THE ENERGY LADDER: A MODEL FOR PROJECTING ENERGY DEMAND

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For over 40 years, Shell's scenarios team has developed long-term scenarios to explore the future of energy in the world. The scenarios are intended to draw attention to potential future developments affecting Shell's business environment, such as innovation and disruptions in the energy sector, or macroeconomic and geopolitical developments.

A core element of Shell's World Energy Model for projecting energy demand in these scenarios, is the so-called energy ladder, describing the relation between energy demand and economic development. This presentation is about these energy ladders, a core element of Shell's World Energy Model for projecting future energy demand. First I give a short introduction about Shell's Scenarios and Shell's World Energy Model, then I explain what the energy ladders are and how they are used for quantifying Shell's scenarios, and finally I discuss the implications for long term energy demand in the world.

Shell's *New Lens Scenarios*, published in 2013, provided two distinct stories for 21^{st} century, called "Mountains" and "Oceans".

In the Mountains scenario, power concentrates at the top. Powerful elites determine policy. Global economic growth is moderate, and energy prices too. Natural gas becomes the backbone of the energy system – the shale gas revolution spreads outside North America, and Carbon Capture and Storage (CCS) is a success.

In the Oceans scenario, people and social forces have the power to influence decisions. There is high economic growth leading to high energy prices. Coal and oil remain the backbone of the energy system and later in the century solar becomes the largest energy source. In this scenario CO2-emissions are higher.
In both scenarios, energy demand doubles over the first half of this century.

In order to quantify such scenarios, Shell uses its *World Energy Model* (WEM). This model has as output energy demand, both primary energy and energy consumption, of a number of different energy sources and energy carriers, in 14 different end-use sectors.

What are the most important drivers of the demand for energy? Energy demand is driven by population and economic growth. Population – because more people use more energy. Economic growth – for example because when people emerge from poverty they buy a car, a fridge etc. Other important drivers are: environmental pressures, technological advancement, resource availability, and the choices people make. The WEM has 75 exogenous input variables, related to these drivers. The input variables can be changed according to the scenarios. The WEM describes how changes to these drivers affect the demand for energy.

Three core models form the heart of the WEM. The first model is the energy ladder and predicts total demand in each end-use sector.Then there is also a choice model for the choice of users and producers between different forms of energy. And there is the global supply model, of the production of energy over time. I will speak about the first model: the energy ladder.

The *energy ladder* is the relation between energy demand per capita and economic development, measured as GDP per capita. The relation is non-linear, and it follows and S-curve. As a country develops, its energy demand tends to shift from agriculture to industry and then to the services and transport sectors which are less energy-intensive.
In most sectors, energy demand saturates at a certain point, for example, when everybody has a car, people's houses are full of appliances, all houses are heated, etc

The point when energy demand saturates varies across countries. Countries with the highest energy demand are countries with more dispersed land-use, are in colder regions or have abundant energy resources; for example, the USA and Canada. The EU and Japan, with relatively high population density and less energy resources, have lower primary energy demand. Mediterranean countries have slightly less energy, because they don't need a lot of heating. Scandinavia and Australia end up in between North America and Western Europe. Korea and Taiwan have saturation levels which lie a bit higher than Europe, because they have relatively large industrial sectors.

The question we would like to answer with the energy ladders, is what will happen to large emerging economies such as China, India and Brazil. We have two main challenges in predicting future energy demand. The first challenge is predicting to what degree emerging economies will follow rich country patterns. The second is to extrapolate rich countries, into unknown levels of GDP for which we have no historical parallel.

The WEM's energy ladders track the non-linear energy demand growth with GDP, specific to each sector, and enable the evolution of energy demand to "mature" at levels of demand, dependent on country-characteristics. We have specific energy ladders for each of 14 end-use sectors.

The energy ladder predicts "energy service" demand (ES), which is then converted to total final consumption of energy (TFC). Energy service is a measure for the practical use of energy; for example, passenger kilometres driven. How much total final consumption you need for a certain amount of energy service, depends on energy service efficiency; for example, the fuel economy of the car.

In each end-use sector we try to model at what level the energy ladder "matures" based on explanatory variables. For example, residential heating demand depends on the temperature in each country, which we measure as heating degree days, the number of degrees times the number of days that heating is required.

We model the energy ladder in three phases. In the first phase, energy demand is approximately linear with GDP; the second phase is an S-curve leading to the maturity level when GDP is around 30,000 US dollars per capita; and in the third phase energy demand is linear again and may converge to a saturation level.

In *phase 1*, the linear phase, until approximately 5,000 US dollars per capita, slope and price elasticity of the energy ladder are estimated from equation (1) using a panel data regression analysis.

(1) $$EScap_{it} = c_{1,i} + \alpha \cdot GDPcap_{it} + \beta \cdot Price_{it} + \varepsilon_{it}$$

for country *i* and year *t*, where *EScap* is energy service per capita, *GDPcap* is GDP per capita, *Price* is the average unit price of energy service in this end-use sector, and ε is an error term.

In *phase 2*, an logistic curve connects phase 1 with the maturity level of energy demand. The maturity level is estimated based on an explanatory variable *X* (e.g. heating degree days) from equation (2). Qualitative variables (e.g. economic policy) are incorporated by assigning countries to a *pattern*.

(2) $$EScap_{i,maturity} = c_{pattern} + \gamma \cdot X_{i,maturity} + \varepsilon_i,$$

For example, energy service demand in Heavy Industry at maturity (when GDP is 30,000 US dollars per capita) depends on price at maturity, availability of natural resources and economic policy. Our unit for demand of energy service in heavy industry is "tonnes of steel equivalent". Based on regression analysis of historical data of countries that have reached maturity, using equation (2), we find an effect of the price at maturity of -0.003. This means that if the price of energy needed for a tonne of steel is one dollar higher, than the demand for energy service in heavy industry in that country is three tonnes of steel equivalent lower.

In *phase 3*, after approximately 30,000 US dollars per capita, energy demand is linear again, slope and price elasticity are estimated from the same equation as in phase 1, and energy demand may then converge to a saturation level. For demand saturation of rich countries, we cannot use historical data, so we incorporate scenario stories or technical limits to growth. For example, when do our houses get full, when do the roads get full, when does the travel time become too long, etc.

The energy ladders indicate that global energy demand may double over the first half of this century. In particular in China and India, the world's two most populated countries, energy demand per capita is expected to rise strongly, as their economies are on the steepest part of the energy ladder. China's energy demand should level off in a decade or so, but India may well become the number one energy demand growth country in the world sometime in the 2020s. From a global perspective, the strong rise in energy demand is expected to continue beyond 2050 in most sectors. Then eventually, as more economies mature, the S-shape of the ladders suggests a saturation in energy demand at an aggregate level. On the other hand, this may be a low-side estimate, as we do not see saturation in all of the sectors, and humans may develop new future potential energy services.

As people in developing countries are emerging from poverty, global energy demand rises to unprecedented levels, as shown by the energy ladders. This will put the world's energy resources increasingly under stress, and at the same time CO_2 emissions continue to grow alongside the demand for energy, as it will take time for low-carbon energy to scale up. Governments and the energy industry face the difficult challenge of ensuring sufficient affordable energy in an environmentally sustainable way.

***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.*