; and annual deployment rate constraints for new energy technologies, e.g. solar PV.
- Supply constraints are source-specific: scenario stories will guide the accessibility of different energy sources, such as public acceptance for nuclear or wind farms.
- Supply scenarios are chosen based on different price and political environments.
- The supply inputs are founded on the research into supply potential, specific to each energy source.

MODELLING THE OIL AND GAS SUPPLY IN THE SHELL GLOBAL SUPPLY MODEL (GSM)



The WEM draws on Shell's Global Supply Model, illustrated here, for detailed oil and gas supply. Balancing is through iteration between the models.

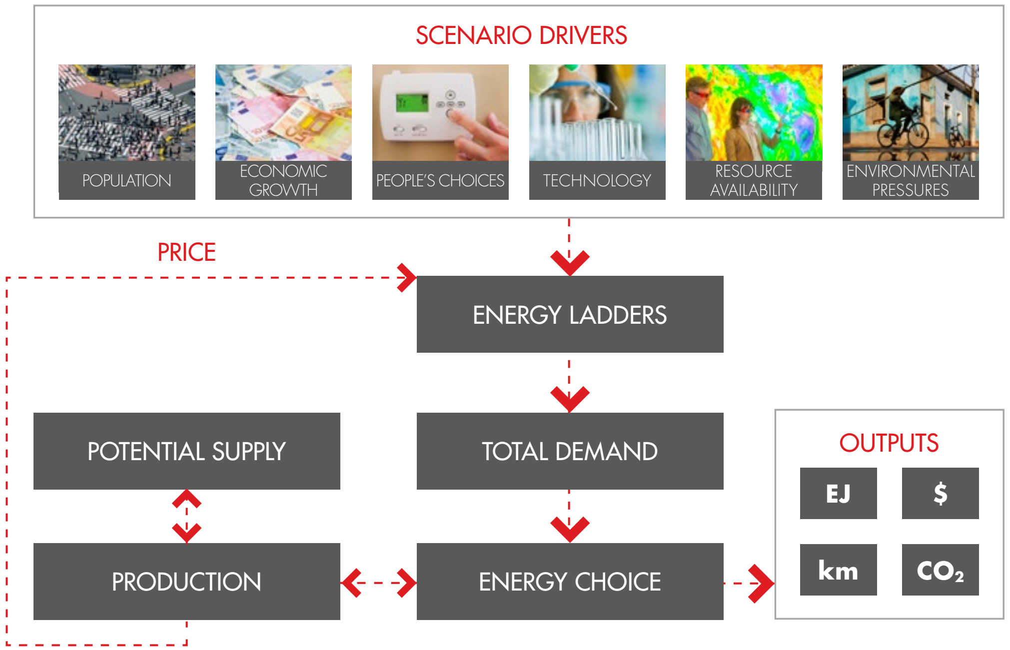
The supplies of all other energy sources are modelled within the WEM.

3. Energy supply

- The Energy Supply module supplies potential annual production for each energy source.
- The annual supply is derived from a combination of build-rate constraints, physical supply potential and scenario-dependent supply outlooks. In addition, oil and natural gas use cost-of-supply curves.
- Nuclear and (electric) renewable sources provide a constraint at a country level, whilst oil, natural gas, coal and bio-energy are balanced globally.
- While Energy Demand and Energy Choice take a predominantly economic-driven perspective, Energy Supply focuses more heavily on the physical capacity to deliver.
- Build-rate constraints are important when energy technologies are new, in the exponential phase of growth. These are derived from leading country experience.
- Longer-term, other societal and political factors predominate. Scenario stories need to inform different political and societal factors that affect the supply of every source. For instance, nuclear energy is influenced by public acceptance, energy security and safety, whilst on-shore wind energy* is affected by natural wind patterns and public acceptance. For fossil energy, uncertainty over the size of the ultimate resource base is also a factor.

(*) Reference: Ecofys study for Shell on potential long-run supply of bio-energy, solar PV and wind. See www.shell.com/scenarios for details

TURNING THE METHODOLOGY INTO OUTPUT



- The WEM models each country's energy demand by sector on an annual basis to the year 2100.
- The model starts from historic data and the selected scenario inputs.
- In order to calculate each year's supply and demand, the model engine begins by forming the prices from energy sources through to energy carriers.
- Energy carrier prices are cost-based, built up from unit capacity costs, and they factor in taxes and subsidies.
- The WEM uses energy ladders followed by two-stages for energy choices to derive the demand for each energy source in every country in each year.
- Finally, if supply constraints are exceeded, it will cycle-back to re-allocate demand.
- Historic data and full-tabulation of the projected energy demand are transferred to an output spreadsheet where the user can select from a range of graphs, e.g. import-export requirements, demand breakdowns by region, CO_2 emissions and total cost of investments.
- It is worth noting that the WEM provides scenario-based simulation of the world energy system, it is not a target-driven (i.e. optimisation) model.

Combining top-down and bottom-up approaches

- Top-down approaches start with the big picture and gradually add more layers of structure.
- Bottom-up methods, by contrast, start with detailed representations of elements of a system, which are then linked into larger systems.
- The scope covered by the WEM is wide: the whole world, the whole energy system, timeframes to 2100. As such, the WEM has a substantial requirement to use aggregate (i.e. top-down) approaches, in order to maintain a coherent structure. The top-down approach also provides the benefit of dynamically linking systems together through the price mechanism.
- The WEM has a greater reliance on top-down econometric methods in the first component *Energy Demand*; whilst bottom-up methods are more visible in the second and third components, *Energy Choice and Energy Supply*.

Using economic drivers

- The WEM uses the economic drivers familiar to top-down energy modelling, like GDP, population and prices. Alongside these, the model holds many bottom-up inputs, like price-based policy (e.g. sector and country CO_2 prices), efficiency standards or stock turnover rates.
- The combination of top-down and bottom-up methods enables a wide range of policy options to be explored.

Assessing impacts

- The WEM reports impacts such as energy-related CO_2, fresh water use from energy production and conversion, footprint (km²) and investment costs.
- Quantifying impacts is valuable to act as a sense check; to inform scenario discussions, including whether there would likely be feedback to various inputs; to aid communication and discussion on policy choices.

Uncertainties within the energy landscape pose key challenges

Climate

- Emergence of international consensus around an implementable CO_2 framework would accelerate the transition to clean and green energy.

Technology

- Breakthroughs in energy or carbon storage technologies pose the greatest disruptive factors to the global energy system.
- Accelerated growth in non-oil based transport could be from natural gas, electricity, biofuels or hydrogen.
- Global success of shale oil and gas will change the inter-regional supply dynamics.

Politics

- A slowdown in the pace of economic growth in China and India would have a significant knock-on effect to worldwide energy demand.
- Rising inter-fuel competition and CO_2 pricing between gas, coal and renewables in electricity generation will shape future pricing mechanisms and markets for gas and coal.

4. HOW TO MODEL SCENARIOS

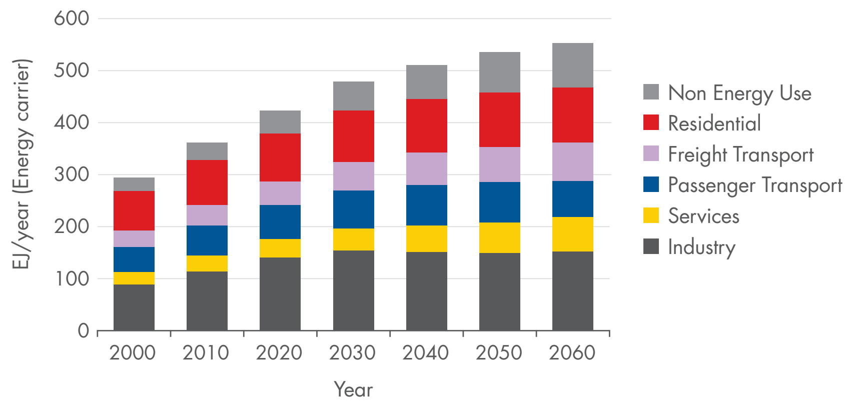
How does the WEM fit into the Shell Scenario process?

- The Scenarios Team historically used quantification to reflect the stories. The robustness of the WEM has changed the role of modelling, so that now it is used to test the stories.
- A danger is that the model structure can drive the scenario story. A focus on the techno-economic can exclude, often more important, behavioural, political or social forces. It is because of this, that the WEM holds a wide range of scenario-based inputs.
- The benefit of keeping many inputs independent is that we can tailor them to the scenario story.
- Tying many inputs together automatically (endogenously) within the model would limit the capability to explore scenarios of differently structured energy systems.
- Instead of a "black box", holding many inputs independently facilitates discussions such as "if the energy system becomes constrained, which elements are likely to give".
- The challenge is then to the model user to carry out sufficient consistency checks, adapt inputs where necessary, and iterate round the wider team involved in building the scenario stories.
- To minimise the other common risk in energy modelling, i.e. losing sight of underlying short-term trends, our model is calibrated with current energy choices in place. The user can then impose scenario stories of how these drivers might evolve.
- In scenario discussions, a valuable benefit of the WEM is to force internal consistency. In addition, it can provide an invaluable check on the plausibility of stretching assumptions, drawing on historical data and empirical relationships.
- The WEM is designed to support the Shell Scenarios methodology of exploring uncertainty through structurally different alternative futures, rather than simply sensitivities.

Source: UN Climate Change Secretariat.

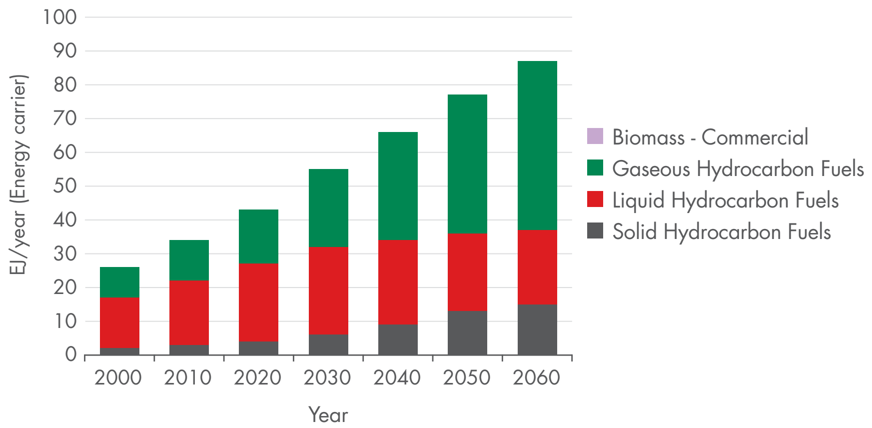
5. WHAT OUTPUTS CAN THE WEM PROVIDE?

MOUNTAINS: A VIEW FROM THE TOP
WORLD – TOTAL FINAL CONSUMPTION – BY SECTOR

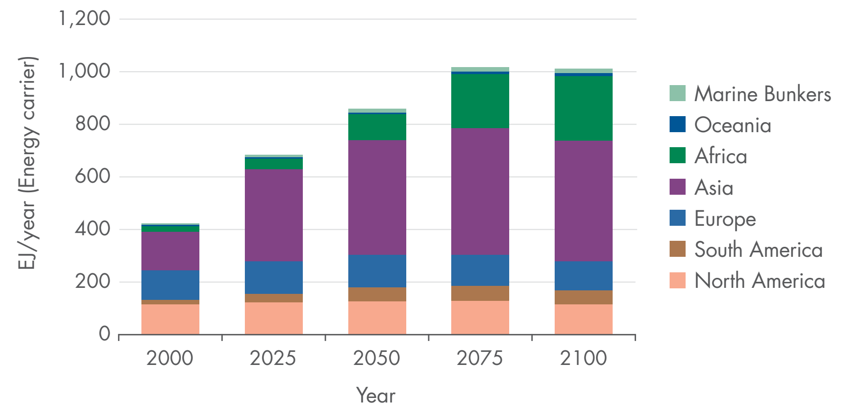


These pages present a tour through a selection of charts from the WEM's output engine. Above, starting with the high level. In this scenario, some sectors flatten, whilst others keep growing. Below, one growing sector is selected. The chart reveals technological change, through a changing feedstock mix for materials, using the scenario's increasing shale gas supply and available coal.

MOUNTAINS: A VIEW FROM THE TOP
WORLD – NON-ENERGY USE – FEEDSTOCK MIX

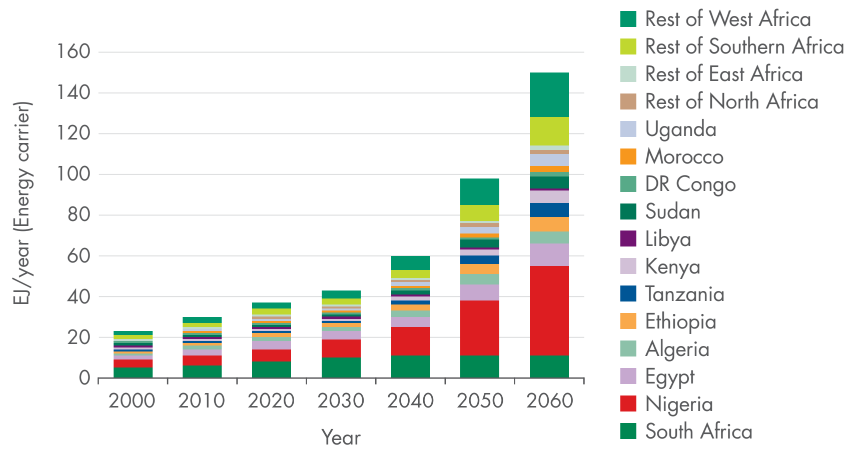


OCEANS: A VIEW OF THE HORIZON
WORLD – TOTAL PRIMARY ENERGY – BY CONTINENT

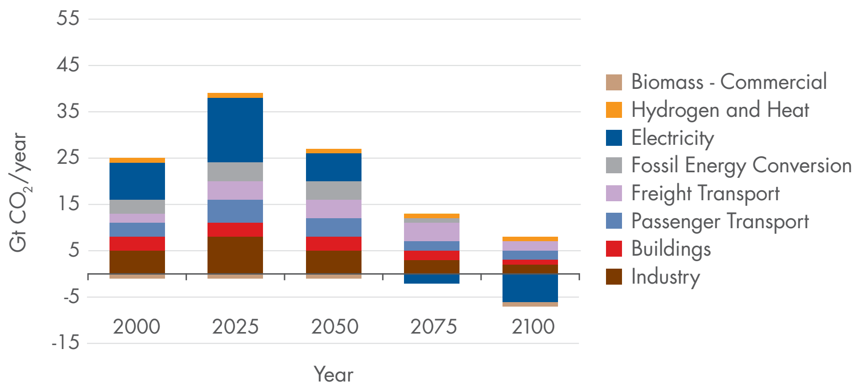


In nearly all scenarios in the WEM, Asia dominates world energy demand growth to mid-century and beyond. In a scenario like Oceans, with faster energy transitions, the WEM presents an intriguing possibility that, late century, world demand could level off as enough economies mature. Below, modelling different countries within Africa can highlight the different stages of development.

OCEANS: A VIEW OF THE HORIZON
AFRICA – TOTAL PRIMARY ENERGY – BY COUNTRY

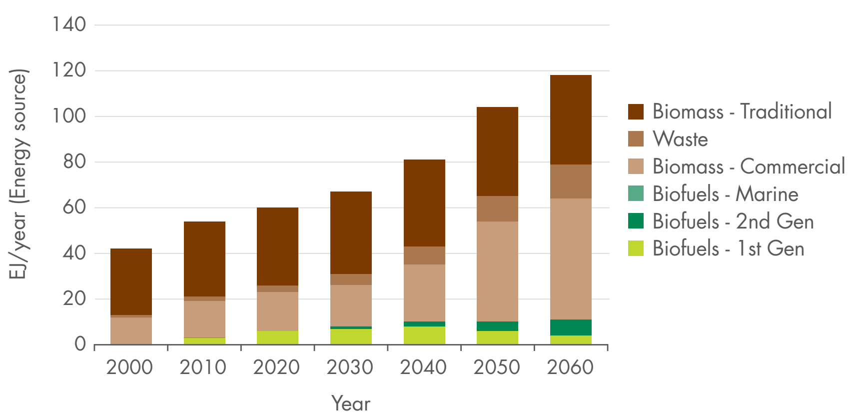


MOUNTAINS: A VIEW FROM THE TOP
WORLD – ENERGY-RELATED CO_2 – BY POINT OF EMISSION

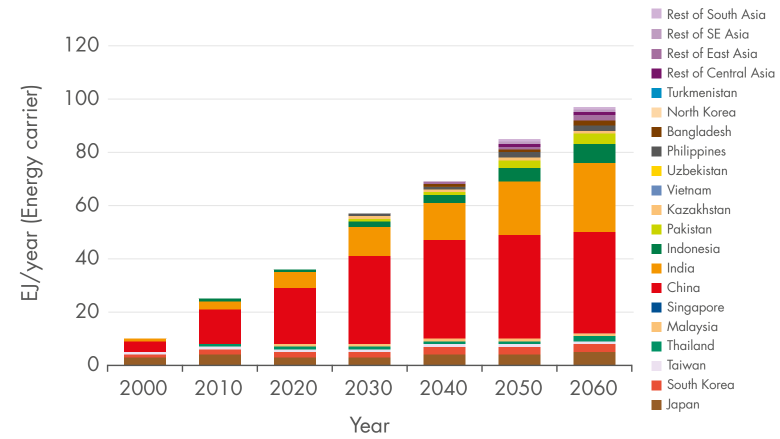


The analysis from the WEM was core to the Scenarios team publication on net-zero emissions. It showed different parts of the energy system decarbonising at different rates, and the role for negative emissions, using biomass with CCS. Below, in the Mountains scenario, the WEM shows different trends for modern biomass and biofuels contrasting with the traditional biomass which dominates biomass today.

MOUNTAINS: A VIEW FROM THE TOP
WORLD – BIOMASS – MODERN AND TRADITIONAL

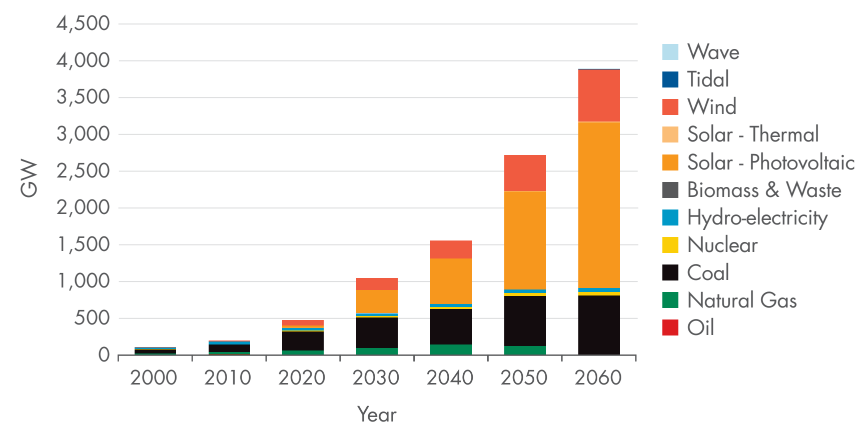


OCEANS: A VIEW OF THE HORIZON
ASIA (EXCL MIDDLE EAST) – TOTAL ELECTRICITY DEMAND

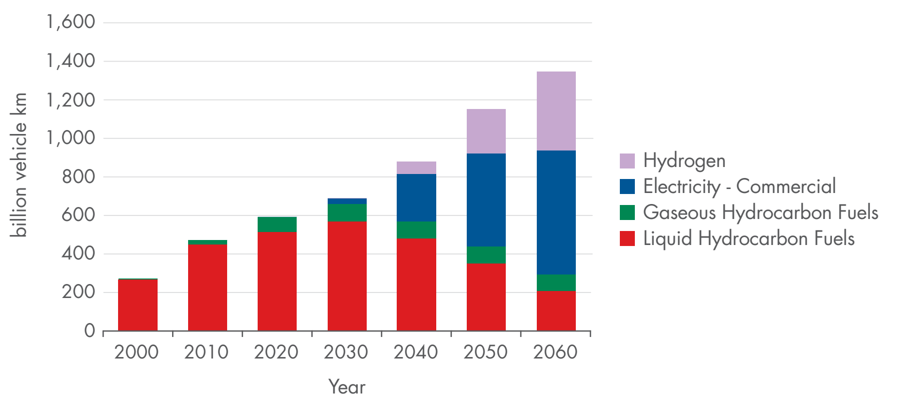


During the scenario-building, the WEM highlighted the strong and long-lasting growth for electricity, which took greater prominence in the storytelling for Oceans as a result. China and India dominate, but China's electricity flattens mid-century as India continues to grow. Below, India's growth is striking, especially measured in capacity terms, with almost all the conditions in Oceans for solar PV to thrive.

OCEANS: A VIEW OF THE HORIZON
INDIA – ELECTRICITY CAPACITY

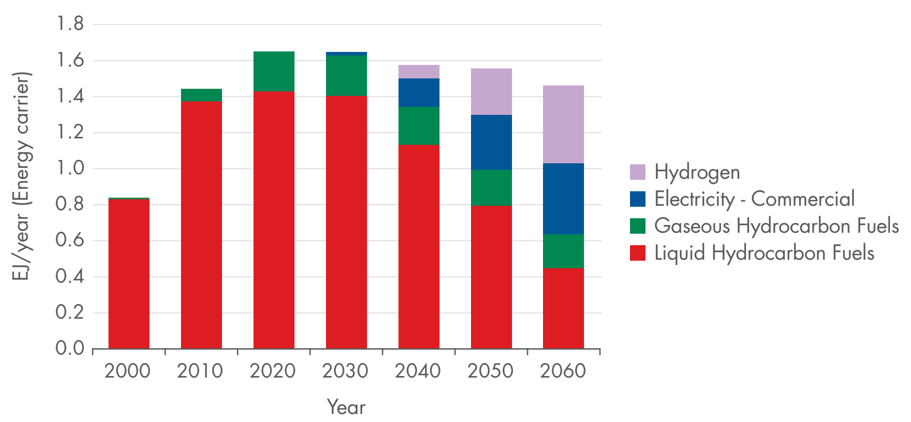


MOUNTAINS: A VIEW FROM THE TOP
BRAZIL – ENERGY SERVICE – PASSENGER ROAD TRANSPORT

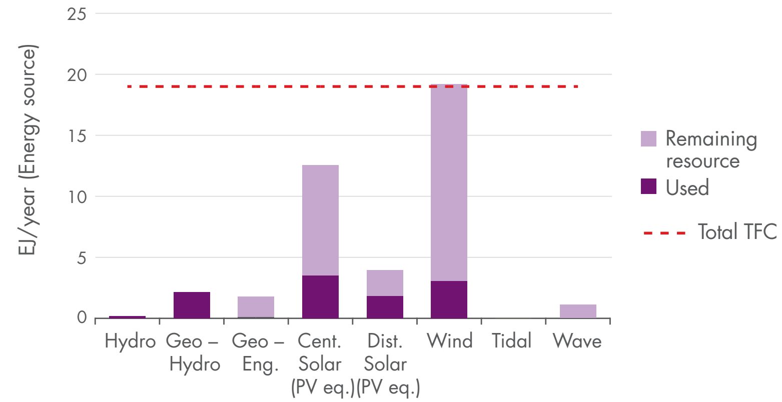


The Mountains scenario explored a rapid take-up of electric vehicles. The WEM's modelling for Brazil illustrates substantial growth in travel demand, a very rapid rise in electric vehicles, alongside a long-term role for hydrogen and liquid fuels in a country with large distances. Below, as a result of both efficiency gains and substitution to new vehicles, total energy demand in the sector flattens in the 2020s.

MOUNTAINS: A VIEW FROM THE TOP
BRAZIL – ENERGY – PASSENGER ROAD TRANSPORT

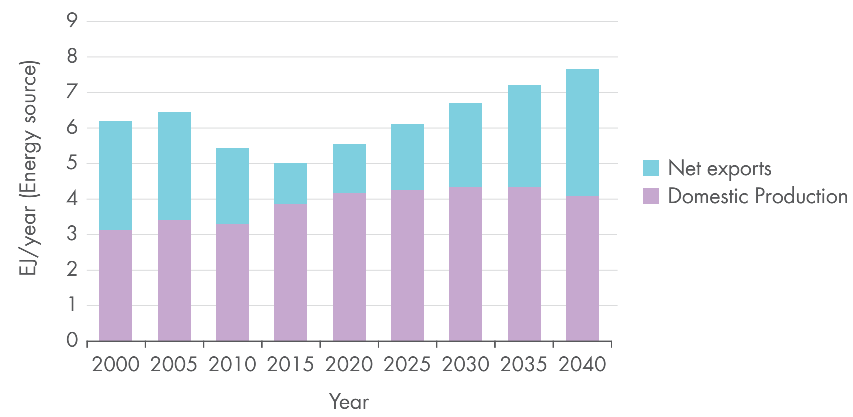


OCEANS: A VIEW OF THE HORIZON
INDONESIA – RENEWABLES – DEMAND VS RESOURCE, 2060



The WEM uses the renewables resource base in each country as a constraint. These resources are themselves scenario-dependent. The Oceans scenario used the high case in the special study by Ecofys for Shell Scenarios. (For details, see www.shell.com/scenarios). Below, the WEM draws together the gas production (from Shell's Global Supply Model) alongside the demand to reveal net exports.

OCEANS: A VIEW OF THE HORIZON
CANADA – NATURAL GAS – EXPORT POTENTIAL



HISTORY OF THE WEM: THE WEM DATES BACK TO THE MID-2000s

Late 1960s
Pioneering thinkers, including Ted Newland and Pierre Wack, begin work on Shell's first scenarios, to replace Shell's Unified Planning Machinery, a single five-year oil forecast. 1967UPM forecast for World energy demand (excl Communist countries) in 2000 was 485 EJ; actual was around 325 EJ

1973
The iconic early scenarios, *The Rapids*, looking at conditions for an oil crisis, with limited quantification. Pierre Wack saw modelling as "the enemy of thought", where, by contrast, Ted Newland saw numbers as essential "to show careful thought behind the ideas"

1974
The team attempts a linear programming global energy model. Comprising 3000 equations, it takes 20 hour run on a mainframe. The 'black box' nature, with unclear linkages, means that it gains little support

1974-79
Scenarios *Belle Epoque* and *World of Internal Contradictions* move into wider societal narratives, whilst development of *The Rapids* focuses on oil markets

1980s
Scenarios focus on stories. Quantification largely limited to oil, based on simple GDP elasticities

1989
Scenarios *Global Mercantilism and Sustainable World* uses energy intensity trends evolving into stories on turnaround in world CO_2 by 2000

1992
Last Shell Scenarios, *New Frontiers* and *Barricades*, to rely on paper-based methods to quantify oil demand

1995
Scenarios *Dawo* and *Just Do It* employ first computer quantification. First models of sectors and the mix of different forms of energy. Focus on oil and emergence of China in 1995; follow-up in 1997 highlights renewables for the first time

2001
Scenarios *Business Class & Prism* with broad-based quantification at regional level of demand to support stories; separate models of transport, electricity and growth of energy sources

2005
Paradigm shifts in the energy system on the horizon lead to the start of work on Shell's first whole energy system model, the World Energy Model

2008
First use of the WEM for scenarios *Scramble* and *Blueprints*, with a level of integrated country-level quantification never before attempted for Shell scenarios; WEM is core for testing internal consistency of levels of stories

2013
Scenarios *Mountains* and *Oceans*
First deployment of more flexible WEM version 2, incorporating energy services and more elements affecting particular energy choices and sources

2016
Recent WEM developments: incorporating electricity capacities and investment; extending Energy Ladders

6. WHO ARE THE PEOPLE INVOLVED?

Many Shell colleagues have worked directly or indirectly on the WEM over the last decade. These cover people developing the model structure, its parameters and data, together with expert users who have carried out extensive testing and running of the WEM in action.

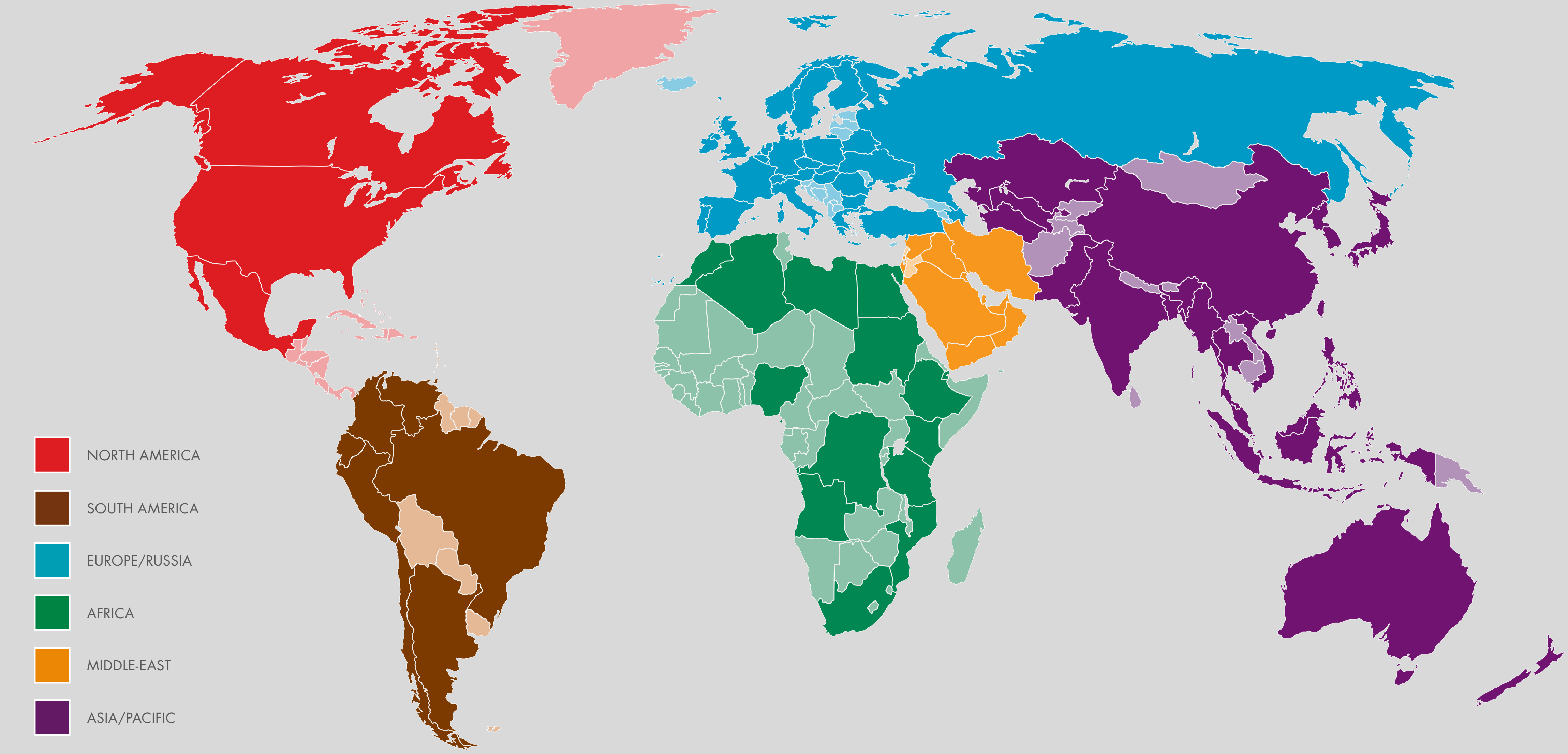
On the module development side, Arthur van Benthem, followed by Katharina Gruenberg, Esther Bongenaar and Tashi Erdmann, all worked on developing the energy ladder concept. Jonathan Sample, Rhodri Owen-Jones, Anna Chroni and Armanda Borggreve all contributed to numerous other modules, such as efficiency, cost curves and investments, as well as running the model in support of scenario and strategy development.

Also, I would like to recognise many other colleagues, past and present, in the team and in other parts of Shell who provided knowledge and support. Not exhaustively, Prof Gert Jan Kramer, Herman van der Meyden, Hadi Hallouche and Tom Yu.

In particular, I would like to thank Martin Haigh, being the principal developer and team lead since 2005, who was able to translate a vision into a state-of-the-art model; and Bram Otto, who was the principle programmer of this latest version of the WEM.

Wim Thomas
Chief Energy Advisor
2017

APPENDIX | COUNTRIES MODELLED



Darker-coloured countries are modelled individually. Lighter-coloured countries are modelled collectively as 'Rest of' regions, such as 'Rest of West Africa'.

This brochure contains data from Shell's New Lens Scenarios. The New Lens Scenarios are a part of an ongoing process used in Shell for 40 years to challenge executives' perspectives on the future business environment. We base them on plausible assumptions and quantifications, and they are designed to stretch management to consider even 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 improve 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 10-20 years.

The companies in which Royal Dutch Shell plc directly and indirectly owns investments are separate legal entities. In this brochure "Shell", "Shell group" and "Royal Dutch Shell" are sometimes used for convenience where references are made to Royal Dutch Shell plc and its subsidiaries in general. Likewise, the words "we", "us" and "our" are also used to refer to subsidiaries in general or to those who work for them. These expressions are also used where no useful purpose is served by identifying the particular company or companies. ''Subsidiaries'', "Shell subsidiaries" and "Shell companies" as used in this brochure refer to companies over which Royal Dutch Shell plc either directly or indirectly has control. Entities and unincorporated arrangements over which Shell has joint control are generally referred to as "joint ventures" and "joint operations" respectively. Entities over which Shell has significant influence but neither control nor joint control are referred to as "associates". The term "Shell interest" is used for convenience to indicate the direct and/or indirect ownership interest held by Shell in a venture, partnership or company, after exclusion of all third-party interest.

This brochure contains forward-looking statements concerning the financial condition, results of operations and businesses of Royal Dutch Shell. All statements other than statements of historical fact are, or may be deemed to be, forward-looking statements. Forward-looking statements are statements of future expectations that are based on management's current expectations and assumptions and involve known and unknown risks and uncertainties that could cause actual results, performance or events to differ materially from those expressed or implied in these statements. Forward-looking statements include, among other things, statements concerning the potential exposure of Royal Dutch Shell to market risks and statements expressing management's expectations, beliefs, estimates, forecasts, projections and assumptions. These forward-looking statements are identified by their use of terms and phrases such as ''anticipate'', ''believe'', ''could'', ''estimate'', ''expect'', ''goals'', ''intend'', ''may'', ''objectives'', ''outlook'', ''plan'', ''probably'', ''project'', ''risks'', "schedule", ''seek'', ''should'', ''target'', ''will'' and similar terms and phrases. There are a number of factors that could affect the future operations of Royal Dutch Shell and could cause those results to differ materially from those expressed in the forward-looking statements included in this brochure, including (without limitation): (a) price fluctuations in crude oil and natural gas; (b) changes in demand for Shell's products; (c) currency fluctuations; (d) drilling and production results; (e) reserves estimates; (f) loss of market share and industry competition; (g) environmental and physical risks; (h) risks associated with the identification of suitable potential acquisition properties and targets, and successful negotiation and completion of such transactions; (i) the risk of doing business in developing countries and countries subject to international sanctions; (j) legislative, fiscal and regulatory developments including regulatory measures addressing climate change; (k) economic and financial market conditions in various countries and regions; (l) political risks, including the risks of expropriation and renegotiation of the terms of contracts with governmental entities, delays or advancements in the approval of projects and delays in the reimbursement for shared costs; and (m) changes in trading conditions. No assurance is provided that future dividend payments will match or exceed previous dividend payments. All forward-looking statements contained in this brochure are expressly qualified in their entirety by the cautionary statements contained or referred to in this section. Readers should not place undue reliance on forward-looking statements. Additional risk factors that may affect future results are contained in Royal Dutch Shell's Form 20-F for the year ended December 31, 2016 (available at **www.shell.com/investor** and **www.sec.gov**). These risk factors also expressly qualify all forward-looking statements contained in this brochure and should be considered by the reader. Each forward-looking statement speaks only as of the date of this brochure, April 2017. Neither Royal Dutch Shell plc nor any of its subsidiaries undertake any obligation to publicly update or revise any forward-looking statement as a result of new information, future events or other information. In light of these risks, results could differ materially from those stated, implied or inferred from the forward-looking statements contained in this brochure.

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www.shell.com/scenarios