WORLD ENERGY MODEL – METHODOLOGY AND ASSUMPTIONS

Contents

1 Background

Since 1993, the IEA has provided medium to long-term energy projections using a World Energy Model (WEM). The model is a large-scale mathematical construct designed to replicate how energy markets function and is the principal tool used to generate detailed sector-by-sector and region-by region projections for various scenarios. Developed over many years, the model consists of six main modules: final energy consumption (with sub-models covering residential, services, agriculture, industry, transport and non-energy use); power generation and heat; refinery/petrochemicals and other transformation; fossil-fuel supply; CO_2 emissions and investment.

Huge quantities of historical data on economic and energy variables are used as inputs to the WEM. Much of the data is obtained from the IEA's own databases of energy and economic statistics, which is recognised as one of the world's most authoritative sources for energy statistics (http://www.iea.org/statistics). Additional data from a wide range of external sources is also used. These sources are indicated in the relevant sections of this document.

The WEM is constantly reviewed and updated to ensure its completeness and relevancy. The development of the WEM benefits from expert review and the IEA works closely with colleagues in the modelling community, for example, by participating, presenting and chairing sessions in the annual International Energy Workshop (http://internationalenergyworkshop.org).

The current WEM is the 15th version of the model and covers 25 regions (see Annex 2). The WEM is designed to analyse:

- *Global energy prospects:* These include trends in demand, supply availability and constraints, international trade and energy balances by sector and by fuel to 2035.
- *Environmental impact of energy use:* CO_2 emissions from fuel combustion are derived from the detailed projections of energy consumption.
- *Effects of policy actions and technological changes:* Alternative scenarios analyse the impact of policy actions and technological developments on energy demand, supply, trade, investments and emissions.
- *Investment in the energy sector:* The model evaluates investment requirements in the fuel supply chain needed to satisfy projected energy demand to 2035. It also evaluates demand-side investment requirements in the alternative scenarios.

1.1 The scenarios

The *WEO-2011* continues past practice in using a scenario approach to examine future energy trends using the WEM. This year, detailed projections for three scenarios were modelled and presented: a New Policies Scenario, a Current Policies Scenario and a 450 Scenario. The scenarios differ with respect to what is assumed about future government policies related to the energy sector. There is much uncertainty about what governments will actually do over the coming quarter of a century, but it is highly likely that they will continue to intervene in energy markets. Indeed, many countries have announced formal objectives; but it is very hard to predict with any degree of certainty what policies and measures will actually be introduced or how successful they will be. The commitments and targets will undoubtedly change in the course of the years to come.

Given these uncertainties, we present projections for a Current Policies Scenario (formerly called the Reference Scenario in *WEO-2009* and earlier editions) as a baseline in which only policies already formally adopted and implemented are taken into account. In addition, we present projections for a New Policies Scenario, which assumes the introduction of new measures (but on a relatively cautious basis) to implement the broad policy commitments that have already been announced, including national pledges to reduce greenhouse-gas emissions and, in certain countries, plans to phase out fossil fuel subsidies.

The 450 Scenario sets out an energy pathway consistent with the goal of limiting the global increase in average temperature to 2°C, which would require the concentration of greenhouse gases in the atmosphere to be limited to around 450 parts per million of carbon-dioxide equivalent (ppm CO2-eq). Its trajectory to

2020 is somewhat higher than in *WEO-2009*, which started from a lower baseline and assumed stronger policy action before 2020. The decline in emissions is, by necessity, correspondingly faster after 2020.

The WEM scenarios allows us to evaluate the impact of specific policies and measures on energy demand, production, trade, investment needs, supply costs and emissions. A policies and measures database, with over 3 600 policies in OECD and non-OECD countries, was compiled to support the analysis. This database is available at: http://www.iea.org/textbase/pm/?mode=weo.

1.2 New Features in World Energy Outlook 2011

The following changes were made to WEM for the purposes of the *WEO-2011*:

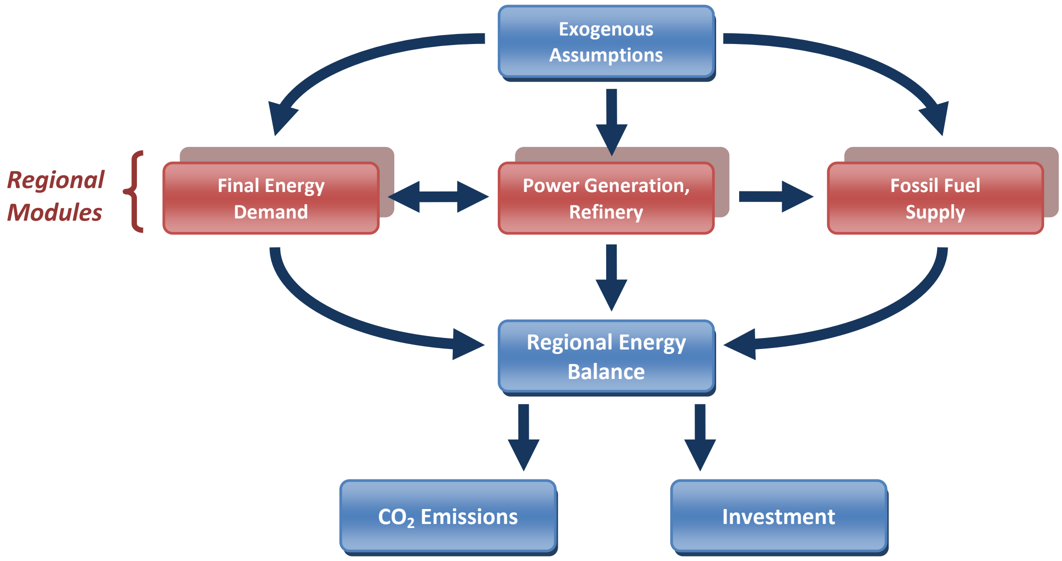
- Power generation:
  - A capacity credit module was added to the power sector module to reflect more accurately the contribution made by variable renewable technologies to system adequacy. This forms part of an improved capacity margin mechanism.
  - Transmission and distribution network module has been improved through additional analysis of historic development patterns and incorporation of costs related to renewables integration.
  - Developed and implemented a new carbon capture and storage (CCS) module that allows for endogenous cost reductions through learning on a regional and global basis (this has a similar structure to the renewables module).
  - Updated analysis on fuel pricing mechanism to generators.
  - Separation of the merit order into peak, mid-load, and base-load segments for the purposes of determining new entry and plant operation.
  - Improved wholesale electricity price module.
  - Increased technology mix to provide greater granularity.
- Transport:
  - An update of the model database to improve the calibration of starting points;
  - The development of an infrastructure module to improve the modelling of natural gas and electricity as potential oil substitutes in road transport.
- Industry:
  - Iron and steel sub-sector modelled together with subsectors of blast furnaces, coke ovens and own use of those two for technology assessment and detailed analysis of coal demand.
  - Unit investment costs now dependent on achieved energy efficiency level rather than by year.
  - Updated analysis on CCS.
- Buildings:
  - End use sub-sectoral split (space heating, water heating, cooking, lighting and appliances) was introduced in the residential sector for three non-OECD regions, namely India, China and Russia.
  - Updates and review of:
    - Activity variables levels (especially in large non-OECD countries).
    - Enhancement of the floor space model, introduction of existing versus new floor space and retirements.
    - Elasticities to intra- and inter-fuel price changes.
    - Investment unit costs for abatement by fuel and by country/region.
    - Abatement potentials by region/country and scenario (abatement cost curves for buildings, review of policies database).

For a description of previous enhancements to the WEM please refer to Annex 1.

1.3 World Energy Model Structure

The WEM is a mathematical model made up of six main modules: final energy demand; power generation; refinery and other transformation; fossil fuel supply; CO_2 emissions, and investment. Figure 1 provides a simplified overview of the structure of the model.

Figure 1: World Energy Model Overview



The main exogenous assumptions concern economic growth, demographics, international fossil fuel prices and technological developments. Electricity consumption and electricity prices dynamically link the final energy demand and power generation modules. The refinery model projects throughput and capacity requirements based on global oil demand. Primary demand for fossil fuels serves as input for the supply modules. Complete energy balances are compiled at a regional level and the CO_2 emissions of each region are then calculated using derived carbon factors.

2 Technical Aspects and Key Assumptions

The parameters of the equations of the demand-side modules are estimated econometrically, usually using data for the period 1971-2009. Shorter periods are sometimes used where data are unavailable or significant structural breaks have occurred. To take into account expected changes in structure, policy or technology, adjustments to these parameters are sometimes made over the *Outlook* period, using econometric and other modelling techniques. Simulations are carried out on an annual basis. Demand modules can be isolated and simulations run separately. This is particularly useful in the adjustment process and in sensitivity analyses related to specific factors.

The WEM makes use of a wide range of software, including specific database management tools, econometric software and simulation programmes.

The same macroeconomic and demographic assumptions are used in all the scenarios, unless otherwise specified. The projections are based on the average retail prices of each fuel used in final uses, power generation and other transformation sectors. These end-use prices are derived from assumptions about the international prices of fossil fuels.

2.1 Population Assumptions

Rates of population growth for each WEM region are based on the most recent medium-fertility variant projections contained in the United Nations Population Division report, *World Population Prospects: The 2010 Revision*. In *WEO-2011*, world population is projected to grow by 0.9% per year on average, from 6.8 billion in 2009 to 8.6 billion in 2035. Population growth slows over the projection period, in line with trends of the last three decades: from 1.1% per year in 2009-2020 to 0.8% in 2020-2035 (Table 1). Population expanded by 1.5% from 1980 to 2009.

Estimates of the rural/urban split for each region have been taken from the United Nations Population Division report, *World Urbanization Prospects: The 2009 Revision Population Database*. This database provides percentage of population residing in urban areas by country in 5 yearly intervals to 2050. By combining this data[1] with the UN population projections an estimate of the rural/urban split may be calculated. In 2009, half of the world population was estimated to be living in urban areas. This is expected to rise to 61% by 2035.

Table 1: Population growth by region

	Population growth (compound annual average)			Population (million)		Urbanisation rate (%)	
	2009-2020	2020-2035	2009-2035	2009	2035	2009	2035
OECD	**0.5%**	**0.3%**	**0.4%**	**1 229**	**1 373**	**77%**	**84%**
Americas	0.9%	0.7%	0.8%	470	571	81%	87%
United States	*0.8%*	*0.7%*	*0.7%*	*312*	*377*	*82%*	*88%*
Europe	0.4%	0.2%	0.3%	557	599	74%	82%
Asia Oceania	0.2%	-0.1%	0.0%	203	203	73%	81%
Japan	*-0.1%*	*-0.4%*	*-0.3%*	*127*	*118*	*67%*	*75%*
Non-OECD	**1.2%**	**0.9%**	**1.0%**	**5 536**	**7 183**	**44%**	**57%**
E. Europe/Eurasia	0.1%	-0.1%	0.0%	335	331	63%	70%
Russia	*-0.1%*	*-0.4%*	*-0.3%*	*142*	*133*	*73%*	*78%*
Asia	0.9%	0.6%	0.7%	3 546	4 271	38%	53%
China	*0.4%*	*0.0%*	*0.1%*	*1 338*	*1 387*	*46%*	*65%*
India	*1.3%*	*0.9%*	*1.0%*	*1 155*	*1 511*	*30%*	*43%*
Middle East	1.9%	1.4%	1.6%	195	293	66%	74%
Africa	2.3%	2.0%	2.1%	1 009	1 730	39%	53%
Latin America	1.0%	0.7%	0.8%	451	558	79%	86%
Brazil	*0.8%*	*0.4%*	*0.6%*	*194*	*224*	*86%*	*92%*
World	**1.1%**	**0.8%**	**0.9%**	**6 765**	**8 556**	**50%**	**61%**
European Union	*0.3%*	*0.1%*	*0.2%*	*501*	*521*	*74%*	*81%*

2.2 Macroeconomic Assumptions

Economic growth assumptions for the short to medium term are based largely on those prepared by the OECD, IMF and World Bank. Over the long term, growth in each WEM region is assumed to converge to an annual long-term rate. This is dependent on demographic and productivity trends, macroeconomic conditions and the pace of technological change.

In the WEO-2011 world GDP (expressed in year-2010 dollars at purchasing power parity [PPP] terms) is expected to grow on average by 3.6% per year over the projection period (Table 2). That rate is a little higher than in last two decades (3.1% in 1990-2009) due to the financial crisis and its rebound. Growth is assumed to drop from 4.2% in 2009-2020 to 3.1% in 2020-2035. India and China are expected to continue to grow faster than all other regions, followed by the Middle East and Africa. The economies of many regions are expected to shift away from energy-intensive heavy manufacturing towards lighter industries and services, though the pace of this process, which is well advanced in the OECD and some emerging economies, varies. Industrial production continues to grow in volume terms in many regions.

[1] Rural/Urban percentage split is linearly interpolated between the 5 yearly intervals.

Table 2: Real GDP growth by region (compound average annual growth rates)

	1990-2000	2000-2009	2009-2020	2020-2035	20209-2035
OECD	**2.8%**	**1.5%**	**2.4%**	**2.0%**	**2.2%**
Americas	3.4%	1.6%	2.7%	2.3%	2.4%
United States	*3.4%*	*1.5%*	*2.6%*	*2.2%*	*2.4%*
Europe	2.4%	1.5%	2.1%	1.8%	2.0%
Asia Oceania	2.2%	1.4%	2.3%	1.4%	1.8%
Japan	*1.2%*	*0.4%*	*1.7%*	*1.1%*	*1.4%*
Non-OECD	**3.2%**	**6.3%**	**6.1%**	**4.0%**	**4.9%**
E. Europe/Eurasia	-3.9%	5.2%	4.1%	3.2%	3.6%
Russia	*-3.9%*	*4.9%*	*4.1%*	*3.3%*	*3.6%*
Asia	7.0%	7.9%	7.4%	4.4%	5.7%
China	*9.9%*	*10.2%*	*8.1%*	*4.3%*	*5.9%*
India	*5.6%*	*7.2%*	*7.7%*	*5.8%*	*6.6%*
Middle East	3.1%	4.4%	4.3%	3.7%	4.0%
Africa	2.5%	5.2%	4.6%	3.0%	3.7%
Latin America	2.9%	3.6%	4.0%	2.8%	3.3%
Brazil	*2.5%*	*3.2%*	*4.3%*	*3.2%*	*3.6%*
World	**2.9%**	**3.3%**	**4.2%**	**3.1%**	**3.6%**
European Union	*2.1%*	*1.4%*	*2.0%*	*1.8%*	*1.9%*

Note: Calculated based on GDP expressed in year-2010 dollars at PPP terms.

3 Description of the demand modules

3.1 Final Energy Demand

The OECD regions and the major non-OECD regions are modelled in considerable sectoral and end-use detail. Specifically:

- Industry is separated into five sub-sectors, allowing a more detailed analysis of trends and drivers in the industrial sector by fuel.
- Residential energy demand is separated into five end-uses by fuel.
- Services demand by fuel.
- Transport demand is modelled in detail by mode and fuel.

Final energy demand is modelled at the sectoral level for each of the WEM regions, but not at such a disaggregated end-use level.

Total final energy demand is the sum of energy consumption in each final demand sector. In each sub-sector or end-use, at least six types of energy are shown: coal, oil, gas, electricity, heat and renewables. However, this level of aggregation conceals more detail. For example, the different oil products are modelled separately as an input to the refinery model. Within each sub-sector or end-use, energy demand is estimated as the product of an energy intensity and an activity variable.

In most of the equations, energy demand is a function of the following variables:

- *Activity variables:* This is often a GDP or GDP-per-capita variable. In many cases, however, a specific activity variable, which is usually driven by GDP, is used.
- *End-user prices:* Historical time-series data for coal, oil, gas, electricity, heat and biomass prices are compiled based on the IEA database Energy Prices & Taxes and several external sources. For each sector and WEM region, a representative price (usually a weighted average) is derived taking into account the product mix in final consumption and differences between countries. International price

assumptions are then applied to derive average pre-tax prices for coal, oil, and gas over the projection period. Average pre-tax electricity prices are derived from changes in marginal power-generation costs. Excise taxes, value added tax rates and subsidies are taken into account in calculating average post-tax prices for all fuels. In all cases, the excise taxes and value added tax rates on fuels are assumed to remain unchanged over the projection period. We assume that energy-related consumption subsidies are gradually reduced over the projection period, though at varying rates across the WEM regions and the scenarios. All prices are expressed in US dollars per tonne of oil equivalent and assume no change in exchange rates. These average end-user prices are then used as an explanatory variable — directly or as a lag.

- *Other variables:* Other variables are used to take into account structural and technological changes, saturation effects or other important drivers.

3.2 Industry Sector

The industrial sector in the WEM regions is split into five sub-sectors: iron and steel, chemical and petrochemical, non-metallic minerals, paper, pulp and printing, and other industry[2]. In *WEO–2011*, iron and steel sub-sector is modelled together with subsectors of blast furnaces, coke ovens and own use of those two.

The intensity of energy consumption per unit of each sub-sector's output and the share of each energy source are projected on an econometric basis with an incorporation of experts' judgement. The output level of each sub-sector is modelled separately and is combined with projections of its energy intensity and end-use shares to derive the consumption of each energy source by sub-sector. This allows more detailed analysis of the drivers of demand and of the impact of structural change on energy consumption trends.

The increased disaggregation also facilitates the modelling of policy scenarios, where output levels, energy intensities, end-use shares and technology descriptions are applied in conjunction with capital stock turnover models to analyse in detail the impact of different policies or choices of technology.

3.3 Transport Sector

The transportation module of the WEM consists of several sub-models covering road transport, aviation, rail and navigation. The WEM fully incorporates a detailed bottom-up approach for the transport sector in all WEM regions.

For each region, activity levels for each mode of transport are estimated econometrically as a function of population, GDP and price. Transport activity is linked to price through elasticity of fuel cost per kilometre, which is estimated for all modes except passenger buses and trains and inland navigation. This elasticity variable accounts for the "rebound" effect of increased car use that follows improved fuel efficiency. Energy intensity is projected by transport mode, taking into account changes in energy efficiency and fuel prices.

3.3.1 Road transport

Road transport energy demand is broken down among *passenger light duty vehicles (PLDVs), light commercial vehicles (LCVs) buses, trucks (distinguishing medium- and heavy-freight traffic) and two- and three-wheelers*. The model allows fuel substitution and alternative powertrains across all sub-sectors of road transport. The gap between test and on-road fuel efficiency, i.e. the difference between test cycle and real-life conditions, is also estimated and projected.

As the largest share of energy demand in transport comes from oil use for road transport, the WEM contains detailed sub-models of the total vehicle stock and the passenger car fleet.

Stock model: The stock model is based on an S-shaped Gompertz function, proposed in a paper titled "Vehicle Ownership and Income Growth, Worldwide: 1960-2030" by Dargay et al. This model gives the vehicle

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[2] Other industry is an aggregate of the following sub-sectors: non-ferrous metals, transport equipment, machinery, mining and quarrying, food and tobacco, wood and wood products, construction, textile and leather, non-specified.

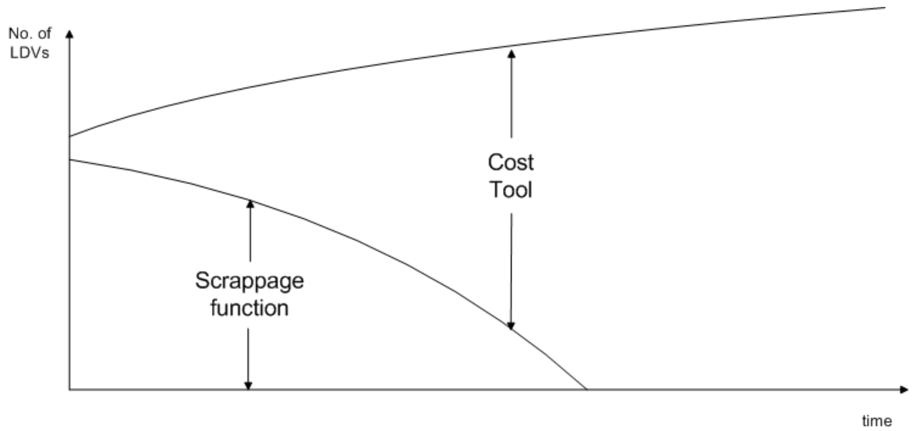
ownership based on income (our GDP assumptions through to 2030) and 2 variables: the saturation level (assumed to be the maximum vehicle ownership of a country/region) and the speed at which the saturation level is reached. The equation used is:

$$V_t = y\ e^{ae^{bGDP_t}}$$

where V is the vehicle ownership (expressed as number of vehicles per 1,000 people), y is the saturation level (expressed as number of vehicles per 1,000 people), a and b are negative parameters defining the shape of the function (i.e. the speed of reaching saturation). The saturation level is based on several country/region specific factors such as population density, urbanisation and infrastructure development. Passenger car ownership is then calculated based on the detailed vehicle fleet data in the IEA Mobility Model (MoMo) plus other regional statistics, all of which were reviewed and overhauled for *WEO-2011* (see below for details). Using the equation above, changes in passenger car ownership over time are modelled, based on the average current global passenger car ownership. Both total vehicle stock and passenger vehicle stock projections are then derived based on our population assumptions.

Passenger car model: For the *WEO-2009*, the passenger light-duty vehicle (PLDV) section of the model has been enhanced by adding a cost model that guides the choice of drivetrain technologies and fuels as a result of their cost-competitiveness. The tool acts on new passenger-LDV sales as depicted in **Figure 2**, and determines the share of each individual technology in new passenger LDVs sold in any given year.

Figure 2: The role of the passenger-LDV cost model in *WEM*



The purpose of the cost tool is to guide the analysis of long-term technology choices using their cost-competitiveness as one important criterion. The tool uses a logit function for estimating future drivetrain choices in passenger LDV.[3] The share of each PLDV type j allocated to the passenger light duty vehicle market is given by

$$Share_j = \frac{b_j P_{PLDV_j}^{r_p}}{\sum_j \left(b_j P_{PLDV_j}^{r_p}\right)}$$

Where

- P_{PLDVj} is the annual cost of a vehicle, including fuel use
- Rp is the cost exponent that determines the rate at which a PLDV will enter the market
- b_j is the base year share or weight of $PLDV_j$

The cost database in the tool builds on an analysis of the current and future technology costs of different drivetrain and fuel options, comprising the following technology options:

[3] Originally developed to describe the growth of populations and autocatalytic chemical reactions, logit functions can be applied to analyze the stock turnover in different sectors of the energy system. Here, it uses the cost-competitiveness of technology options as an indicator for the pace of growth.

- conventional internal combustion engine (ICE) vehicles (spark and compression ignition)
- hybrid vehicles (spark and compression ignition)
- plug-in hybrids (spark and compression ignition)
- electric cars with different drive ranges
- hydrogen fuel cell vehicles

The model takes into account the costs of short- and long-term efficiency improvements in personal transport distinguishing numerous options for engine (e.g. reduced engine friction, the starter/alternator, or transmission improvements) and non-engine measures (e.g. tyres, aerodynamics, downsizing, light-weighting or lighting). In addition, it uses projections for the costs of key technologies such as batteries (NiMH and Li-ion) and fuel cells. The pace of technology cost reductions is then calculated using learning curves at various different learning rates.

The cost analysis builds on a comprehensive and detailed review of technology options for reducing fuel consumption, undertaken in collaboration with the ETP team of the IEA. The database was reviewed by a panel of selected peer-reviewers, and feeds into the cost tool as well as the mitigation cost database, published for the *WEO-2009*.

Other road model features: Based on projections of the average fuel consumption of new vehicles by vehicle type, the road transport model calculates average sales and stock consumption levels (on-road and testcycle) and average emission levels (in grammes of CO_2 per kilometre).

Finally, the road transport model calculates incremental investment costs relative to other scenarios and calculates implicit CO_2 prices that guide optimal allocation of abatement in transport.

3.3.2 Aviation

The aviation sub-model was vastly expanded for *WEO-2006*. A database of all global regions of projected traffic measured in revenue passenger kilometres was compiled based on data from Boeing and Airbus, and is updated every year since then. We have calculated current and projected regional average aircraft fleet efficiency based on data from The Intergovernmental Panel on Climate Change, the Annual Review of Energy and the Environment and the International Air Transport Association. The projected traffic growth combined with the assumed efficiency improvements in the Reference Scenario allows the projected oil aviation demand to be calculated region by region. For the *WEO-2009*, collaboration with the International Air Transport Association (IATA) lead to the creation of a sub-model that calculates investment costs and marginal abatement costs split by the following types of abatement measure: technological, operational, infrastructure.

3.3.3 Biofuels

As part of the transport analysis for *WEO-2009* a detailed biofuels cost tool was added, which complemented the existing projections for biofuels by type including a first and second generation split. The new cost tool uses cost projections based on feedstock prices (as a function of oil prices) and refining costs by technology (with assumed learning rates) to access the penetration of different types of biofuels versus competing biofuels and petroleum based fuels. Based on the market penetration of the different conversion technologies, it also directly calculates biofuels investment. The model was enhanced by a sub-module for WEO-2010 that allows calculating government support to biofuels by comparing the costs of biofuels with projected fossil fuel end-user prices excluding taxes.

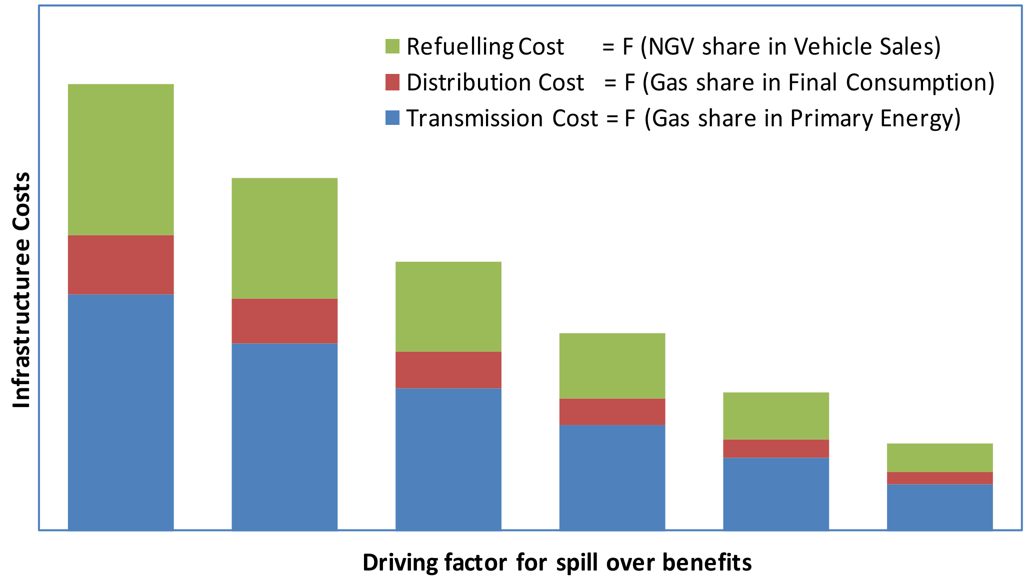
3.3.4 Model updates for WEO-2011

Two main efforts were undertaken to improve the modelling of road transport: an update of the model database to improve the calibration of starting points; and the development of an infrastructure module to improve the modelling of natural gas and electricity as potential oil substitutes in road transport.

Update of model database: The WEO-database was overhauled for *WEO-2011* to capture more recent developments in vehicle markets more accurately and precisely. In particular, all vehicle stocks and sales for all major regions were revised using statistics from governments, car industry, scientific institutions and others. As part of this process, the split between different vehicle segments and the average mileage driven were re-assessed.

Infrastructure modules: In order to assess the problems created due to chicken-and-egg-type of situations when it comes to the deployment of those alternative fuels in transport that require a dedicated refuelling infrastructure, and to better reflect potential spill-over effects of the use of such alternative fuels in other sectors of the energy system, the WEM model was enhanced for *WEO-2011* by developing two dedicated sub-models, one covering natural gas infrastructure and the other electricity-related refuelling infrastructure. In principle, both modules seek to quantify the costs and benefits of increased infrastructure availability for transmission and distribution of these alternative fuels. Thus, in the case of natural gas, an enhanced share of natural gas use in primary energy demand (for example in the power generation sector) would lead to the development of a transmission grid in the economy; and similarly, an increased share of natural gas in final energy consumption by end use sectors (for example, in industry or buildings) will lead to an expanded distribution grid close to the consumption centres, thereby impacting the overall availability of natural gas in the economy and simultaneously driving down the transmission and distribution costs for all consumers, including the transportation sector. Moreover, an increased share of natural gas vehicles (NGVs) in total vehicle sales in the region would gradually improve the development and utilization of a refuelling network due to increased density of vehicles served per station, thereby reducing the average cost of refuelling. This relationship is thus implemented as a positively reinforcing loop, wherein increased penetration of natural gas (in all other sectors, not just transport) and natural gas vehicles helps driving down the overall refuelling infrastructure costs. In essence, the relationship of these spill-over benefits can be illustrated as in Figure 3.

Figure 3: Refuelling Infrastructure Cost Curve (illustrative)



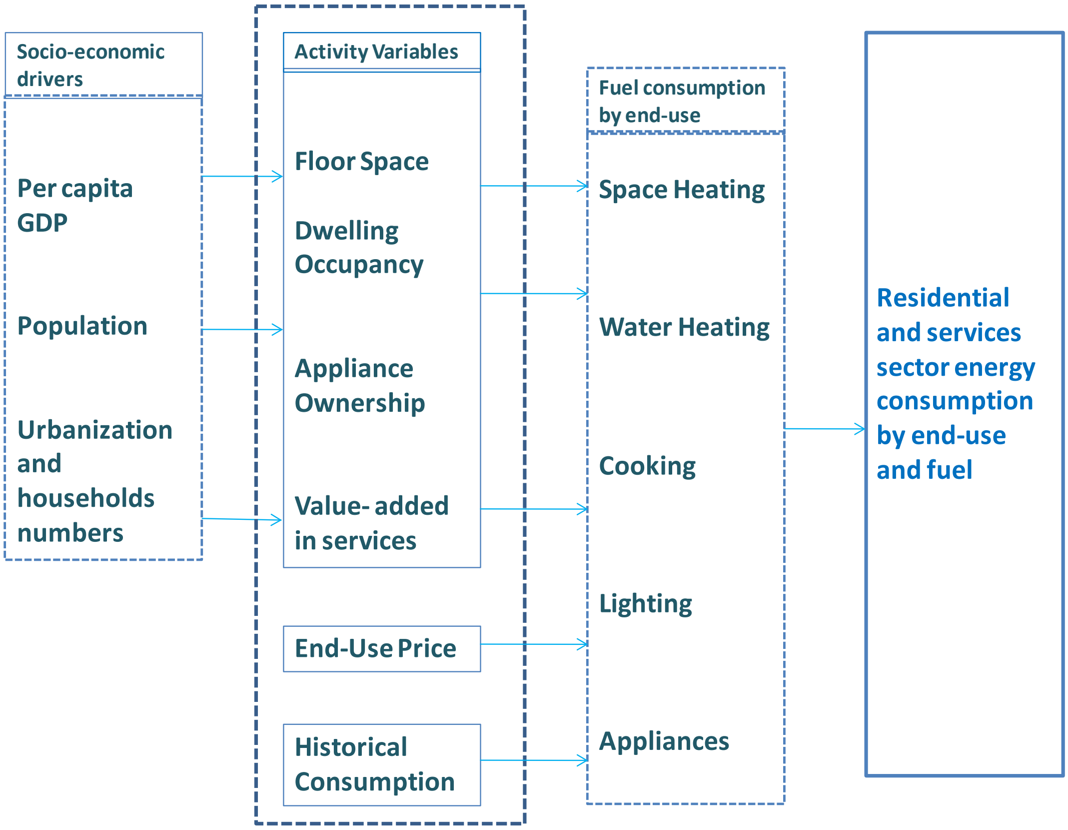
For the case of electric vehicles, availability of transmission and distribution grid is less of an issue, especially in OECD countries, thanks to the already existing widespread use of electricity in different end use sectors (especially buildings). However, the availability of electric recharging infrastructure is one of the important constraints in this case, and hence it is important to determine how a reduction in refuelling costs could influence the possibility for oil substitution in road transport. Therefore, the electric vehicle (EV) sub-module assesses the cascading effect of an increased share of electric vehicles in overall vehicle sales on bringing down the refuelling costs. Detailed cost curves were prepared outlining the reduction of refuelling costs with the increase in overall vehicle stock of electric vehicles. These costs curves were provided as an exogenous input to the model, so as to continuously adjust the refuelling costs as the share of EV sales rises in the future.

3.4 Residential and Services Sectors

Residential sector's energy consumption in the OECD regions is split into five end uses: space heating, water heating, cooking, lighting and appliances (Figure 4). The energy consumption related to each end use is computed as the product of an intensity variable and an activity variable –residential floor space area, dwelling occupancy or the stock of appliances. For each end use, the intensity variable is projected econometrically and is linked with average end-user prices and a variable representing the impact of policies and measures to reduce the energy intensity and promote energy efficiency. The fuel shares are also projected econometrically and are linked to the change in average end-user prices for that fuel (using price elasticity), average end user price of competing fuels (using inter-fuel substitution elasticity), and a variable representing the impact of policies and measures to promote fuel switching. For example, in the case of modern biomass, fuel share is the function of a variable that, taking into account the regional potentials, simulates the impact of policies such as feed-in tariffs, financial incentives or installed capacity targets. In non-OECD countries, the residential sector also includes projections for traditional biomass consumption, which are linked to the GDP per capita, the urbanization rate and the price of alternative (competing) fuels. In WEO 2011, special efforts were made to attain detailed data on sub sector level for non-OECD countries, and as a result we have introduced end use sectoral split for three additional regions, namely India, China and Russia.

In the services sector also, energy consumption is computed as a product of an intensity variable and an activity variable. The activity variable for the services sector is as a function of the value added of the sector to GDP of the region. As in the case of residential sector, the intensity variable is projected using an econometric model and is linked with the average end-user prices and a variable representing the impact of policies and measures to reduce the energy intensity and promote energy efficiency. The fuel shares are also projected using a similar approach as used in the residential sector model.

Figure 4: Structure of the Residential and Services Sectors Demand Modules



4 Refinery Module

For each WEM region, the module estimates a base case refinery output, given past domestic demand and the region's share in global trade. Demand in the medium term is based on existing projects in all WEM regions. On the basis of information obtained regarding these projects and on regional capacity utilisation rates, the model determines the additional capacity needed by region.

Historical capacity figures for the module are based on data from the *Oil and Gas Journal* and British Petroleum. Current capacity figures are from the IEA's *Oil Market Report*, company sources, industry journals and national statistics. Throughput and capacity projections are based on the Reference Scenario oil demand projections by WEM region.

The model adjusts global refinery demand among the major regions: OECD, Eastern Europe/Eurasia, China, India, Middle East, North Africa and rest of non-OECD. Capacities are then disaggregated according to production, demand, exports of crude and refined products, and costs. Figure 5 shows the structure of the refinery module.

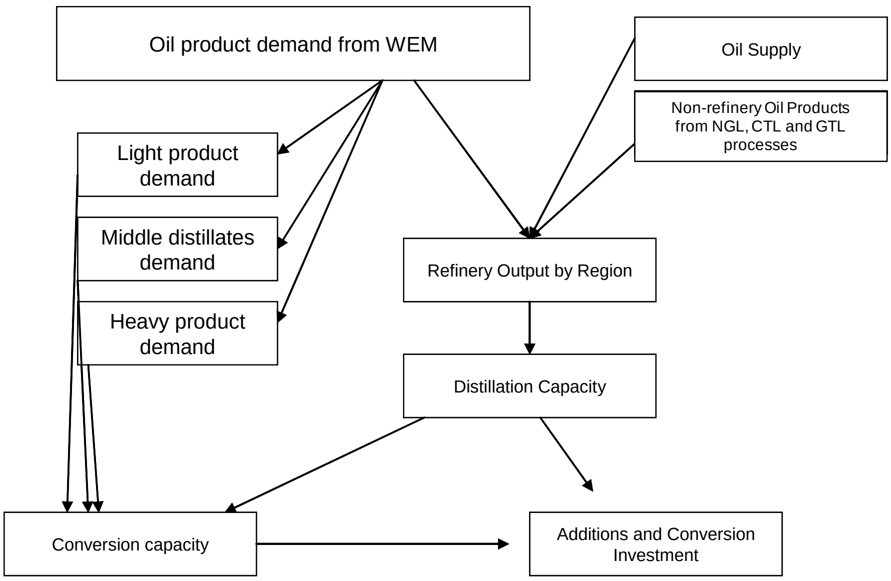
After determining individual refinery output and capacity, the module calculates the global oil products balance. Total demand for oil products (excluding direct use of crude) is matched with the total supply of oil products, including products from NGLs, CTLs and GTLs. Thus, at the global level:

Total refinery output = total oil product demand – (NGLs + CTL products + GTL products)

+ (own-use of refineries)

The refinery model balances supply and demand through an optimisation process. Excess demand is split according to an optimisation matrix which takes into account unit costs, environmental and political constraints and capacity constraints.

Figure 5: Structure of the Refinery Module



There are three types of distillation capacity additions: new refinery (highest cost); added capacity at an existing refinery; and capacity creep (lowest cost). Distillation capacity refers to calendar day capacity. Investment requirements are separated between *additions investments* and *conversion investments*. Additions investments are based on current costs which vary among regions/countries. For additions investment, the model projects the share of distillation capacity additions for each region/country and allocates costs accordingly. Conversion investments are based on the estimated costs of modifying existing capacity to cope with new demand (lighter products) or new environmental restrictions on products (sulphur content). Demand is divided into three products: light, middle and heavy. The model uses the sectoral breakdown and the region/country specification to project product demand.

The refinery module projects the necessary capacity conversions, based on the demand projections for light, middle and heavy products and on anticipated environmental regulations. The projections are used to calculate investment in cost per million barrels per day converted. We calculated a weighted average technology cost, taking into account the cost of each different technology such as catalytic crackers and hydro-skimmers, from industry sources. The refinery investments do not include maintenance costs.

5 Power Generation and Heat Plants

The power generation module calculates the following:

- Amount of new generating capacity needed to meet demand growth and cover retirements.
- Type of new plants to be built by technology.
- Amount of electricity generated by each type of plant to meet electricity demand, cover transmission and distribution losses and own use.
- Fuel consumption of the power generation sector.
- Electricity prices.

5.1 Electricity Demand

For each WEM region, electricity demand is computed in the demand modules by sector. Various factors influence demand for electricity services, including electricity price, household income, and the possibility to switch to others energy sources to provide the same service. The long-term own-price elasticity of electricity demand is very low, ranging from -0.01 to -0.14 for the 25 WEM regions. Economic activity is the main driver of electricity demand in all regions. Average income elasticities of demand across all end-use sectors, using per-capita GDP as a proxy for income, range from 0.4 to 1.3. Elasticities are generally highest in non-OECD regions: on average, their electricity demand rises faster than income. OECD electricity demand is income-inelastic. This difference reflects saturation effects in the OECD and catching-up by the poorer developing countries. It also reflects changes in the structure of economic activities. Heavy electricity-intensive industry has contributed more of the increase in GDP in non-OECD countries than in the OECD. The energy efficiency of electrical equipment and appliances in non-OECD countries is also generally lower, boosting electricity intensity.

5.2 Electricity Generation

The structure of the power generation module is outlined in Figure 6. The purpose of the module is to ensure that enough electrical energy is generated to meet the annual volume of demand in each region, and that there is enough generating capacity in each region to meet the peak electrical demand, while ensuring security of supply to cover unforeseen outages.

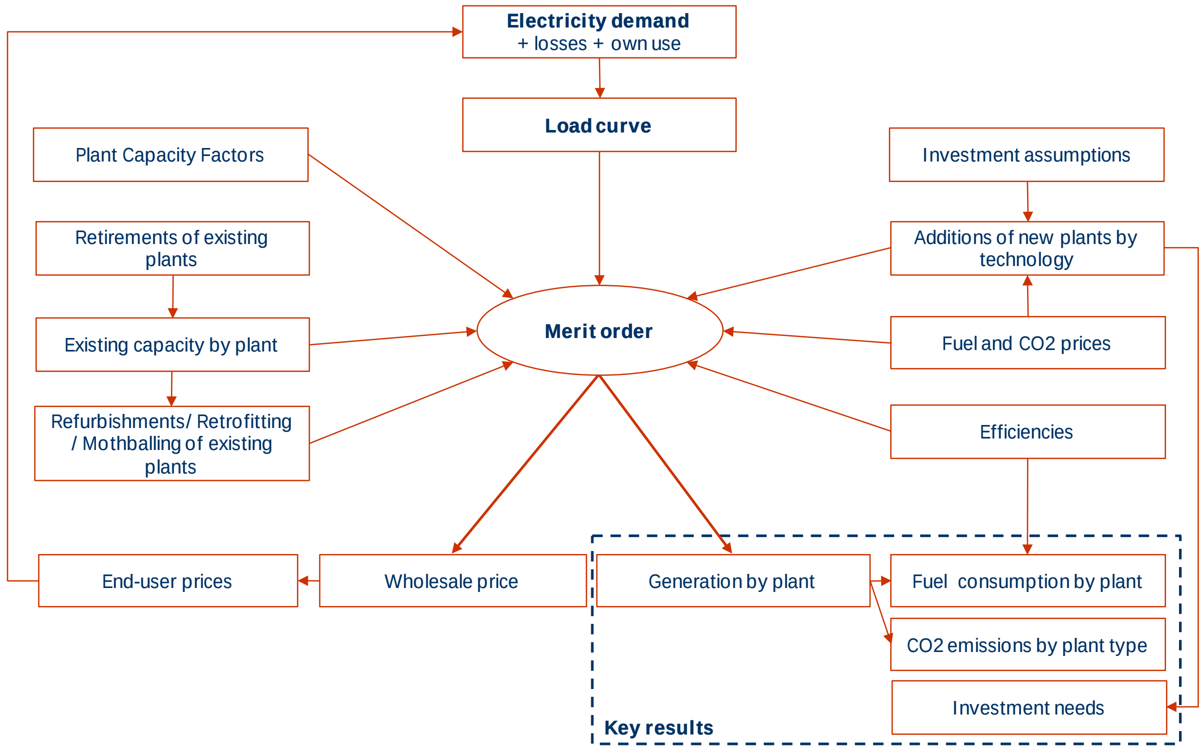
The model begins with existing capacity in each region, which is based on a database of all world power plants. Plant lives are assumed to range between 45 and 60 years for existing fossil-fuel plants and nuclear plants (unless otherwise specified by government policies). Wind and solar PV installations are assumed to have a 20 year lifetime; hydro plants 50 years; and biomass 25 years.

The model determines how much new generation capacity is required annually in each region by considering the change in peak demand compared to the previous year, retirements of generation capacity during the year, and any increase in renewable capacity built as the result of government policy. Installed generating capacity must exceed peak demand by a security-of-supply margin; if this margin is not respected after changes in demand, retirements, and renewables additions, then the model adds new capacity in the region. In making this calculation, the model takes into account losses in transmission and distribution networks and electricity used by generation plants themselves.

Because of the stochastic nature of the output of variable renewables such as wind and solar PV, only a proportion of the installed capacity of these technologies can be considered to contribute to the available generation margin. This is reflected in the modelling by the use of a capacity credit for variable renewables.

This capacity credit is estimated from historical data on hourly demand and hourly generation from variable renewables in a number of electricity markets, and it reflects the proportion of their installed capacity that can reliably be expected to be generating at the time of peak demand.

Figure 6: Structure of the Power Generation Module



When new plants are needed, the model makes its choice between different technology options on the basis of their regional long-run marginal costs (LRMCs). The LRMC of each technology is calculated as a sum of levelised capital costs, fixed operation and maintenance (O&M) costs, and variable operating costs. Variable operating costs are in turn calculated from the fuel cost and plant efficiency. Our regional assumptions for capital costs are taken from our own survey of industry views and project costs, together with the OECD/IEA/NEA publication "Projected Costs of Generating Electricity" (2010 Edition).

The LRMC calculated for any plant is partly determined by their utilisation rates. The model takes into account the fact that plants will have different utilisation rates because of the variation in demand over time, and that different types of plants are competitive at different utilisation rates. (For example, coal and nuclear tend to be most competitive at high utilisation rates, while gas and oil plants are most competitive at lower utilisation rates).

The specific numerical made on capital costs, fixed O&M costs, and efficiency can be found on the World Energy Outlook website: http://www.worldenergyoutlook.org/investments.asp.

The levelised cost module computes LRMCs for the following types of plant:

- Coal, oil and gas steam boilers with and without CCS;
- Combined-cycle gas turbine (CCGT) with and without CCS;
- Open-cycle gas turbine (OCGT);
- Integrated gasification combined cycle (IGCC);
- Oil and gas internal combustion;
- Fuel cells;
- Biomass;
- Geothermal;
- Wind onshore;
- Wind offshore;

- Hydro (conventional);
- Solar photovoltaics;
- Concentrating solar power; and
- Marine

Regional LRMCs are also calculated for nuclear generation but additions of nuclear capacity are subject to government policies.

5.3 Electricity Transmission and Distribution Networks

The model calculates investment in transmission and distribution networks, which consists of three elements. The first is the cost of new infrastructure required to meet growth in demand. This is estimated from historic relationships between network growth and demand growth. The second is investment required to replace ageing infrastructure, which is estimated using data on the age profile of networks in each region. The third is the additional cost associated with integrating renewables to the transmission and distribution networks (thee can be higher than other technologies because renewable resources can be located relatively far from demand and the capacity factor of renewable generators can be low). This is based on industry and academic studies that have sought to estimate the network costs associated with renewable technologies.

5.4 Renewables, Combined Heat and Power and Distributed Generation Modules

The projections for renewable electricity generation, combined heat and power (CHP), and distributed generation (DG) are derived in separate sub-modules. The future deployment of these technologies and the investment needed for such deployment were assessed on the basis of potentials in each country/region.

5.4.1 Combined Heat and Power and Distributed Generation

The CHP option is considered for fossil fuel and biomass plants. The CHP sub-module uses the potential for heat production in industry and buildings together with heat demand projections, which are estimated econometrically in the demand modules. The distributed generation sub-module is based on assumptions about market penetration of DG technologies.

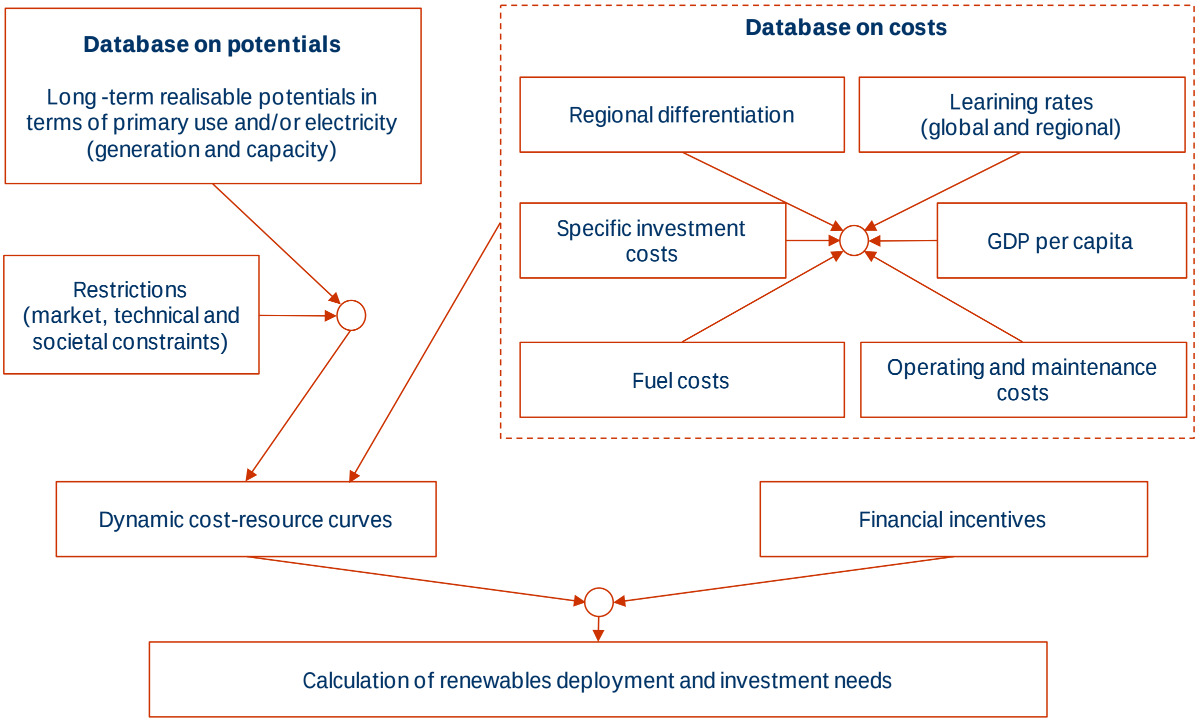
5.4.2 Renewable energy

The projections of renewable electricity generation are derived in the renewables sub-module, which projects the future deployment of renewable sources for electricity generation and the investment needed. The deployment of renewables is based on an assessment of the potential and costs for each source (biomass, hydro, photovoltaics, concentrating solar power, geothermal electricity, wind, marine) in each of the 25 WEM regions.[4] By including financial incentives for the use of renewables and non-financial barriers in each market, as well as technical and social constraints, the model calculates deployment as well as the resulting investment needs on a yearly basis for each renewable source in each region. The methodology is illustrated in Figure 7.[5]

[4] A number of sub-types of these technologies are modelled individually, as follows. Biomass: small CHP, medium CHP, electricity only power plants, biogas-fired, waste-to-energy fired and co-fired plants. Hydro: large (≥10MW) and small (<10MW). Wind: onshore and offshore. Solar photovoltaics: large-scale and buildings. Geothermal: electricity only and CHP. Marine: tidal and wave technologies.

[5] For a detailed description of the approach used in this model – which was originally developed by Energy Economics Group (EEG) at Vienna University of Technology in cooperation with Wiener Zentrum für Energie, Umwelt und Klima – see Resch et.al. (2004).

Figure 7: Method of Approach for the Renewables Module



The model uses *dynamic cost-resource curves*[6]. The approach consists of two parts:

First, for each renewable source within each region, *static cost-resource curves*[7] are developed. For new plant, we determine long-term marginal generation costs. Realisable long-term potentials have been assessed for each type of renewable in each region.

Next, the model develops for each year a *dynamic assessment* of the previously described static cost-resource curves, consisting of:

Dynamic cost assessment: The dynamic adaptation of costs (in particular the investment and the operation and maintenance components) is based on the approach known as "technological learning". Learning rates are assumed by decade for specific technologies.

Dynamic restrictions: To derive realisable potentials for each year of the simulation, dynamic restrictions are applied to the predefined overall long-term potentials. Default figures are derived from an assessment of the historical development of renewables and the barriers they must overcome, which include:

- Market constraints: The penetration of renewables follows an *S-curve* pattern, which is typical of any new commodity.[8] Within the model, a polynomial function has been chosen to describe this impact – representing the market and administrative constraints by region.

[6] The concept of dynamic cost-resource curves in the field of energy policy modelling was originally devised for the research project Green-X, a joint European research project funded by the European Union's fifth Research and Technological Development Framework Programme – for details see www.green-x.at.

[7] Renewable energy sources are characterised by limited resources. Costs rise with increased utilisation, as in the case of wind power. One tool to describe both costs and potentials is the (static) cost-resource curve. It describes the relationship between (categories of) available potentials (wind energy, biomass, hydropower) and the corresponding (full) costs of utilisation of this potential at a given point-of-time.

[8] An S-curve shows relatively modest growth in the early stage of deployment, as the costs of technologies are gradually reduced. As this is achieved, there will be accelerating deployment. This will finally be followed by a slowing-down, corresponding to near saturation of the market.

- Technical barriers: Grid constraints are implemented as annual restrictions which limit the penetration to a certain percentage of the overall realisable potential.

Box 1: Long-term Potential of Renewables

The starting point for deriving future deployment of renewables is the assessment of long-term realisable potentials for each type of renewable and for each world region. The assessment is based on a review of the existing literature and on the refinement of available data. It includes the following steps:

1. The *theoretical* potentials for each region are derived. General physical parameters are taken into account to determine the theoretical upper limit of what can be produced from a particular energy, based on current scientific knowledge.
2. The *technical* potential can be derived from an observation of such boundary conditions as the efficiency of conversion technologies and the available land area to install wind turbines. For most resources, technical potential is a changing factor. With increased research and development, conversion technologies might be improved and the technical potential increased.

Long-term *realisable* potential is the fraction of the overall technical potential that can be actually realised in the long term. To estimate it, overall constraints like technical feasibility, social acceptance, planning requirements and industrial growth are taken into consideration.

By defining financial incentives for the use of renewables and non-financial barriers in each market, as well as technical and societal constraints, the model calculates deployment as well as the resulting investment needs on a yearly base for each renewable source in each region.

5.4.3 Subsidies for renewable energy

Another sub-module was added to the WEM in 2011 to calculate projected subsidies for renewable electricity generators.

The sub-module performs a separate calculation for each renewable technology in each region. It calculates the difference between each technology's LRMC (in $/MWh) and the wholesale price of electricity (in $/MWh) for each year of its economic lifetime, and then multiplies this by the capacity installed. Because the wholesale electricity price changes from one year to the next, the difference between the levelised cost and the wholesale price also changes from year to year.

For example, for onshore wind turbines built in the US in 2011, with an assumed lifetime of 20 years, the sub-module calculates the difference between the LRMC of new onshore wind built in the US in 2011 and the wholesale price in each of the years 2011-2030. Multiplying this difference by the annual volume of generation from onshore wind built in the US in 2011 gives the required support in each of these years for onshore wind capacity built in 2011. Repeating this for the volume of onshore wind built in each year and summing the results gives the total support required for onshore wind in the US over the *Outlook* period. The sub-module then sums these numbers across all technologies and in all regions to give the total support required for renewables globally over the period.

6 Emissions

6.1 CO_2 emissions

As energy-related CO_2 accounts for the lion's share of global greenhouse gas emissions, one of the important outputs of the WEM is region by region CO_2 emissions from fuel combustion. For each WEM region, sector and fuel, CO_2 emissions from fuel combustion are calculated by multiplying energy demand by an implied CO_2 content factor. Implied CO_2 content factors for coal, oil and gas differ between sectors and regions, reflecting the product mix. They have been calculated as an average of the years 2007, 2008 and 2009 from IEA energy-related sectoral approach CO_2 data for all WEM regions and are assumed to remain constant over the projection period.

6.2 SO_2, NO_x, PM emissions

Emissions of major air pollutants resulting from energy scenarios developed for the *WEO-2011* have been estimated in co-operation with the International Institute for Applied Systems Analysis (IIASA). Using the IIASA GAINS model, estimates have been made for the following local air pollutants: SO_2, NO_x and PM (fine particulate matter is particulate matter that is 2.5 microns in diameter and less; it is also known as $PM_{2.5}$ or respirable particles because they penetrate the respiratory system further than larger particles). A detailed report outlining the approach and results is available to review at:
http://www.worldenergyoutlook.org/analysis.asp. Additional information about health impacts and air pollution control costs are also available in that report.

6.3 Carbon-Flow modelling

Since *WEO-2009*, a carbon flow model was integrated in the WEM. The carbon flow sub-model determines the efficient (i.e. least-cost) allocation of abatement across countries. This sub-model has been built in order to inform the 450 Scenario and to take on board more refined data on national costs and the latest analysis of potential barriers and restrictions to international trading of emissions allowances. This enables a clear distinction to be drawn between abatement actions that are undertaken domestically and the potential flows of allowances and credits.

The model draws on economic trade theory applied in the context of climate change (see Ellerman and Decaux, 1998, and, den Elzen and Both 2002). It allows quantification of international emissions offsets and financing under different assumptions, estimating the price of permits, the volume and value of primary market trading and the overall cost of abatement.

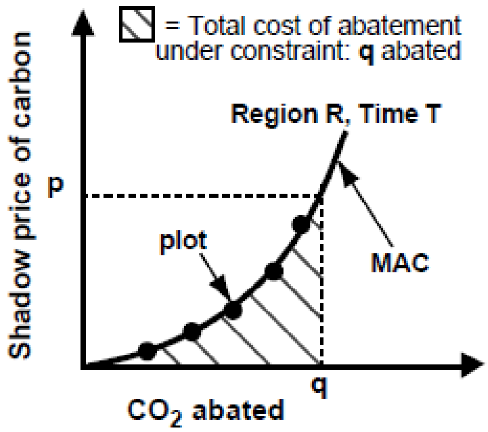
We use marginal abatement cost curves to represent the cost of abating CO_2 emissions in a given sector and/or country (Figure 8). Such a marginal abatement cost (MAC) curves plots the marginal cost of abating CO_2 against the corresponding volume of abatement. It is upward-sloping as the marginal cost rises with the volume of abatement.

The model uses country- and sector-specific marginal abatement curves derived from the WEM. These are summed for all CO_2 prices to build a global abatement curve. The global emissions level in the 450 Scenario determines the international equilibrium price for credits along this supply curve and trade can be determined depending on countries' marginal abatement costs – those whose costs are higher than the market price will purchase credits (Figure 9) from those whose costs are below the market price (Figure 10). Subject to the constraints imposed on the model, such as a requirement to undertake a proportion of abatement domestically, marginal abatement costs are equalised, allowing the global abatement target to be met at minimum cost.

Our analysis adjusts the OECD+ demand for international credits to various configurations of the carbon market, each reflecting different levels of supply from non-OECD countries – depending on eligibility of different types of abatement – and each implying different levels of international funding support through the carbon market.

We calculate the integral below each regional abatement curve to obtain the total abatement cost (shown as the shaded area in Figure 8). The net cost for a given region is then the difference between total abatement cost and the costs of purchasing (positive) or selling the permits (negative) (shown as dashed rectangles in Figure 9 and Figure 10).

Figure 8: Marginal abatement curve



Source: Ellerman and Decaux, 1998

Figure 9: Illustration of a country acting as net buyer of emission credits

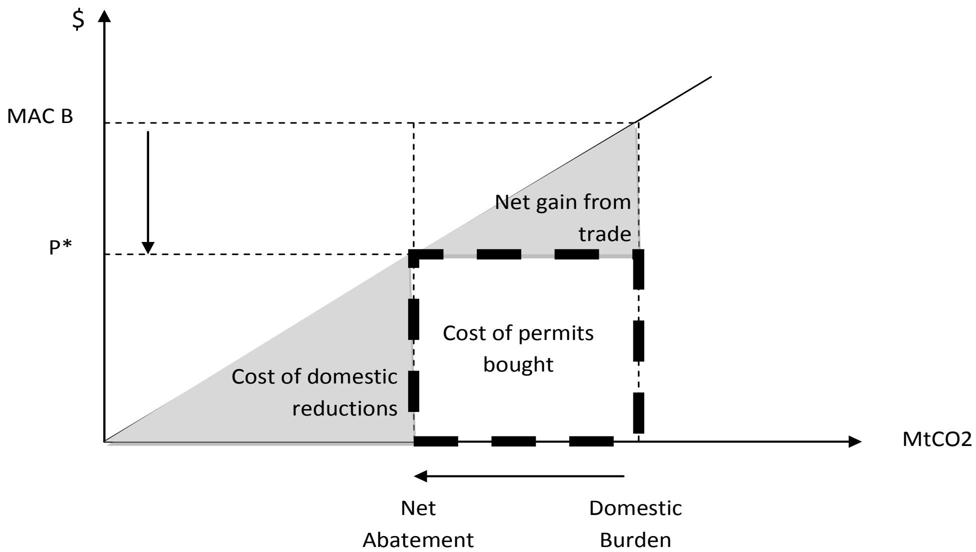
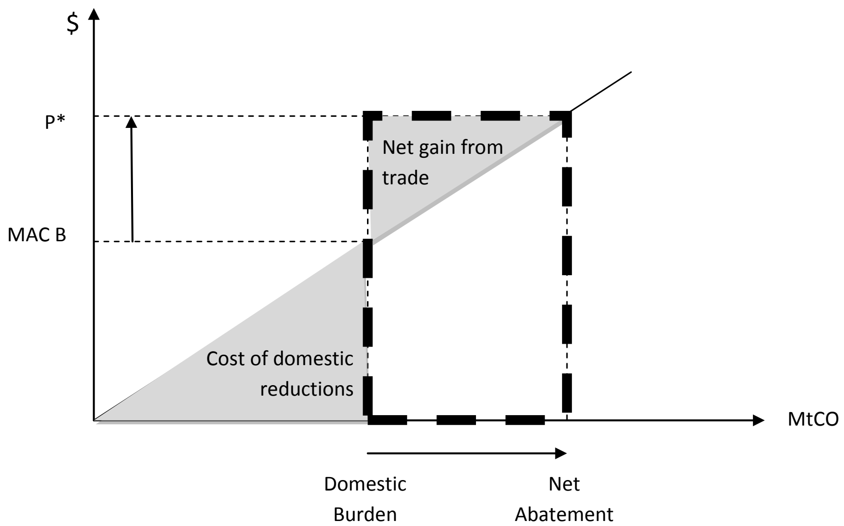


Figure 10: Illustration of a country acting as net seller of emission credits



7 Fossil Fuel Supply - Oil Supply Module

The purpose of this module is to project the level of oil production in each country through a partial bottom-up approach building on:

- the historical series of production by countries;
- standard production profiles and estimates of decline rates at field and country levels derived from the detailed field-by-field analysis undertaken in WEO-2008;
- an extensive survey of upstream projects sanctioned, planned and announced over the short term in both OPEC and Non-OPEC countries, including conventional and non-conventional reserves, as performed by the IEA OMR team; This is used to drive production in the first 5 years of the projection period;
- a new methodology, introduced in WEO-2008 and enhanced in WEO-2010, which aims to replicate as much as possible the decision mode of the industry in developing new reserves by using the criteria of Net Present Value of future cash flows;
- a set of economic assumptions discussed with and validated by the industry including the discount rate used in the economic analysis of potential projects, finding and development costs, and lifting costs;
- an extensive survey of fiscal regimes translating into an estimate of each government's take in the cash flows generated by projects; and
- the values of estimated ultimately recoverable resources calculated with input from IEA databases, USGS, BGR and other sources.

Each country's projected oil production profile is made of six components:

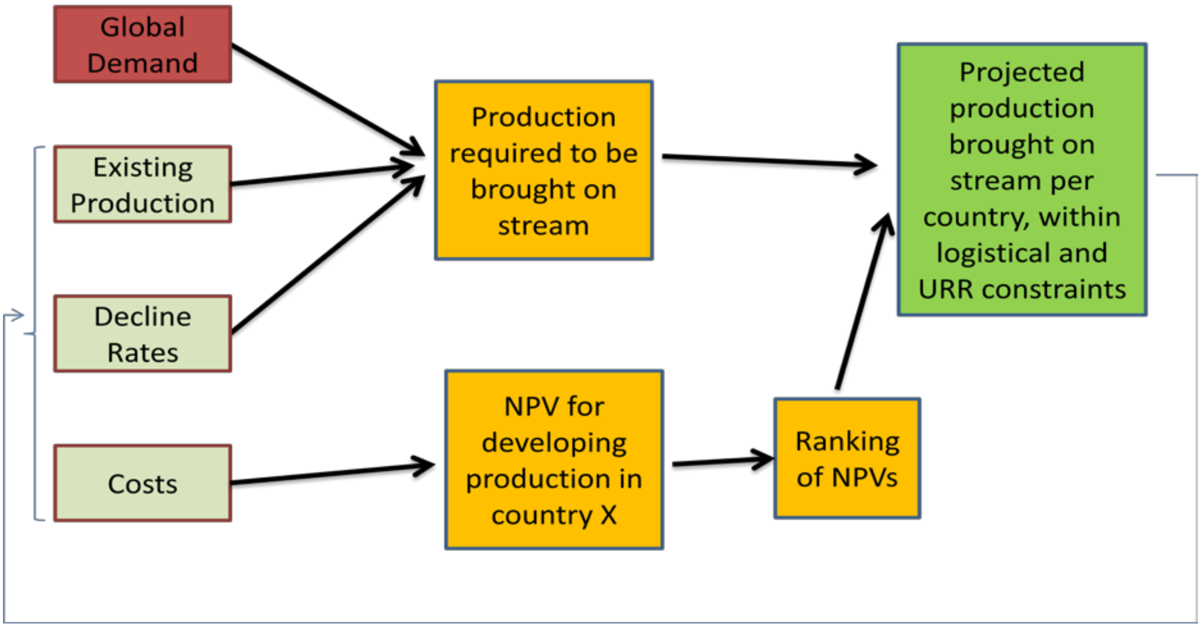
- Production from currently producing fields (year 2010 in WEO-2011): the projected decline rates in each country are derived from the analysis performed for WEO2008;
- Production from discovered fields with sanctioned, planned and announced developments;
- Production from discovered fields awaiting development;
- Production from fields yet to be discovered;
- Production of Natural Gas Liquids; and
- Production on unconventional oil.

Trends in oil production are modelled using a bottom-up methodology, making extensive use of our database of worldwide proven and probable reserves in discovered fields, and country-by-country estimates of ultimately recoverable resources calculated with input from IEA databases, USGS, BGR and other sources. The methodology aims to replicate investment decisions in the oil industry by analysing the profitability of developing reserves at the project level (Figure 10).

In the model, production in each country or group of countries is separately derived, according to the type of asset in which investments are made: existing fields, new fields and non-conventional projects. Standard production profiles are applied to derive the production trend for existing fields and for those new fields (by country and type of field) which are brought into production over the projection period.

The profitability of each type of project is based on assumptions about the capital and operating costs of different types of projects, and the discount rate, representing the cost of capital. The net present value of the cash flows of each type of project is derived from a standard production profile. Projects are prioritised by their net present value and the most potentially profitable projects are developed. Constraints on how fast can projects be developed and how fast production can grow in a given country are also applied. These are derived from historical data and industry inputs.

Figure 11: Structure of the Oil Supply Module



8 Fossil Fuel Supply - Gas Supply Module

The gas production and trade projections in the *WEM* are derived from a hybrid model involving bottom-up and top-down approaches. The model has similar inputs, logic and functionality as the oil supply model described above. However, contrary to oil which is assumed to be freely traded globally, gas is assumed to be primarily regionally traded, with inter-regional trade constrained by existing or planned pipelines, long –term contracts and LNG plants. So the model is first run for a small number of regional blocks. Indigenous production is first modelled for each block, on the basis of ultimate recoverable resources and depletion rates, taking account production costs and prices in the region. Subtracting domestic production from demand, in aggregate for each importing regional block, yields gas import requirements. For each net gas-exporting regional block, aggregate production is determined by the level of domestic demand and the call on that region's exportable production (which is determined by the import needs of the net importing regions and supply costs). This provides an inter-block gas trade matrix.

Production within each regional block is then allocated to individual countries according to ultimately recoverable resources, depletion rates and relative supply costs, with a logic similar to that of the oil model, but with "demand" being provided by the block production derived at the previous step. New features in WEO-2011 for oil and gas modules

Apart from updating all key parameters with the latest data, the main updates to the oil and gas supply models implemented for WEO2011 have been:

- Split of Russia into main hydrocarbon basins
- Update of shale gas resources and future production to reflect recent changes.
- Implementation of a methodology to impose a cap on upstream investment in some regions (functionality used for the Deferred Investment Case described in chapter 3)

9 Fossil Fuel Supply - Coal Supply Module

The coal module is a combination of a resources approach and an assessment of the development of domestic and international markets, based on the international coal price. Production, imports and exports are based on coal demand projections and historical data, on a country basis. Three markets are considered: coking coal, steam coal and brown coal. World coal trade, principally constituted of coking coal and steam coal, is separately modelled for the two markets and balanced on an annual basis.

10 Investment

10.1 Investment in the Energy Supply Chains

The estimates of supply-side investment requirements in *WEO-2011* cover the period 2011-2035 and are derived from the projections of energy supply and demand of the three Scenarios. The quantification of capital requirements, notably the compilation of unit capital cost estimates and capacity needs for each fuel, component and region, involved compiling and processing large quantities of data. A significant contribution to this work has been made by a number of organisations in the energy sector and in the financial community. The component cost and capacity estimates may prove to have as much value as the final investment numbers.

The calculation of the investment requirements for power generation and coal supply involved the following steps for each region:

- New capacity needs for production, transportation and (where appropriate) transformation were calculated on the basis of projected supply trends, estimated rates of retirement of the existing supply infrastructure and decline rates for oil and gas production.
- Unit capital cost estimates were compiled for each component in the supply chain. These costs were then adjusted for each year of the projection period using projected rates of change based on a detailed analysis of the potential for technology-driven cost reductions and on country-specific factors.
- Incremental capacity needs were multiplied by unit costs to yield the amount of investment needed.

The results are presented by decade in year-2010 dollars. The estimates of investment in the current decade take account of projects that have already been decided and expenditures that have already been incurred. The convention of attributing capital expenditures to the year in which the plant in question becomes operational has been adopted (i.e. overnight costs). In other words, no attempt has been made to estimate the lead times for each category of project. This is because of the difficulties in estimating lead times and how they might evolve in the future.

For the purposes of this study, investment is defined as capital expenditure only. It does not include spending that is usually classified as operation and maintenance.

10.2 Short-term Oil and Gas Investment

Our projections of upstream investment are based on a combination of bottom-up and top-down approaches. The former involves a detailed analysis of the plans and prospects for oil and gas industry investment over the period 2011 to 2015, with the aim of determining whether the industry is planning to invest more in response to higher prices and to a growing need for new capacity and of assessing the resulting additions to production capacity. This analysis is based on a survey of the capital-spending programmes of 70 of the largest upstream oil and gas companies (national and international companies and pure exploration and production companies), covering actual capital spending from 2000 to 2011 and their plans or forecasts of spending through to 2015 when available. Companies were selected on the basis of their size as measured by their production and reserves, though geographical spread and data availability also played a role. The surveyed companies account for close to 80% of world oil production and 79% of oil reserves, 66% of gas production and 71% of gas reserves. Total industry investment was calculated by adjusting upwards the spending of the 70 companies, according to their share of world oil and gas production for each year.

Data was obtained from companies' annual and financial reports, corporate presentations, press reports, trade publications and direct contacts in the industry.

10.3 Long-term Oil and Gas Investment

The estimates of oil supply-side investments requirements in *WEO-2011* are derived from the Oil Supply and Gas Supply Models. The methodology establishes a direct link over time between new production brought on stream, the cash flow generated and the investments required. The cost of each project is estimated from a set of variables: size of the reserves, degree of depletion, location type of resource and project (conventional crude, oil sands, extra-heavy oil, GTL, CTL), and underlying assumptions on cost inflation (itself a function of oil prices) and technology learning.

11 Demand-Side Investments

Relative to the Current Policies and New Policies Scenario, for the 450 Scenario, the WEM incorporates an economic analysis of the net change in investment by energy suppliers and energy consumers; the net change in energy import bills and export revenues; and how the cost to consumers of investing in more energy-efficient equipment compares with the savings they make through lower expenditure on energy bills. Demand-side investments are consumers' outlays for the purchase of durable goods, that is, end-use equipment. Increases in demand-side investments are thus increases in cash outlays on durable goods. All investments and consumers' savings in energy bills are expressed in year-2009 dollars. Consumers' outlays are attributed to the year in which the equipment is purchased, but their savings are spread over a number of years. An analysis of the policies under consideration, combined with the modelling of their impact on final energy demand, leads to a reduction in demand in the 450 Scenario versus the Current Policies and New Policies Scenarios. More capital investment is needed to move to more efficient energy using equipment.

For the 25 WEM regions and for five sectors, the capital needs to move to greater efficiency levels have been analysed. The analysis takes into account the level of efficiency in the Reference Scenario, the policy-driven demand reductions in the 450 Scenario, the costs of more efficient equipment, the useful lifetime of equipment and ownership levels.

The five sectors are:

- Transport
- Electrical appliances in residential and services sectors
- Fuel burning equipment in residential and services sectors
- Electrical equipment in industrial sectors
- Fuel burning equipment in industrial sectors

To account for the different structure and development stage of each world region, we engaged in several partnerships and made use of various data sources. The estimates of capital costs for end-use technology used in this analysis are based on the results of work carried out in co-operation with a number of organisations, including the UNEP Risoe Centre on Energy, Climate and Sustainable Development, the European Environment Agency, Centro Clima at COPPE/UFRJ, the Indian Institute of Management and the Energy Research Institute in China.

The estimates of capital costs also benefitted from collaboration with the Argonne Laboratory in the United States (Hanson and Laitner, 2006). Argonne Laboratory's AMIGA model calculates the additional capital needed for many types of energy-using equipment to move to less energy consumption. A number of independent sources were used for consistency-checking. Given the variability in the quality of many of the specific regional and sectoral data used, there are many uncertainties surrounding these estimates.

Due to the large share of transport in additional oil demand over the *Outlook* period, we further expanded the analysis for road transport. Based on the efficiency improvements needed, the best technological options were assessed and priced. The investment needs for the transport sector were determined by linking this information with the stock model of the WEM transport demand module. Detailed figures from Airbus/Boeing were used to assess the need for new planes and the increased capital cost of increasing efficiency in the aviation sector.

Outputs include the additional annual capital needs for the 25 regions and five sectors. The impact of the energy savings on consumers' bills is analysed. The sectoral end-user prices (including taxes) have been used to assess the overall impact of the policies on consumers over time. The results also include the impact on main importing countries.

12 Energy and Development

The **World Energy Outlook** has for many years devoted attention to the energy and development issue, developing a series of databases and publishing quantitative analysis. The latest contribution to the debate is the special early excerpt of the 2011 *World Energy Outlook*, entitled "Energy for All: financing access for the poor" released in October 2011. The report tackles the critical issue of financing the delivery of universal modern energy access.

This document explains in detail the methodology used to derive the quantitative analysis presented in the report as well as the methodology underpinning the supplementary energy and development material available at the website: http://www.worldenergyoutlook.org/development.asp

This note is structured as follows:

1. Electricity access
    a. Database
    b. Outlook under the New Policies Scenario
2. Reliance on traditional use of biomass
    a. Database
    b. Outlook under the New Policies Scenario
3. The Energy for All Case:
    a. Achieving universal electricity access
    b. Achieving universal access to clean cooking facilities
4. The Energy Development Index

12.1 Electricity Access: database and outlook under the New Policies Scenario

12.1.1 Electricity access database

The electricity access database shows detailed data on urban and rural electrification collected from industry, national surveys and international sources. The database was updated with the latest information for *WEO-2011* to provide the best available picture of access to electricity services by region and country. The major revision since electricity access database was published last year occurs in India.

There is no single internationally-accepted definition for electricity access. The definition used in this analysis covers electricity access at the household level, that is, the number of people who have electricity in their home. It comprises electricity sold commercially, both on-grid and off-grid. It also includes self-generated electricity for those countries where access to electricity has been assessed through surveys by government or government agencies. The data does not capture unauthorised connections. The national, urban and rural electrification rates shown indicate the number of people with electricity access as a percentage of the total population.

The analysis is a combination of desktop research and information from workshops in the area of rural development and energy poverty. If available, international statistical surveys or census data has been used in order to ensure maximum consistency and uniform methodology. In situations where country data was unavailable from international statistical sources, data has been derived from national websites, governmental bodies, the energy sector and other reports. If electricity access data was unavailable for 2009, data for the last available year before that was used. Data has been validated through consistency-checking amongst different data sources and expert judgements.

Using the electrification rate data collected, estimates of the number of people without electricity access, as well as the urban and rural breakdown, are determined based on population estimates from OECD statistics in conjunction with the United Nations Population Division report, *World Urbanization Prospects: The 2009 Revision Population Database.* Electricity access data was adjusted to be consistent with demographic patterns of urban and rural population.

Due to differences in definitions and methodology from different sources, data quality may vary from country to country. Where country data appeared contradictory, outdated or unreliable, the IEA Secretariat made estimates based on cross-country comparisons and earlier surveys.

12.1.2 Outlook for electricity access under the New Policies Scenario

The electricity access database provides invaluable information about the current electrification rates in all countries. In order to provide an outlook for electricity access in the next decades, a model able to generate projection of electrification rates by regions has been developed under the New Policies Scenario assumptions.

The projections are based on an econometric panel model that regress electrification rates of different countries over many variables, to test their level of significance. Variables that were determined statistically significant and consequently included in the equations are:

- per capita income
- demographic growth
- urbanisation level
- fuel prices
- level of subsidies to electricity consumption
- technological advances
- electricity consumption
- electrification programmes

The model was developed using the same economical and demographical assumptions as that in the New Policies Scenario. This scenario takes account of the broad policy commitments and plans that have been announced by countries around the world, to tackle either environmental or energy-security concerns as well as plans to phase out fossil-energy subsidies. However, we assume that no additional policies to expand energy access, over and above those in place today, are enacted over the projection period.

12.2 Reliance on traditional use of biomass: database and outlook under the New Policies Scenario

12.2.1 Reliance on traditional use of biomass database

The database showing reliance on the traditional use of biomass is based on survey and national data sources, and refers to those households where biomass is the primary fuel for cooking. We define the term "biomass" broadly to cover the various resources like wood, charcoal, tree leaves, crop residues and animal dung. The traditional use of biomass refers to the basic technology used, such as a three-stone fire, traditional mud stoves or metal, cement and pottery or brick stoves, with no operating chimneys or hoods. As a consequence of the pollutants emitted by these inefficient devices, pollution levels inside households cooking with biomass are often many times higher than typical outdoor levels, leading to more than 1.45 million premature death each year according to the World Health Organization.

The database on reliance on the traditional use of biomass combines information on percentage of people using biomass as primary fuel for cooking with country data on level of consumption of biomass by type. The latest update was for *WEO-2011* to provide the best available picture of population reliant on the traditional use of biomass for cooking by region and country.

12.2.2 Outlook for the reliance on biomass under the New Policies Scenario

In order to provide an outlook for the number of people relying on the traditional use of biomass in the next decades, a regional model was developed under the New Policies Scenario assumptions. As for the electrification rates model, the projections are based on an econometric panel model that regress reliance on biomass rates of different countries over many variables, to assess their level of significance. Variables that were determined statistically significant and consequently included in the equations are:

- per capita income
- demographic growth
- urbanisation level
- level of prices of alternative modern fuels
- level of subsidies to alternative modern fuel consumption
- technological advances
- programmes

As for the electrification model, we assume that there are no additional policies implemented to reduce reliance of households on traditional biomass for cooking, over and above those in place today.

12.3 The Energy for All Case

The outlook for energy access under the New Policies Scenario shows that worldwide the electrification rate in 2030 will not reach 100% and the number of people relying on the traditional use of biomass will rise to 2.7 billion. To illustrate what would be required to achieve universal access to modern energy services, we have developed the Energy for All Case (Referred to in *WEO-2010* as the Universal Modern Energy Access Case.

This case quantifies the number of people that need to be provided access to modern energy services and the scale of the investments required by 2030 in order to achieve universal access to modern energy services. For our analysis, we define modern energy access as *"a household having reliable and affordable access to clean cooking facilities, a first connection to electricity and then an increasing level of electricity consumption over time to reach the regional average".* Access to electricity involves more than a first supply connection to the household; our definition of access also involves consumption of a specified minimum level of electricity, the amount varies based on whether the household is in a rural or an urban area. This definition of energy access also includes provision of cooking facilities which can be used without harm to the health of those in the household and which are more environmentally sustainable and energy efficient than the average biomass cookstoves currently used in developing countries. This definition refers primarily to biogas systems, liquefied petroleum gas (LPG) stoves and advanced biomass cookstoves that have considerably lower emissions and higher efficiencies than traditional three-stone fires for cooking.

The Energy for All Case also includes interim targets to 2015, adopted to be consistent with the achievement of the first Millennium Development Goal - eradicating extreme poverty. We interpret this, in this context, as meaning that no more than one billion people should be without access to electricity by that date and no more than 1.7 billion should still be using traditional biomass for cooking on open fires or primitive stoves (see Table 3). The relationship between poverty and modern energy access has been derived from a cross-country analysis covering 100 countries and the projections are based on regression analyses, which are applied to each region.

Table 3: Targets in the Energy for All Case

	2015		2030	
	Rural	Urban	Rural	Urban
Access to electricity	Provide 257 million people with electricity access	100% access to grid	100% access, of which 30% connected to the grid and 70% either mini-grid (75%) or off-grid (25%)	100% access to grid
Access to clean cooking facilities	Provide 800 million people with access to LPG stoves (30%), biogas systems (15%) or advanced biomass cookstoves (55%)	Provide 200 million people with access to LPG stoves	100% access to LPG stoves (30%), biogas systems (15%) or advanced biomass cookstoves (55%)	100% access to LPG stoves

The targets presented in the table above uses Liquefied petroleum gas (LPG) stoves as a proxy for modern cooking stoves (including kerosene, biofuels, gas and electric stoves). Advanced biomass cookstoves are biomass gasifier-operated cooking stoves which run on solid biomass, such as wood chips and briquettes. Biogas systems include biogas-fired stoves.

The Energy for All case thus has two sub-models, one for universal electricity access and one for universal access to clean cooking facilities, presented separately below.

12.3.1 Achieving universal electricity access

The Energy for All Case is based on the assumption that new policies are introduced that result in a progressive increase in electrification rates to 100% of the world's population by 2030. Achieving universal access to electricity by 2030 would result in higher global energy demand than projected in the New Policies Scenario. It would also have implications for energy investment and for energy-related CO_2 emissions. The Energy for All Case seeks to quantify these increments and is calculated in four main steps.

1. Determine the additional number of people gaining access to electricity every year to reach universal electrification in 2030

The number of people gaining access over time is estimated by the outlook for the electricity access under the New Policies Scenario. In order to reach 100% electrification by 2030, the Energy for All Case projects an exponential addition of people gaining access over time. This exponential distribution was chosen to be consistent with the system for building electricity network extensions and results in quantifying the annual additional people by region gaining access to electricity compared to the New Policies Scenario projection.

2. Calculate the consumption patterns over time of the new connected and thus the power generation needs

The Energy for All Case assumes a basic consumption for each person gaining access, as well as its evolution over time, in order to estimate the additional demand compared to the New Policies Scenario projection and needed to achieve the universal electrification by 2030. It is assumed that each person gaining access is at first going to use electricity only as a substitute for the traditional fuels used to cover basic needs (e.g. candles, liquefied petroleum gas [LPG], kerosene). To assess the extent of the additional generating capacity required to achieve universal access, we have made assumptions about minimum levels of consumption at both the rural and urban level: rural households are assumed to consume at least 250 kWh per year and urban households 500 kWh per year. In rural areas, this level of consumption could, for example, provide for the use of a floor fan, a mobile telephone and two compact fluorescent light bulbs for about five hours per day. In urban areas, consumption might also include an efficient refrigerator, a second mobile telephone per household and another appliance, such as a small television or a computer. This higher consumption in urban areas reflects specific urban consumption patterns. This assumes that the consumption per capita of an individual catches up the average consumption of their region over time. On average, consumption level of each newly connected person reaches the regional average after 10 years, but although the starting consumption is the same across regions, there is a regional difference in the "catching-up" process, depending on the average consumption of each region under the New Policy Scenario and the rural and urban disparity**.**

Once the new level of demand is determined, and therefore the generation needs are estimated, the Energy for All Case assumes a breakdown by power generation options. The generation options have been chosen according to the 100% electrification target in 2030. The Energy for All Case, as a global plan, sets the most cost-efficient and likeliest picture for 2030 and defines generation addition patterns accordingly.

For urban-area electricity demand, the less costly choice is electricity grid extension, thus the model assumes that generation in urban areas is made entirely through grid options. In rural areas, options to increase electrification include extension of existing grids, creation of mini-grids and isolated off-grid generation. That part of the rural area – around one-third of total rural demand – closest to urban areas and/or likely to become more densely populated by 2030 is also projected to be supplied through the grid, as this will be the most economic option. The remaining rural generation is off-grid, divided between mini-grids and isolated off-grid generation, including PV, mini-hydro, biomass, wind, diesel and geothermal. Mini-grids, defined as village- and district-level networks with loads of up to 500 kW, will constitute the bulk of off-grid generation, while isolated off-grid options will provide electricity to the remotest populations.

3. Quantify the investment costs and distribution and transmission costs

To evaluate the cost associated with generation, the Energy for All case feeds the added required generation to 2030 into the power generation module of the *WEM* and the transmission and distribution model of the New Policies Scenario (see Chapter 5: Power and Renewables Outlook). Costs for off-grid generation are adjusted on the base of available costs for the various options (mini-grid and isolated off-grid) by region and country. Consumer density is a key variable in providing electricity access: the cost per MWh delivered through an established grid is cheaper than that through mini-grids or off-grid systems, but the cost of extending the grid to sparsely populated areas can be very high and long distance transmission systems have additional system losses.

4. Calculate the implication of the additional electricity generation on energy-related CO_2 emissions

The Energy for All case quantifies the additional electricity generation needed to have 100% electrification rate by 2030. Generating this additional power would have an impact on energy-related CO_2 emissions. The model assume that the electricity is generated using the fuel mix set out in the New Policies Scenario for the country or region in question. Additional CO_2 emissions are then calculated using the country specific CO_2 content of the power generation. Finally, this calculation is repeated assuming that the generation fuel mix to supply the additional demand were that of the 450 Scenario.

12.3.2 Achieving universal access to clean cooking facilities

In the New Policies Scenario, 2.7 billion people in 2030 rely on the traditional use of biomass as primary source for cooking, with serious consequences for their health. The Energy for All case shows a possible path towards the progressive penetration in the next two decades of clean cooking facilities (clean cooking fuels and stoves, advanced biomass cookstoves and biogas systems) until universal access is achieved in 2030.

LPG stoves are more likely to penetrate in urban zones, where infrastructure, distribution and fuel costs can benefit from economy scale and consumers have relatively higher ability to pay. Thus LPG stoves are assumed to provide clean cooking services for all urban zones still relying on the traditional use of biomass but for only 30% of rural households. The large majority of rural households (55%) are assumed to be provided with advanced biomass cookstoves, and the remaining 15% with biogas digester. Those global targets are then reflected in regional allocations of the various options (LPG, biomass cookstoves and biogas systems) that are derived from assumptions regarding the most likely technology solution in each region, given resource availability and government policies and measures.

Once determined the number of people by country -with rural/urban split- that need to be provided with each clean cooking facility option, investment are calculated on the base of unit costs of the devices. Advanced biomass cookstoves, with emissions and efficiencies similar to those of LPG stoves, are assumed to cost $50. The assumed cost of an average-sized biogas digester varies by region. Based on 2010 data provided by SNV, the Netherlands Development Organisation, the cost is $437 for India, $473 in China, $660 in Indonesia, $526 in other developing Asia, $702 in Latin America and $924 in sub-Saharan Africa. An LPG stove and canister is assumed to cost $60. Infrastructure, distribution and fuel costs are not included in the investment costs. We assume one stove or biogas system per household over the projection period, thus replacement costs are not included.

Expanding household access to modern fuels would inevitably increase global demand for these fuels, notably oil. Using World Heath Organisation (WHO) data for developing country households currently using LPG, we have estimated an average LPG consumption of 22 kg per person per year. The additional oil demand associated with access to LPG in the Energy for All Case is calculated based on the average per capita consumption (converted into mb/d of LPG) and the estimated number of people who switch to LPG stoves by 2030.

The impact on greenhouse-gas emissions of switching to advanced biomass technologies or LPG is very difficult to quantify because of the diversity of factors involved, including the particular fuels, the types of stoves and whether the biomass used is replaced by new planting and that a sustainable forestry management programme is in place. But it is widely accepted that improved stoves and greater conversion efficiency would result in emissions reductions

12.4 The 2011 Energy Development Index

The IEA has devised an Energy Development Index (EDI) in order to better understand the role that energy plays in human development. The index, which first appeared in *WEO-2004*, has been updated and modified to better track progress in a country's or region's transition to the use of modern fuels. The 2011 EDI is calculated in such a way as to mirror the UNDP's Human Development Index and is composed of four indicators, each of which captures a specific aspect of potential energy poverty:

- *Per capita commercial energy consumption*: which serves as an indicator of the overall economic development of a country.
- *Per capita electricity consumption in the residential sector*: which serves as an indicator of the reliability of, and consumer's ability to pay for, electricity services.
- *Share of modern fuels in total residential sector energy use*: which serves as an indicator of the level of access to clean cooking facilities.
- *Share of population with access to electricity*.

The choice of indicators is constrained by the type of data related to energy poverty that is currently available. For example, the per-capita commercial energy consumption figure is one indicator of overall economic development of a country but for reasons of data deficiency it fails to take account of biomass resources, including wood, charcoal and biofuels, which are used for productive activities in developing countries. Biomass data is seldom disaggregated in a sufficient manner to capture this reality. With the introduction of low-emission, high-efficiency stoves, biomass consumption will decline in many countries. Yet the EDI cannot adequately compensate for the fact that this decline will be slower than in those countries where households switch to liquid fuels for cooking, even though the impact on energy poverty could be similar. The countries included in the EDI are those for which IEA collects energy data.

A separate index is created for each indicator, using the actual maximum and minimum values for the developing countries covered (see Table 4 for the 2011 EDI minimum and maximum values).

Table 4: The minimum and maximum values used in the calculation of the 2011 Energy Development Index

Indicator	Minimum value (country)	Maximum value (country)
Per capita commercial energy consumption (toe)	0.03 (Eritrea)	2.88 (Libya)
Per capita electricity consumption in the residential sector (toe)	0.001 (Haiti)	0.08 (Venezuela)
Share of modern fuels in total residential sector energy use (%)	1.4 (Ethiopia)	100 (Yemen, Lebanon, Syria, Iran)
Share of population with access to electricity (%)	11.1 (Dem. Rep. of Congo)	100 (Jordan, Lebanon)

Performance in each indicator is expressed as a value between 0 and 1, calculated using the formula below, and the EDI is then calculated as the arithmetic mean of the four values for each country.

$$\text{Indicator} = \frac{\text{actual value-minimum value}}{\text{maximum value} - \text{minimum value}}$$

By publishing updates of the EDI on an annual basis the IEA hopes to raise the international community's awareness of energy poverty issues and to assist countries to monitor their progress towards modern energy access

Annex 1: Previous Features to the *WEM*

The *WEM* underwent a significant transformation for the *WEO-2002*, extending the time horizon to 2030. The model was further extended for the *WEO-2004*, including – among other developments – twenty regional models, more detailed sub-models for industry, transport, residential and services sectors in the major non-OECD countries, a new renewable energy model, a separate CHP model and a new coal production model. The model for the 2005 *Outlook* was further expanded to include nine country models: Algeria, Egypt, Iran, Iraq, Kuwait, Libya, Qatar, Saudi Arabia and UAE, and two new regional aggregates, other Middle East and other North Africa, to cover the entire Middle East and North Africa (MENA) region. Other important additions included: an oil and gas field-by-field production analysis for the key countries in the MENA region; a water desalination module to project energy demand for desalination in the Saudi Arabia, Qatar, the UAE, Kuwait, Algeria and Libya; and a global refinery model to project product demand and capacity additions to 2030.

For WEO-2006

The *WEO-2006* saw significant expansion to the *WEM* with the following new features added:

- Greater regional disaggregation, with the development of new, separate models for Canada, Japan, Korea, North Africa and the United States.
- More detailed sectoral representation of end-use sectors for non-OECD countries, including aviation and detailed transport-stock models.
- Detailed analysis of the use of cooking fuels in developing countries.
- More sophisticated treatment of biofuels use and supply, and of renewables for heating in end-use sectors.
- An updated analysis of power-generation capital and operating costs, including a more detailed assessment of nuclear power and renewable energy technologies.
- Calibration of the oil and gas production and oil-refining models to the results of a detailed analysis of the near-term prospects for investment.

For WEO-2007

WEO-2007 saw numerous modelling improvements, notably the integration of a general equilibrium model (GEM), the addition of a new High Growth Scenario, an expansion of the China model to allow deeper analysis of the coastal region, and an investigation into what would be required in the energy sector to reach a global CO_2 concentration stabilisation of 450 ppm:

- The WEM was integrated with a GEM, for more information see http://www.worldenergyoutlook.org/docs/weo2007/WEM-ECO_Description.pdf
- High Growth Scenario
- Chinese Coastal model
- 450 Stabilisation Case
- Expanded and improved global natural gas trade model.
- SO_2, NO_x and PM local emissions model.
- Improved electrification modelling and an energy development index to access the links between energy and poverty
- Urban/rural modelling in India

The High Growth Scenario. The Reference Scenario projections are based on what some might consider conservative assumptions about economic growth in China and India. They envisage a progressive and marked slow-down in the rate of growth of output over the projection period in both countries. To shed light on the global impact of faster than expected economic growth in China and India, we have developed a High Growth Scenario. The starting point of this analysis is the assumption that GDP growth in both countries is on average 1.5 percentage points per year higher than in the Reference Scenario. This results in an average growth rate to 2030 of 7.5% for China and 7.8% for India. For China, we assume that the main driver of growth in this scenario is sustained high investment and continued rapid productivity gains, as the government pushes ahead with reforms to increase the role of the private sector and to open up the economy to foreign investment. For India, we assume an acceleration and deepening of structural and institutional reforms, combined with faster infrastructure development.

The China Coastal Model. The *WEO-2007* includes a special analysis of current and future energy trends in the coastal region of China. The detailed model of the coastal region was built with an extensive effort to collect energy, economic and demographic data. Comprehensive energy balances by fuel and by sector were compiled for each of the 11 municipalities and provinces comprising the coastal region of China. The data cover the period 1996 to 2005 and are based on the China Energy Statistical Yearbook and the provincial statistical yearbooks, published by the National Bureau of Statistics. Following the IEA methodology of compiling non-member countries' energy balances, the 11 provincial energy balances were integrated into one single regional balance, from which full sector-by-sector projections were made through to 2030. This exercise was undertaken for the first time in 2007.

The 450 Stabilisation Case. For the *WEO-2007* we included a new case, corresponding to stabilising the greenhouse-gas concentration in the range of 445-490 ppm of CO_2-equivalent – the most ambitious of the IPCC's scenarios. In response to requests from policy makers, we describe one possible pathway – which we have called the 450 Stabilisation Case – to achieving this very ambitious target in order to illustrate the magnitude and urgency of the challenge of transforming the global energy system over the projection period. We have not used the WEM, the modelling tools used to prepare the Reference, Alternative Policy and High Growth Scenario projections. Rather, a backcasting methodology has been used, which involved identifying a combination of technological changes that would allow the target to be met, based on the expected availability of end-use and power-generation technology options and estimates of potential efficiency gains by sector. In the 450 Stabilisation Case, cleaner and more advanced technologies are deployed more quickly than in the Alternative Policy Scenario. In addition, technologies that are not yet financially viable, including carbon capture and storage and second-generation biofuels technologies, are assumed to be widely deployed.

Urban and rural household energy demand projections. The energy demand model for the residential sector in India was expanded for *WEO-2007* in order to evaluate rural/urban differences. A new database was created, with the rural/urban breakdown of energy demand, based on historical data from India's National Sample Survey Organisation (NSSO). As a result of our bottom-up analysis, estimated aggregate biomass use in the residential sector was revised downwards. Energy consumption for both rural and urban areas was calculated econometrically for each fuel as a function of GDP per capita, the urbanisation rate, the related fuel price and past consumption levels. The residential sector module covers five end uses by fuel and area: space heating, water heating, cooking, lighting and appliance use. Fuel demand is projected per household. Total demand for household consumption is derived from two components. An "existing stock" component bases energy consumption on historical shares for each fuel, while a portion of demand is allocated to "new stock", where fuel shares are a function both of relative prices and of existing shares of each fuel.

For WEO-2008

The following new features were added:

- The demand module for all regions was completely rebuilt, involving re-estimating parameters using more recent time-series data and introducing more detailed coverage of demand by sector and fuel. The power generation model now includes more detailed representation of coal-fired technologies, inclusion of carbon dioxide capture and storage and endogenous modelling of nuclear power
- The oil and gas production and trade models were expanded to take better account of economic variables and to reflect the recent surge in cost inflation and the fall in the value of the dollar against most other currencies.
- Oilfield decline rates were analysed in detail on a field-by-field basis in order to assess the prospects for future decline rates. Read more at: http://www.worldenergyoutlook.org/docs/weo2008/chapter10.pdf

- The WEM energy-related CO_2 emissions were combined with greenhouse gas emissions from all sources to explain the relationship between the level of annual emissions and the long-term concentration of greenhouse gases in the atmosphere, which will determine the increase in the future global average temperature.
- How overall emissions limitation levels would translate back into an atmospheric concentration of CO_2-equivalent gases and what means might be used to achieve stabilisation of that concentration. Energy and emissions are modelled in two scenarios: the 550 Policy Scenario, in which greenhouse-gas concentration is stabilised at 550 parts per million of CO_2-eq, and a 450 Policy Scenario, in which concentration are limited to 450 ppm CO_2-eq.
- Biofuels demand was modelled in more detail, taking account of technical and economic factors.
- Power-generation capital and operating costs were assessed in detail and the cost assumptions in the WEM were revised to take account of recent cost inflation.
- In addition, the integration of the *WEM* into a general equilibrium model, started in 2007, was taken a step further, in order to model more precisely the feedback links between energy markets and the macro-economy.
- A model for oil and gas revenue has been established for the top 10 resource-rich Sub-Saharan African countries. The revenue model was split into an oil revenue module and a gas revenue module. The revenue estimates are derived from the net exports of oil and gas which in turn depends on the projections of each country's oil and gas demand and production. The projections of each country's energy demand are based on many factors, including incomes, urbanisation levels, population, fuel prices and technological advances. The model estimates oil and gas revenue for each of the top 10 resource-rich Sub-Saharan African countries (in 2007 US dollars) over the projection period based on the oil and gas net exports, projections for oil and gas prices in the Outlook period and the share of government take for oil and gas revenue.

For WEO-2009

- Power-generation and gas-supply modules have been completely overhauled.
- The transport and carbon-flow models have been enhanced.
- A new water desalination/power module has been incorporated for the Middle East and North Africa.
- There are now 24 WEM regions (see Annex 2) compared to 21 WEM regions that were in place for *WEO-2008*. Furthermore for the purposes of the special focus on the ASEAN region included in the *WEO-2009*, country-level models for Malaysia, Philippines and Thailand were also developed.

For WEO-2010

In addition to the Current Policies Scenario (formerly the Reference Scenario) and the 450 Scenario previously modelled, we presented for the first time in *WEO-2010* a New Policies Scenario. This new scenario examines a pathway resulting from the uptake of new measures to implement announced policy commitments in addition to current enacted government policies. The projection period for all scenarios has been extended to 2035. Comprehensive historical data to 2008 feeds into the model as inputs but, in many cases, preliminary data are available for 2009 and these have been incorporated where possible.

The following changes were made to WEM for the purposes of the *WEO-2010*:

- Update and enhancement of subsidies data for the year 2008 and 2009
- Update of the policies and measures database (on-going)
- Improved price formula and elasticities to international prices, enabling strengthened price sensitivity analysis
- Development of new heat price formulation
- Greater granularity of CO_2 price/tax for each country/sector
- In addition to the 24 WEM regions modelled, for the special focus on the Caspian region, country-level models for Azerbaijan, Kazakhstan, Turkmenistan and Uzbekistan were also developed.
- Power generation:

- Development of a global renewable model to calculate global learning by technology. Supply curves have been produced for 16 renewable technologies in each WEM region.
- Endogenous estimates of subsidies to renewables are computed within the renewables module (including the capability to model between premiums or feed-in tariffs by technology and country). The impact of renewable subsidies on end-use electricity prices can be now calculated.
- Nuclear module has been updated with the capability to extend plant lifetimes by plant technology, country or plant by plant. Similarly the capability for plant uprates has been incorporated. Investment costs, including lifetime extension and uprates may now be determined.
- CHP plants may now be divided into a must-run component (driven by heat load) and an additional dispatchable component competing alongside the other thermal electricity only plants. Revised methodology allows for improved allocation of CHP fuel inputs to provide a better estimate of CO_2 intensity for electricity generation.

- Industry and non-energy use:
  - Basic chemical materials production is now used as the activity variable in the chemical sector to provide a better estimate of energy demand.
  - Improved the fuel switching mechanisms in each subsector
  - Split renewables into combustible renewables and other renewables (geothermal & solar thermal)
  - Differentiation of thermal efficiency of combustible renewables vs. fossil fuels. A lower efficiency for combustible renewables and wastes is assumed compared to fossil fuels. This leads to more energy consumption when fossil fuels are substituted with combustible renewables and wastes.
  - Reviewed and updated the short- and long-term price elasticities by subsector
  - Split of non-energy use into feedstock and other non-energy use (this includes lubricants, asphalts, etc).
- Transport:
  - Improvements to the passenger light-duty vehicle model, including a refinement of the scrappage function and the calculation of implicit CO_2 prices for the optimal allocation of emission abatement.
  - Improved technology detail in freight traffic, distinguishing light commercial vehicles from medium- and heavy-freight traffic.
  - Revision of all road-transport related energy balances, and refinement of data output in terms of fuel consumption and emissions per vehicle and average fuel consumption of new sales and total stocks.
  - Calculation of battery sales per year, total battery capacity and possible vehicle-to-grid capacity.
- Residential and services sector:
  - Enhancement of the fuel allocation module for modern biomass
  - Revision of the price effect formula to include biomass price
  - Updates of the activity variables database
- Energy and Development:
  - Updates of the electricity access database
  - Updates of the database on reliance on traditional use of biomass
  - New outlook for electricity access under the New Policies Scenario
  - New outlook for reliance on traditional use of biomass under the New Policies Scenario
  - Development of the Universal Modern Energy Access Case
  - Development of the 2010 Energy Development Index

Annex 2: *WEM* Regional Definitions

The *WEM* is made up of 25 country/regional models of which Brazil, Canada, Chile, China, India, Indonesia, Japan, Korea, Mexico, Russia, South Africa and the United States are modelled on an individual country basis. These 12 countries in 2009 accounted for: 65% of world CO_2 emissions from fuel combustion, 62% of world primary energy demand, 59% of world GDP (PPP) and 56% of world population.

In Tables 1, 2 and 3 of this methodology document, the 25 *WEM* regions are grouped in the following manner:

OECD Americas (comprising 4 country models)
- Canada.
- Chile
- Mexico.
- United States.

OECD Europe (comprising 3 regional models)
- France, Germany, Italy and the United Kingdom.
- Austria, Belgium, the Czech Republic, Denmark, Estonia, Finland, Greece, Hungary, Ireland, Luxembourg, Netherlands, Poland, Portugal, Slovak Republic, Slovenia , Spain, and Sweden.
- Iceland, Norway, Switzerland and Turkey and Israel.

OECD Asia Oceania (2 country models, 1 regional model)
- Australia and New Zealand.
- Japan.
- Korea.

Eastern Europe/Eurasia[9] (comprising 1 country model and 3 regional models)
- Bulgaria, Cyprus, Latvia, Lithuania, Malta, and Romania*.
- Albania, Belarus, Bosnia and Herzegovina, Croatia, Gibraltar, the Former Yugoslav Republic of Macedonia, the Repulic of Moldova, Serbia[10] and Ukraine.
- Russia
- Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan.

Non-OECD Asia (comprising 3 country models and 2 regional models)
- People's Republic of China, including Hong Kong.
- India
- Indonesia
- Brunei Darussalam, Cambodia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand and Vietnam.
- Bangladesh, Chinese Taipei, the Democratic People's Republic of Korea, Mongolia, Nepal, Pakistan, Sri Lanka and other non-OECD Asian countries (Afghanistan, Bhutan, Cook Islands, East Timor, Fiji, French Polynesia, Kiribati, Macau, Maldives, New Caledonia, Papua New Guinea, Samoa, Solomon Islands, Tonga and Vanuatu).

Latin America (comprising 1 country model and 1 regional model)
- Brazil
- Argentina, Bolivia, Colombia, Costa Rica, Cuba, the Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, Trinidad and Tobago, Uruguay, Venezuela and other Latin American countries (Antigua and Barbuda, Aruba, Bahamas, Barbados, Belize, Bermuda, British Virgin Islands, Cayman Islands,. Dominica, Falkland Islands, French Guyana, Grenada, Guadeloupe, Guyana, Martinique, Montserrat, St. Kitts and Nevis, Saint Lucia, Saint Pierre et Miquelon, St. Vincent and the Grenadines, Suriname and Turks and Caicos Islands).

[9] For statistical reasons, this region includes Cyprus, Gibraltar and Malta.
[10] Serbia includes Montenegro until 2004 and Kosovo until 1999.

Middle East (comprising 1 regional model)

- Bahrain, the Islamic Republic of Iran, Iraq, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, the United Arab Emirates and Yemen.

Africa (comprising 1 country model and 2 regional models)

- Algeria, Egypt, Libya, Morocco and Tunisia.
- Angola, Benin, Botswana, Cameroon, Congo, Democratic Republic of Congo, Côte d'Ivoire, Eritrea, Ethiopia, Gabon, Ghana, Kenya, Mozambique, Namibia, Nigeria, Senegal, Sudan, United Republic of Tanzania, Togo, Zambia, Zimbabwe and other African countries (Burkina Faso, Burundi, Cape Verde, Central African Republic, Chad, Comoros, Djibouti, Equatorial Guinea, Gambia, Guinea, Guinea-Bissau, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Niger, Reunion, Rwanda, Sao Tome and Principe, Seychelles, Sierra Leone, Somalia, Swaziland and Uganda).
- South Africa

Other Regional Groupings Used

European Union

Austria, Belgium, Bulgaria, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden and United Kingdom.

G8

Canada, France, Germany, Italy, Japan, Russian Federation, United Kingdom and the United States.

G20

Comprises the G8 countries, Argentina, Australia, Brazil, China, India, Indonesia, Mexico, Saudi Arabia, South Africa, South Korea, Turkey and the European Union.

Annex 3: References

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