Undressing the emperor: A critical review of IEA's WEO

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Abstract

Since the turn of the century The International Energy Agency (IEA) has assumed a gradually more important role in defining the agenda and outlook for energy and climate policies. This essay reviews the methodology and methods behind IEA's World Energy Outlook, and then offers a critical review of assumptions and projections, focusing in particular on the outlook for economic growth, technological change, and investment in new renewable energy. The analysis suggests that important aspects of IEA's scenarios are driven by critical exogenous assumptions. Moreover, vast resources and a competent research organization offer limited mitigation for outlook uncertainty, and IEA's outlook should therefore be approached with the same caution as other global energy projections.

Keywords: Energy economics, macroeconomics, modelling
JEL classification: Q41, Q43, Q47

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[1] Valuable comments from Oluf Langhelle, Ottar Skagen og Eirik Wærness are highly appreciated.

Introduction

In November every year The International Energy Agency (IEA) release a new issue of their 700-page flagship publication *World Energy Outlook* (WEO; IEA, 2105a) at a packed press conference in London. This comprehensive long-term energy outlook enjoys significant attention across the entire oil and energy industry, and has established itself as a reference document for energy and climate policies across large parts of the world (Van de Graaf, 2012; Heubaum og Bierman, 2015).

At the same time, IEA's *World Energy Outlook* has attracted increasing criticism from several camps. For example, the IEA has been criticized for under-estimating the dynamic development of renewable energy (e.g., Metayer et al, 2015). IEA's projections have fallen particularly short of the realised development of solar energy and wind power.

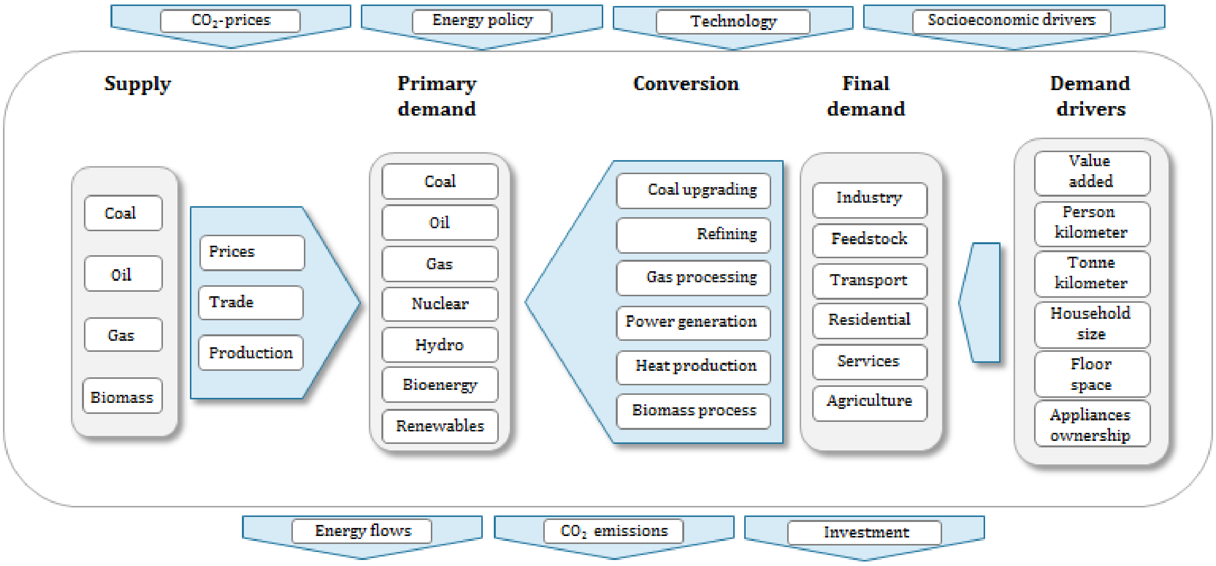
IEA's *World Energy Outlook* is based on a comprehensive and very detailed system of models, drawing on insights from geology, technology, economics, and political science. A common argument against the methodology and models of the IEA is that the flexibility of economic behaviour is effectively contained, and that the relations of the modelling system are not sufficiently responsive to shifts and shocks in technology, preferences, policies, and prices. Critics also argue that IEA's *World Energy Outlook* largely is a product of historical trends and developments, combined with a rich set of exogenous assumptions and coefficients for the evolution of technology, prices, and policies. A specific example relates to the outlook for economic growth, which is assumed identical across three scenarios which span substantial variation in a range of areas of the world economy, including oil and gas prices.

The purpose of this essay is to shed light on the question if IEA's WEO has deserved the role as key reference document for global energy-related developments and corresponding policy design. A review of the methodology and models behind IEA's energy projections is followed by a critical discussion of three areas of the outlook. The first relates to IEA's treatment of the interaction between energy developments and general macroeconomic developments. We then take a closer look at IEA's approach to general and energy-specific technology developments, before we discuss implications related to new renewable energy sources, or more specifically investments in solar energy and wind power capacity.

Methodology and model

Over more than 20 years the IEA has presented long-term model-based projections of energy demand, supply and price formation at the global level and in each of IEA's member countries. A comprehensive simulation model called the *World Energy Model* has gradually been for the purpose. What follows is a general introduction to this very detailed simulation tool, to illustrate the principles, methods and modelling strategies that form the basis for IEA's long-term energy projections. Note that a range of details and nuances will escape such a brief introduction. For a closer look at the *World Energy Model*, see IEA's own introduction to the model (IEA, 2015b).

Figure 1. Overview of IEA's World Energy Model



Source: IEA (2015b).

Figure 1 gives an overall stylised overview of IEA's *World Energy Model* (WEM). The model is based on annual data,[2] and have three main model blocks for 1) energy supply, 2) conversion, and 3) energy demand, respectively. The most important exogenous assumptions relate to costs of CO_2-emissions, plans and measures for energy and climate policies, technological progress by industry and region, and assumptions for macroeconomic developments (i.e., economic growth). Reflecting this broad set of exogenous assumptions, Figure 1 illustrates that final demand from different sectors in each country is a result of economic activity in these sectors. Final demand is directed at a range of conversion processes, and primary demand is determined by the energy required for these processes. Production, trade, and price formation for energy commodities like coal, oil, and natural gas, natural gas and bio mass is then determined by the interaction with primary energy demand in different industries and regions.

WEM divides the world in 25 regions, 12 of which are countries, and the remaining 13 are groups of countries. The horizon of projections is typically 25-30 years, and exogenous assumptions include forecasts for economic growth, population growth, technological progress, and policy developments. Technically speaking, crude oil and natural gas prices are also exogenous, whereas end-user prices for a range of energy

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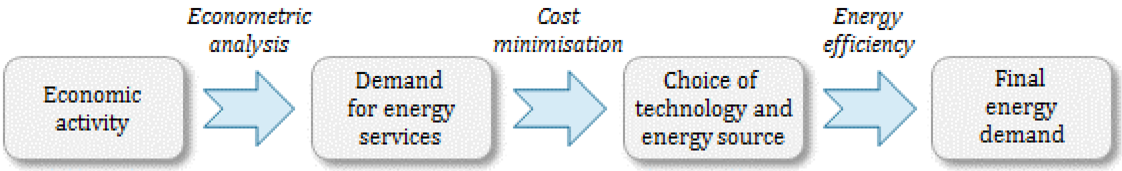
[2] Energy data for model input is retrieved from IEA's own databases (http://www.iea.org/statistics),

products is determined by the model.[3] Output from the model typically includes supply and demand for different energy carriers, costs and investments, end-user prices and energy-related greenhouse gas emissions.

Figure 2. Stylised illustration of the modelling of energy demand in WEM



Kjelde: IEA (2015b).

Demand

Figure 2 illustrates the general modelling approach to energy demand in WEM. The model splits demand by five different main sectors (industry, transport, households, services, and agriculture).[4] In addition comes demand for energy products as feedstock for the petrochemical industry and other industries. For each of these sectors and sub-sectors, WEM specifies calibrated relationships between energy demand (E_t) and a suitable proxy for economic activity (Y_t)

$$E_t = A_t Y_t. \quad (1)$$

The choice and definition of activity variable will vary across sectors. Value-added is a typical candidate for the industrial sectors, where econometric equations are fitted to explain energy demand as a result of historical production, GDP, population size, and energy prices. Corresponding relationships for household energy demand are based on dwelling size, number of households, and access to electrical appliances, and services,[5]

For each sector, the next step involves econometric discrete choice models to allocate total demand for energy services between different technologies and energy carriers. In

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[3] The model computes an index for end-user prices in each sector which is based on energy commodity prices, costs and margins of conversion and/or refining, transportation costs, taxes and duties. Energy products include three types of coal (coking coal, steam coal, and lignite), natural gas, more than 10 products from oil refining (LPG, naphta, gasoline, kerosene, diesel, bunker oil, petroleum coke, refinery gas, asphalt, solvents, wax, etc; IEA (2015b), p. 30). In addition, WEM provides end-user prices for electricity, various type of bio energy, and heat production.

[4] Each of these main sectors are split in 5-7 sub sectors. As an example, the «industry» sector will include sub sectors like 'aluminium', 'iron and steel', 'chemical and petrochemical', 'cement', 'pulp and paper' og 'other manufacturing industries'. The «transportation» sector includes 'road transport', 'aviation', 'railway transport', 'shipping' and 'other transport', whereas enegy demand from the household sector is made up by 'heating', 'cooling', 'water heating', 'cooking', and 'lighting'.

[5] 'Passenger kilometer' and 'tonne kilometer' form the basis for energy demand from person and goods transportation, respectively.

this step of demand decision-making, the choice between various categories is guided by cost-minimisation, implying that demand over time will drift towards the most cost-efficient alternatives. More specifically, the point of departure for each energy carrier (i) is the specification and estimation of linear indirect utility functions (V_{it}) for each area of application:

$$V_{it} = \alpha_i p_{it} + \beta_i t + \gamma_i \ , \tag{2}$$

where p_i is the price of energy carrier i compared to average energy prices, t is a trend term, α_i og β_i are parameters, and γ_i is an exogenous adjustment parameter to account for influence from variables beyond prices and the time trend (e.g., specific policy measures). In accordance with standard multinomial logit modelling, the likelihood of a specific choice of energy carrier in each application (π_{it}) is now determined by the odds factor:[6]

$$\pi_{it} = \frac{e^{V_{it}}}{\sum_i e^{V_{it}}} \ . \tag{3}$$

To translate this choice to final energy demand, the above equation is combined with an exogenous trajectory for technical energy efficiency. These coefficients for energy efficiency are determined by IEA's professional judgent for each of the sectors in all thre regions, and will ideally reflect plausible assumptions for energy prices, technology development and energy policies. At this stage of modelling, adjustment parameters are also calibrated to mimic sluggishness and gradual adjustment of energy demand over time, which again may stem from vintage mechanisms in household and business capital formation.

With 25 countries/regions, 18 application areas for energy, and potentially seven different energy types for each application, the result is indeed a detailed modelling scheme.

Power generation

Production of electricity is determined by demand from various sectors and region. A specific block of the WEM computes estimates for capacity requirements, allocation of production over different technologies, demand for energy from the power generation sector, infrastructure investment, and produce and end-user prices for electricity by sector and region.

Installed production capacity in each region is required to meet peak demand with a safety margion. If capacity falls short of this requirement, the model will add new

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[6] At this point the modelling strategy implies that improved properties for a specific energy carrier will reduce the choice probability for all other alternatives by the same percentage. This pattern of proportional substitution imposes a strait-jacket on preferences and production technology that limits the flexibility of energy demand (e.g. Train, 2009).

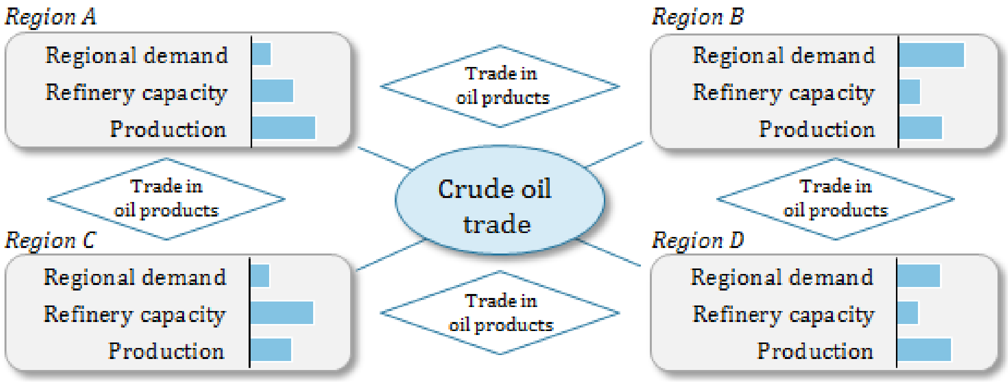
production capacity for the region. The choice of technology in these capacity investments is guided by long-term marginal cost.[7]

The modelling of electricity markets follow the textbook standard (e.g., Bhattacharyya, 2011). Demand from hour to hour is sorted in a variety of categories from base load to peak load. Generators are then sorted according to flexibility and short-term marginal cost (merit order). In consequence, base load is met by generators characterised by low marginal cost and limited flexibility, whereas generators with higher marginal costs and more flexibility are hooked up as demand approaches 'peak load' in the afternoon every day.

Power production from solar energy will normally correate with daily demand fluctuations, with potentially significant contributions during the middle of the day. The situation is slightly diffent for wind power, as the variations in wind are less systematic through the day. However, wind turbines may be more exposed to seasonal variation in wind strength. Whatsoever, the electricity system will absorb the production from both solar energy and wind power as long as their market shares are moderate.

More substantial contributions from solar power and wind energy will raise a requirement for reserve capacity to meet the inherent intermittency of new renewables in power generation. A challenge for these technologies is that their marginal value and competitiveness is gradually weakened the higher their market share.[8]

Figure 3. Trade in crude oil and oil procuts in the World Energy Model



Source: IEA (2015b).

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[7] New renewables introduce a significant stochastic element in electricity supply. Solar energy and wind power are therefore attributed with a capacity discount to reflect the share of installed capacity that can be expected to deliver at daily'peak demand'.

[8] Transport of electricity in space and time would alleviate this challenge, Flytting av elektrisk kraft i rom og tid vil avhjelpe denne problemstillinga, og her ser ein korfor framveksten av ny fornybar energi har stimulert interessa for nye løysingar for magasinering og lagring av elektrisk kraft.

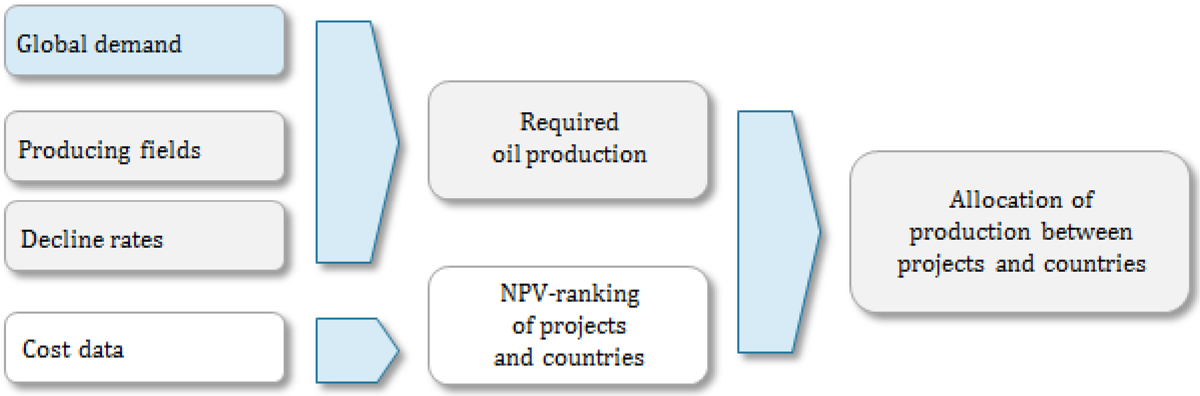
Oil refining and trade
A specific model block of IEAs' WEM is assigned for the connection of oil demand and supply through oil refining and trading activities. Over the short to medium term, refinery activity is determined by demand for oil products, and development of new capacity is given by identified projects and plans. In the longer term, the evolution of refinery capacity is influenced by the regional market balance for oil products on the one hand, and by the access to crude oil on the other.

Note that some oil products are supplied by other sectors than oil refining, and that the demand for oil products is corrected for bio fuels, liquefied petroleum gas (LPG), ethane and naphta (NGL), and also by synthetic fuels from alternative upgrading processes like coal-to-liquids (CTL), and gas-to-liquids (GTL). At the crude end of the value chain, refineries make use of all types of crude oil with refinery potential in line with conventional oil.

Consequently, oil product demand, refinery capacity, and crude oil production is modelled separately for each of the 25 regions of IEA's WEM. The result is regional market balances and unbalances for both crude and oil products, which in turn are equilibrated through inventory change and trade between the regions. More specific information on how these trade flows are determined in the model is not offered by the model documentation (IEA, 2015b).

Energy supply
The supply side of IEA's WEM splits energy commodities into four groups. Those are coal (32 per cent of the global primary energy mix in 2013), oil (34 per cent), natural gas (23 per cent), and bio mass (11 per cent). Oil is blessed with the most ambitious modelling strategy, with a somewhat more simplified procedure for natural gas, and in particular for coal. Finally, there is a specific model block for bio energy, separating energy products from processes where they are a main product on the one hand, from bio energy as a by-product of forestry and agriculture on the other.

Figure 4. Oil supply in IEA's World Energy Model



Source: IEA (2015b).

The mindset of supply modelling in IEA's WEM will be illustrated through their approach to oil production, which is also the most ambitious module of producer behaviour in the model. For a more specific and detailed introduction, including other energy products, see IEA (2015b).

The point of departure for oil supply is a comprehensive set of historical field-specific resource data, which is obtained from a broad range of sources, including the United States Geologica Survey (USGS, 2012) and German Bundesanstalt für Geowissenschaften und Rohstoffe (BGR, 2014). Moreover, data on reserves and production draw on BP's Annual Statistical Review of Energy (BP, 2015), supplemented with IEA's own studies of global decline rates of producing fields. This data forms the basis for the estimation of future production profiles for each of the countries in IEA's WEM.

A broad set of information on fields under development is exploited to enrich the short- to medium-term outlook for oil supply, both for OPEC countries and for non-OPEC countries. Moreover, rankings of net present values (NPV) of all known projects and prospects is finally applied for the calibration of a long-term oil supply curve, which agan forms the basis for the allocation of oil future production between countries and regions in the longer term.

Following standard practice of resource accounting, future production profiles for conventional crude oil are split in four different categories: Producing fields, fields under development, fields where final investment decision (FID) is still pending, and resources that are yet to be discovered. On top of conventional crude oil, the IEA then adds natural gas liquids (NGL) and production from unconventional resources like oil sands and shale/tight oil.

Oil supply in the short- to medium-term is largely based on identified projects and plans, where survey data from a large number of oil companies is applied to scale investment and capacity up or down over the first 3-4 years of the projection period. These plans also include OPEC countries, and the modelling approach does not reflect any enactment of market power on OPEC's behalf.[9] In their modelling of long-term capacity additions in the upstream oil industry, IEA (2015b) lends support from some method that links investment to capacity requirements and cash flows. However, the specifics on how this translates to modelling remain in the dark.[10]

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[9] At this point, IEA's model documentation is long on ambiguity, and short on accountability. According to IEA (2015, p 33), «… OPEC is not treated as the swing producer, though constraints thought to represent OPEC policies are incorporate in the WEM oil supply module.» Without further detail, the IEA leaves us with no possibility to evaluate their modelling strategy on a very important aspect of oil price formation.

[10] Note that Hotelling-style behavior plays no role in IEA's WEM, and that oil producers in their model seem oblivious to any form of dynamic optimization, both inside and outside OPEC. Still, exogenous assumptions are applied, whereby increasing resource scarcity (i.e., oil) contributes to a gradual escalation in both costs and prices over time. However, the documentation of these mechanisms makes makes no reference to capital market returns or interest rates.

Emphasizing variation in technology and extraction costs between countries and regions, IEA's modelling strategy does imply a competitive advantage for countries with large reserves and low costs of extraction. A reflection of this mechanism is evident in the *New Policies* scenario of IEA (2015a), where OPEC's global market share is set to increase from 41 per cent in 2014 to 49 per cent in 2040.

The modelling of gas production follows a similar pattern as for oil production. However, the gas supply module is less rich in data and granularity, and with more restrictions on trade between the countries and regions of the model. Even simpler is the modelling of the coal market, where the outlook combines projections of demand and prices with current resource endowments to distribute future production of coal between product categories and regions.

Price formation
Technically speaking, prices of coal, crude oil, and natural gas are exogenous to IEA's WEM. In practice, however, crude oil prices are determined through an iterative ad hoc procedure, to secure that investments and production will meet the requirements implied by the demand outlook. When running the model, the IEA starts out with an initial set of price assumptions, which forms the basis for a first-round projection of investment and production. Demand is then computed based on the same set of price assumptions. If supply and demand does not balance, demand and supply are recalculated at a higher/lower oil price until market balance is established. Corresponding mechanisms are arguably imposed for coal and natural gas prices, but less detail leaves the impression that the approach is somewhat simplified compared to the iterative proces for the crude oil price.

CO_2 prices are reflected in IEA's WEM through a detailed set of exogenous assumptions to capture costs of emissions in households and industries imposed through energy and climate policies in each country and region of the model. This approach takes account of current policies and communicated plans to make polluters pay. However, any specific quota regime, with our without trade, is not a part of the model.

End-user prices are computed fossil fuels in each sector and region, reflecting regional variation in energy mix an tax policies. Correspondingly, end-user prices of electricity are computed on the basis of regional marginal costs of production, system operation, distribution, local supply, taxes and subsidies.

Energy and the macro economy

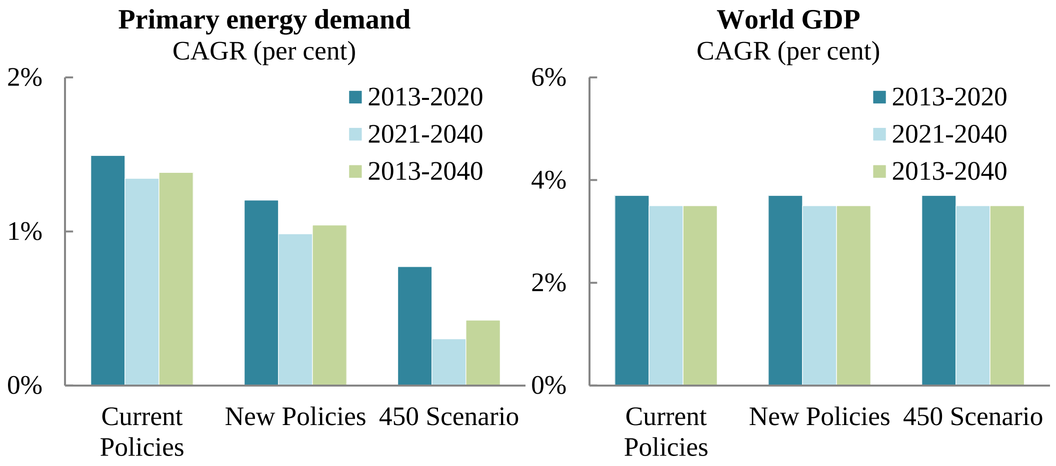
The annual long-term projections for IEA's *World Energy Outlook* are based on a scenario approach. Over the last years three specific scenarios have formed the core of IEA's analysis of future energy prospects, with differences driven by assumptions regarding energy and climate policies, technological change, energi efficiency improvements, and energy prices.

The *Current Policies* scenario can basically be read as a projection of 'business-as-usual', where energy policies of today are continued without any further tightening to improve energy efficiency and/or in response to global warming. In this scenario projected trends of technology are largely an exptrapolation of historical developments. Consequently, future energy demand growth turns out on the high side, with limited changes in the energy mix, limited growth in the development of renewable energy, and continued high growth in global emissions of greenhouse gases.

New Policies is presented as IEA's central scenario, and is based on a set of assumptions whereby energy and climate policies evolve according to announce future measures, plans and intentions in different countries and regions across the world. This scenario account for national and regional ambitions for renewable energy growth, substition of fossil fuels in the transport sector, fossil subsidy reforms, and pricing of CO_2 emissions, The result is a more moderatre growth in energy demand and greenhouse gas emissions, but not by far sufficient to limit global warming to 2°C.

The *450-scenario* is therefore designed to ilustrate what it would take to contain the concentration of CO2 in the athmosphere to 450 ppm (parts per million), which is the maximum level that can be allowed if global warming is to be limited to 2°C. This scenario is based on a set of aggressive plans and policies to reduce emissions of greenhouse gases, with ambitions for technological development and energy efficiency improvemtnet which really is a challenge to the credibility and realism of the entire exercise.

Figur 5. IEA's outlook for global GDP and primary energy demand



Source: IEA (2015a).

A relevant and reasonable assertion would be that the substantial variation in energy policies, technological development, energy efficiency improvement, and energy prices across the scenarios would have implications for macroeconomic developments.

Moreover, there are good reasons to argue that the significant variation between the scenarios in energy and climate policies for each region and country should reflect upon the macroeconomic developments in the same regions and countries.

However, this is not the case in IEA's *World Energy Outlook*. Assumptions for GDP growth are exogenous to the model, and are typically retrieved from the most recent forecasts from the OECD (short to medium term) and the IMF (longer term). A weakness IEA's methodology and model is therefore that macroeconomic developments are by no account a result of the model projections. What makes this even worse is the fact that no variation is allowed for economic growth between the three scenarios of the outlook. Any potentially bilateral interaction between energy and macroeconomic development therefore remains a blind spot in IEA's work on energy projections.

At the same time, the IEA do appreciate the role of economic activity as an important driver of energy demand, stating that «The projections in this *Outlook* are, therefore, highly sensitive to the underlying assumptions about the rate and pattern of growth in gross domestic product (GDP)». However any sort of feedback effects from energy policies, technological change and energy back on economic activity (growth) is totally neglected.

A role for energy prices as a determinant for economic activity and economic growth is firmly supported by contemporary academic research activity, where the role of the oil price has been subject to particularly close scrutiny. For countries that are largely importers and consumers of oil, Jimenez-Rodriguez and Sanchez (2005) and Hamilton (2008, 2012) argue that oil price shocks is an important factor behind macroeconomic recessions. Recent research does suggest that the connection between oil price shocks and business cycles has faded over time. A literature survey by Killian (2008) also argues that the business cycle impact of an oil price shock will depend on the source of the shock, with demand-driven shocks being more influential than shocks driven by supply. Nonetheless, Schwark (2014) studies the macroeconomic impact of oil price shocks in a DSGE model for oil-consuming countries, and finds significant effects on investment, productivity and economic growth over a horizon of 8-50 years. The conclusion therefore is that the simultaneity of energy price formation and macroeconomic development in the real world should be reflected in modelling strategies and projections.

The link between energy prices and macroeconomic development is even more obvious for countries who are large producers of energy commodities. Economic growth in resource-rich countries can not possibly be seen as isolated from energy-related shocks in policies, technology or energy prices. For an example of the impact of oil price shocks on a small, open petroleum ecnomy, see Bjørnland and Thorsrud's (2016) study of the oil-fire boom in the Norwegian economy over the last 15 years. Note also that the study by the International Monetary Fund (IMF, 2015) of the outlook for commodity-exporting countries in the aftermath of the late plunge in oil prices, with clear indications that a setback in commodity prices will dampen both actual and potential GDP in these countries. The implication is that permanent energy-related shocks will have long-term consequences for economic activity in countries that are rich in energy-related commodities.

Turning now to longer-term growth in potential GDP, a well-establihed perception is that global economic growth from the industrial revolution and onwards has been supported by access to cheap energy. (e.g., Stern, 2011; Stern og Kander, 2012). Still, the empirial research literature is still short on studies of the long-term implications of shocks and fluctuations in energy-related variables, including energy prices. One exception is Berk and Yetkiner (2014), who apply cointegration techniques for growth regressions on a panel data set for 15 OECD countries over the period 1997-2011, concluding that an increase in energy prices will dampen the growth rates of production and consumption also in the longer term. In a related study, Stern and Enflo (2013) establish Granger causality between energy consumption and economic activity base don 150 years of time series data for the Swedish economy.[11]

The differences between scenarios of IEA's *World Energy Outlook* are largely driven by variation in energy prices, energy and climate policies. This should attract the interest of any possible influence from this group of variables on overall macroeconomic development. However, the IEA methodology implies that economic growth is insensitive to any variation in energy-related variables. More seriously, this also means that the IEA offers an opportunity for industry leaders and politicians to argue that energy and climate policies will have no consequence for economic activity or employment. Conclusions like this are generally embraced by politicians who would hate to dissapoint their electorate (sjå td. Stern, 2007; Tol, 2009; New Climate Economy, 2015). However, this is no guarantee for the validity of these results.

The risk is that demand among industry leaders and politicans may give rise to a bias in analyses, messaging, and policy design in the energy and climate domain. It therefore becomes especially important to remind that recent research leaves a far more diversified impression (e.g., Bretschger et al., 2011; Mohammadi and Parvaresh, 2014; Hartley et al., 2016;). An increasingly common perspective is to view climate policy efforts as a long-term investment, with long-term returns compared to some reference scenario, but only in 30-100 years time. During the interim period, policies will have to provide for higher cost of energy and reduced energy consumption. In other words, what such a development would require is an upheaval of the current energy system, including a crowd-out of fossil fuels at the benefit of renewable energy solutions. This transition is likely to have a dampening effect on production and consumption throughout the relatively lengthy investment period (Hartley mfl., 2016), which only partly can be offset by higher investment in new technology, improved energy efficiency and the development of new renewable energy solutions.

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[11] Other studies with similar results include Stern (2000), Ayres et al (2013) and Thompson (2014).

This discussion leads inevitably to the conclusion that the IEA should allow for variation in economic growth between the three scenarios of the *World Energy Outlook* (IEA, 2015). Endogenisation of economic activity could then imply that the *Current Policies* scenario would be associated with higher economic growth over the first 10-30 years, which would then fall significantly beyond this horizon due to long-term costs of global warming. Correspondingly, one could readily imagine that the *450* scenario would be characterised by somewhat lower economic growth over the first 10-30 years, with returns in terms of a positive growth differential to the other two scenarios, as investments in climate policies start to pay off. Unless the methodology and models of the IEA open for this kind of mindset, it is hard to see that their research and outlook can fully inform the interaction between economic activity, energy, and climate policies.

Development of energy technology

Energy saving, energy efficiency improvement, and new energy solutions are critical factors to succede in bringing down the global greenhouse gas emissions and dampen the process of global warming. Relevant measures to change corporate and household behaviour include quantitative political regulation (e.g., standards and requirements) and manipulation of prices and costs. The very high ambitions of climate policies agreed upon in Paris last year will remain far beyon reach without development of new competence and widespread implementation of new energy technology. Adoption of new technology leaves a potential for significant reduction in energy consumption by all sectors in the economy. Moreover, application of new technologies will potentially support the continued development of new energy solutions. Finally, the cost-saving implied by technological progress may release resources for additional investment in measures to reduce greenhouse gas emissions.

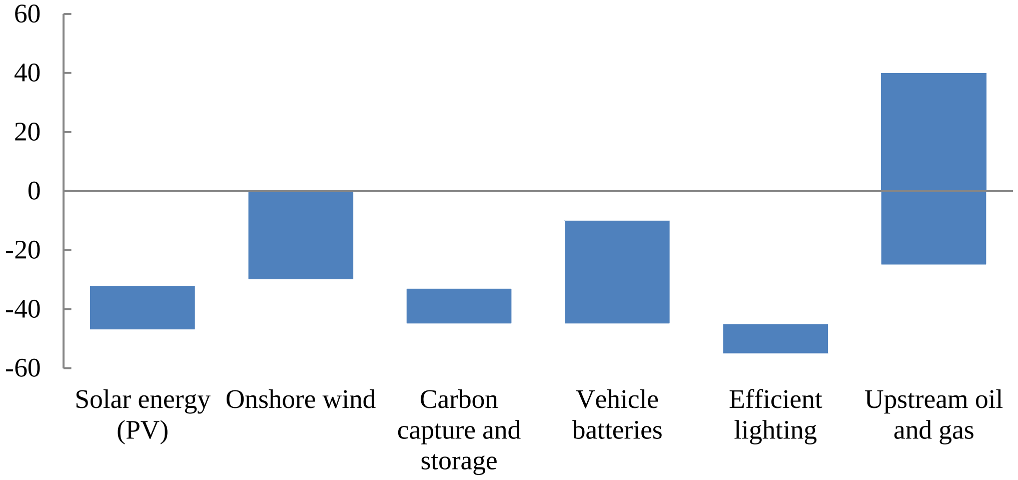
The potential of new technology to bring about the desired change in the global energy system is heavily stressed by IEA (2015a,c,d), who also underlines that the proections of the *World Energy Outlook* are sensitive to the choice of technology assumptions, and how these assumptions will influence on energy efficiency. In line with standard practice of economic modelling, technological change is approached through a gradual and continuous process in IEA's analyses, with exogenous increments imposed for each sector and region of the model. Any technology shock or sudden break-through is therefore ruled out of IEA's scenario apprach.

Still, implications of variation in technology assumptions between IEA's scenarios are still visible at the aggregate level. As an example, IEA (2015a) inform that the global energy intensity is foreseen to fall by 45 per cent over the period 2014-2040 in the *Current Policies* scenario, by approximately 50 per cent in the *New Policies* scenario, and by some 55 per cent in the *450* scenario.

More specific examples are offered in Figure 6, with illustrations of cumulated changes in unit cost for different technologies over the period 2014-2040 in the *New Policies* scenario (IEA, 2014a). We see from Figure 6 that the central *New Policies* scenario implies continued considerable reduction in the costs of renewable energy, and in particular for solar energy. Wind power is offered a somewhat more modest potential in terms of cost improvement, because these technologies are more mature, and because wind power is more likely to meet challenges relating to land access and declining resource quality.

Figure 6. Unit cost development for different technologies

Percentage change over the period 2014-2040 (*New Policies* Scenari



Source: IEA (2015a).

A break-through for carbon capture and storage (CCS) is critical for IEA's *450*-scenario, and the embedded ambitions are indeed high. If the world fails in developing technologies to sink CO_2, an ambition to limit warming to 2°C will limit the room left for oil and natural gas in the future energy mix significantly more than implied by the IEA's *450* scenario. This also mean that the speed of the required fossil fuel phase-out will depend on the the development of carbon sink technologies. This is an important explanation for the interest in CCS from industrialised (oil-consuming) nations and from the oil and gas industry, both of which are among the most important stakeholder groups for the IEA.

By 2040, IEA's *450* scenario will require a capacity for annual capture and storage of 5.1 billion tonnes of CO_2, 3 billion tonnes of which are foreseen in the power generation sector, and the rest in manufacturing industries. Projects that are developed so far typically have an annual capacity of 1 million tonnes, and an investment requirement of 1-3 billion dollars.[12] To meet the ambitions of IEA's 450 scenario, one would therefore

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[12] Note that costs are significantly lower for new-builds than for projects implying retro-fitting of CCS technology on producing plants. There is no chance that the CCS ambitions of IEA's 450 scenario can be met by new-builds only, and the relevance of such cost estimates is therefore limited.

have to develop some 5,000 CCS projects. With a decent start by 2020, this would imply the opening of five new CCS projects every week over 20 years. As seen from Figure 6, the IEA assumes that dynamic scale economies and learning-by-doing will reduce the costs of CCS in the *New Policies* scenario by approximately 40 per cent over the period.[13] A corresponding estimate for the *450* scenario is not available, but the logic of the scenario approach would suggest an even larger potential for cost reduction than in the *New Policies* scenario.

Even with very optimistic technology assumptions for CCS, annual investments of more than USD 110 bn are required every year through the 2030s to meet the ambitions of IEA's *450* scenario. For these investment to provide reasonable returns, IEA's assumptions point towards a sharp increase in unit costs of CO_2 emissions towards 2040, to 140 USD/tonne in the OECD area and 125 USD/tonne outside the OECD. For comparison, the current ETS price is 9 USD/tonne, and CCS investment is currently therefore of limited interest among private investors and companies (Emhjellen and Osmundsen, 2015). For CCS technologies, assumptions and ambitions of the IEA seem to be stretched beyond realism. Their *450* scenario requires a technology optimism that so far is poorly supported by both theory and empirical research.[14]

Important aspects of contemporary energy and climate policies aim at a reduction in fossil fuel consumption. These policies will have to include the transport sector, where oil so far virtually has enjoyed a fuel monopoly. Even though shale gas and progress for fuel cell technology open a potential for natural gas and hydrogen as transport fuels, electrical vehicles (EV) seem to be attracting most of the interest from politicians and the automobile industry these days. Electrical vehicles still face challenges and restrictions in terms of power storage, driving length, charging time, and infrastructur, continued progress for battery technology is key to a break-through of EVs in the transport sector.

IEA's *New Policies* scenario is based on a reduction in EV battery technology of 10-35 per cent by 2040. Beyound rather general statements around relative prices, political measures and accelerated rates of innovation, there is limited information on the

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[13] See Al-Juaied and Whitmore (2009) and Lohwasser og Madlener (2012) for deeper analyses of the cost, technology, and development potential for CCS.

[14] 13 large CCS projects are currently operating around the world (IEA, 2015c), and they capture a total of 27 million tonnes of CO_2 every year. However, only 5.6 million tonnes are subject to formal surveillance and verification. Projects that have been developed so far are relatively simple ('low-hanging fruits'), as they are typically fitted to new industrial projects in the oil refinery and gas processing business. Note also that the development cost is significantly lower for new-builds than if CCS technology is retro-fitted on already producing plants. As an example, capital expenditure estimates for the Norwegian Mongstad project were approaching USD 4 bn at the time that the project was stopped, for a project with a annual capacity of 1-1.5 million tonnes CO_2. What was left was a test pilot facility at a cost of USD 800 M. Similar full-scale CCS facilities have been built elsewhere in the world for USD 1 bn per million tonne of annual capturing capacity (e.g., the Boundary Dam and Quest projects in Canada, see Global CCS Institute, 2015). If the CCS ambitions of IEA's 450 scenario are to be met, there is no escape from wide-spread and large-scale retro-fitting of CCS technology in power plants and industrial facilities during operation.

specific drivers of such a development, how the implied cost reduction will play out, and how this technology will spread across sectors and regions.

Improved energy efficiency is undoubtedly an important area of any policy plan to contain energy demand, and this is also reflected in IEA's *World Energy Outlook*. As an example, Figure 6 illustrates a potential for another 50 per cent reduction in the global cost of lighting. Continued innovation in LED technology is foreseen to support further penetration both in established and new markets. However, lighting does still not represent more than 20-25 per cent of global electricity demand. An IEA (2015c) analysis targeted directly at the delegates at last year's climate summit in Paris (COP21) concludes that half the reduction in energy-related CO_2 emissions will have to come from efforts to improve energy efficiency if a 2-degree target is to be met.[15] Consequently, progress on technology and cost is required way beyond lighting. The question then arises if other sectors and appliances exist with an energy improvement potential as large as for the lighting sector.

IEA's analyses and discussions of energy efficiency improvements also seem to downplay the role of behavioural response in households and companies. Economists will know that a input-specific technology shock is equivalent to a reduction in the price of the same input (e.g., Allen et al., 2011; Sorrell, 2011; Saunders, 2014). The implication is that a input-specific technology shock will involve a substitution of demand in favour of the more efficient input, and an income effect that will lift both the output level and demand for all inputs. The implication that improvements in energy efficiency are offset through behaviour adjustment. This is what is referred to as the rebound effect.

Consequently, empirical evaluations show that policies to improve energy efficiency regularly fall short of original promises (e.g., Chitnis og Sorrell, 2015). How behavioural responses to energy efficiency policies is approached by the IEA remains unclear. The discussions of policies to improve energy and reduce emissions of greenhouse gases by IEA (2014a, b, c) leave few traces of potential rebound effects.[16] This supports a general suspicion that IEA's methodology and modelling strategy puts too little emphasis on the flexibility in economic behaviour.

Finally, Figure 6 illustrates a widely dispersed development in unit costs of upstream oil and gas activities. The constant race between technology and scarcity/decline is fundamental to the cost of oil and gas extraction (Lindholt, 2013). Casual inspection of unconventional resources in juvenile provinces clearly indicate that unit cost in the early phase of development will benefit from the accumulation of general competence and industry-specific learning-by-doing in exploration and field development activities. As an oil and gas province matures, the potential of learning-by-doing and technological

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[15] This reference goes to IEA's (2015) specific recommendation on how to move the world from a the path of development implied by the INDCs agreed upon in Paris last year (COP21; *INDC* scenario) and on to a development path which is consistent with target to limit global warming to 2°C (*Bridge* scenario).

[16] The exogeneity of economic and growth will also limit the the appreciation of feedback effects on energy demand via aggregate economic activity.

progress will gradually be exhausted, whereas mechanisms related to scarcity and depletion exert a gradualy increasing upward push on unit cost.

For the variety of resources and provinces in the world, expected costs of exploration and production will therefore span a broad spectrum, including technologies of unconventional resources like shale gas, shale oil, and oil sands. Nonetheless, it is worth noting that the IEA expect average cost of oil and gas extraction to increase of the coming 25 years, whereas costs of new renewable technologies are expected to fall. This will support a transition whereby renewable energy will gain market shares at the expense of fossil fuels.

Technological change in IEA's scenarios is the result of a detailed set of exogenous assumptions for regional and industry-specific innovation rates, and is therefore not a result of the model. The establishment of these technology coefficients is based on professional judgment, allowing for influences on technological change from both policies and prices. This method lacks robust support from economic theory and the model documentation (IEA, 2015b) is also rather weak for the process of innovation and technological progress.

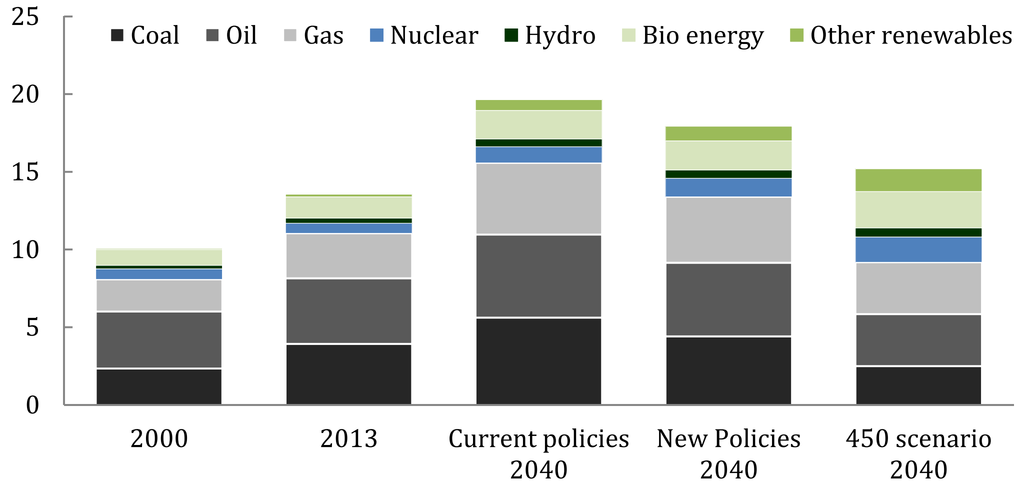
In practice, technological development will be a product of a set of explanatory variables inclucing, prices, policies, economic activity, (R&D) investment, and research. Ideally speaking, technological progress should therefore be endogenized in models energy, economics, and climate change. Gillingham et al (2011) for a survey of recent literature on endogenous technological change in studies of climate policies. A more explicit representation of the process of technological development would support the credibility the IEA's methodology and modelling approach.

IEA (2015a, b) also raise suspicions that substitution possibilities are under-rated both for households and companies. Moreover, the exact variation in technological progress between IEA's three scenarios is not specified, and the exact drivers of this variation also remain unexplained. As an example, relative energy prices play a role for energy-specific R&D investments (e.g., Ley et al., 2016). Consequently, more weight should be put on motivation and explanation of how variation in energy prices between the three scenarios influence on the technology process. Althugh IEA's World Economic Outlook leaves the impression of great detail and and care, the importance of technological progress would suggest an even more considerate modelling strategy.

New renewable energy

The facilitation of further capacity expansion in renewable energy is one of the most important areas in contemporary energy and climate policies. An energy mix with less fossil fuels and more renewable energy will make it easier to combine ambitions to stem global warming with general welfare aspirations. Consequently, relevant R&D activitites, innovation, and commercialisation of renewable technologies is an area of strong interest, among polticians, industry leaders, and NGOs. Renewable energy includes traditional bio fuels and conventional hydropower for electricity production. However the majority of attention over recent years has been directed at solar energy and wind power. The background is obviously an enormous technical potential, promising improvements in technology and cost, and widespread government support (Timilsina mfl, 2012, Timilsina mfl, 2013).

Figure 7. Global primary energy demand by energy carrier and scenario
2000-2040, bn toe oil equivalents



Source: IEA (2015a).

Despite the expansion of general interest and strong growth over the last 10-15 years, new renewable energy sources still play a modest role in the primary energy mix. Figure 7 provides a breakdown of global primary energy mix in 2013, with a share of renewables of approximately 14 per cent. With 10 per cent for traditional bio fuels, and 2.5 per cent for the sum of hydropower, thermal, and solar thermal energy, modern renewable energy makes up less than 1.5 per cent of total primary energy demand. Modern renewables is largely made up by photovoltaic solar energy (PV) and wind power, but also includes concentrated heat plants (CHP) and modern thermal energy.

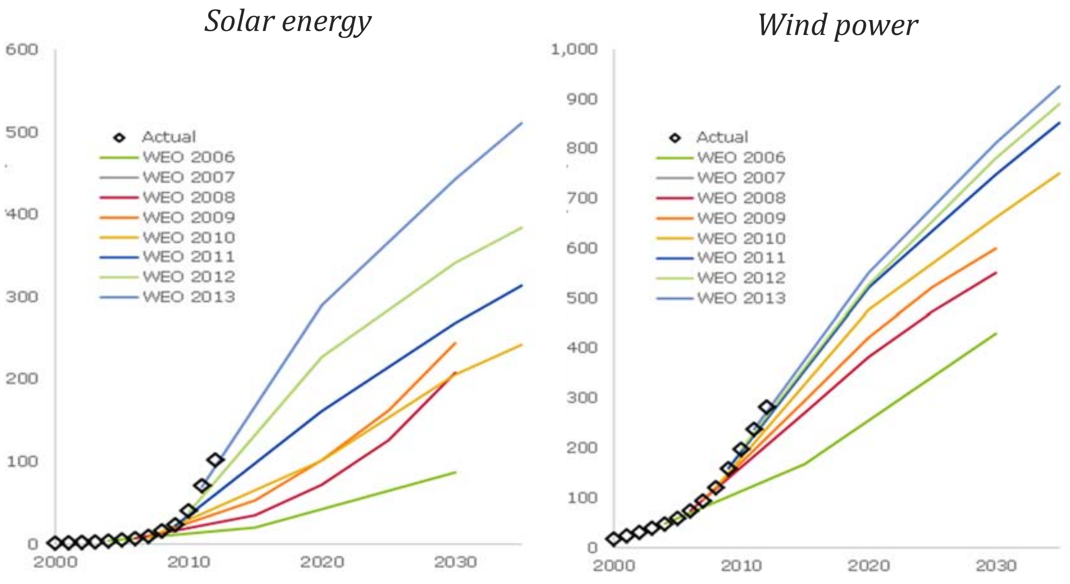
With compound annual growth of 8 per cent since the turn of the century, new renewables have incrased their share of total primary energy demand by 1 percentage point in 13 years. With a shar acceleration of capacity expansion over recent years, the question is how to approach the outlook for these new and interesting sources of energy supply. Before we discuss this question, let us have a closer look at the modelling approach for new renewable energy in IEA's World Energy Model.

According to IEA (2015b), a separate block has been developed to account for capacity additions and production of power heat from renewable energy sources in the World

Energy Model. This model block combines historical data with methodology from both engineering and economics to adapt projections for solar energy and wind power to the scenarios of the World Energy Outlook. Investment in various types of power production are driven by estimated capacity requirements basded on calibrated static cost functions for different technologies, which also account for regional and sectoral variation in taxes and duties, subsidies, technical and/or geographic constraints. The static cost functions are then augmented with an ad hoc dynamic element to account for technological progress and dynamic scale economies, or learning-by-doing mechanisms. These dynamics are constrained to diminish over time, in line with a standard S-pattern for models of the market peneteration for new products and services.

The specific approach to this calibration is not documented any further, and the relevant relations and parameters are also not available to the public. Again, it is therefore difficult to give a full evaluation of the modelling approach. However, as we will see, the published projections do suggest that the IEA's modelling approach most probably could improve on review and revision. The reason is simply that so far, IEA's projections for new renewable energy have been outpaced by real-world developments.

Figure 8. IEA's outlook for solar energy and wind power over time
Accumulated installed capacity (GW), *New Policies* scenario



Solar energy

Wind power

Source: de Vos og de Jager (2014).

IEA's (2015) central *New Policies* scenario implies annual average capacity additions of 7 per cent for renewable energy sources apart from hydropower and bio energy. This is roughly in line with annual growth since the turn of the century, both slower than the growth observed over recent years. In general, IEA's projections for new renewable energy have been consistently outpaced by actual developments over the last 10-15 years (cf Figure 8). A stabilization of investment rates has been a key feature of IEA's projections, whereas observed investment rates have continued to climb. The dynamics of solar energy and wind power have clearly been under-estimated, at least in the short to medium term. This has obviously triggered critical remarks, from the press, from renewable market analysts, environment and climate NGOs, and from interests of the renewable industry itself (e.g., Cloete, 2014; de Vos og de Jager, 2014; Osmundsen, 2014; Roberts, 2015).

A more detailed evaluation IEAs projections for renewable energy in electricity generation is provided by Metayer et al (2015), who have traced relevant developments in annual volumes of IEA's *World Energy Outlook* over the period 1994-2014. Their conclusion is also that projections for solar energy and wind power have been significantly under-estimated. This provides sufficient evidence to conclude that the IEA indeed has been too conservative on behalf of new renewable energy expansion. However, the shortfall remains to be explained. Metayer et al (2015) argue that the choice of functional form in IEA's World Energy Model puts a linearised straitjacket on the development of renewables for electricity production, which is simply impossible to align with real-world developments of solar energy and wind power over the last years. The functional form itself is hardly the main problem in this respect, and the issue is more likely to be about biases relating to parameterisation, restrictions, and (cost) assumptions.

Other explanations are flavoured by politics, and some studies argue that the IEA simply reflect the interests of their 29 industrialised member countries, and also the the interests of the oil and gas industry of these countries (e.g., Roberts, 2015). The arguement implies that a status-quo bias in the preferences of key IEA stakeholders could imply a corresponding bias in analyses and projections. If this was the case, one should probably expect a shortfall in attention and effort from the IEA on issues relating to renewable energy, in analyses, communication, and advisory activity. However, the opposite is probably more true, as IEA continuously demonstrates heavy emphasis on renewables in thei stakeholder outreach. Activities include technology studies, special reports and permanent working groups. The impression is that the IEA takes every opportunity to stress the importance of renewables growth in facilitating a more sustainable energy mix.

A more plausible explanation arise from the combination of institutional conservatism, vintage effects in capital formation, and substantial adjustment costs. The result is a sluggish adaptation of the global energy mix, which also agrees well with historical developments. At the same time, an important role for the IEA is to illuminate and explain potential changes in the global energy situation – over the long term. This priority might be difficult to unite with the concern for detailed information on every sector and country, and in particular for more peripheral aspects of the general energy picture. Even after several years of double-digit growth for solar energy and wind power capacity, the contribution from these sources to global power generation remains well below 5 per cent.

One should also bear in mind that the evaluation of modelling and analyses at this level of complexity most often will give a mixed result. The degree of sucess will vary by industry, energy sector, and by region. In some areas IEA's outlook performs pretty well, whereas other areas are less successful. At the end of the day, IEA's *World Economic Outlook* is not a forecast, but a scenario exercise. In this context, it is interesting to note that IEA's *Current Policies* scenario has provided the most accurate projection of aggregate developments in energy demand and GHG emissions, whereas ex post developments for new renewables have been more in line with the *450* scenario. The general tendency for the central *New Policies* scenario is an over-estimation of the role for oil and gas, and an under-estimation of the growth of new renewables – and coal (Cloete, 2015).

Finally, it is not straightforward to raise objections to the theoretical basis for IEA's modelling of new renewables. An S-shaped peneration of new renewable energy is a reasonable approximation of a process which has been observed for a range of product and service markets. Increasing marginal costs of new renewables in each sector and region will also imply that the marginal value of capacity additions will decrease in the market share. Consequently, the issue of deceleration for new renewables in power generation therefore boils down to a question of timing. With well-supplied electricity markets in Western Europe, low oil and gas prices, and empty government coffins, the IEA might be right renewables stagnation before we know.

Concluding remarks

Over the last 15 years, competent leadership, high ambitions, and fruitful promotion has gradually lifted the status of IEA's annual flagship publication *World Energy Outlook* to a leading reference for governments, politicians, non-government organisations, business and industry. Today no global debate on energy and climat policies can escape the premises implied by the IEA's analyses. This development makes it more important than ever to look the IEA in the cards, shed light on both the strength and weaknesses of their analytical approach, and make sure that energy and climates build on transparent analyses and the latest insights from academic research.

Questions can be raised on several areas of the IEAs' methodology and modelling strategy. Energy prices and economic activity are exogenous to the model, and so is a long series of variables for energy technology and policy development. The modelling approach is therefore not particularly well suited for characterisation of market equilibria, and also leaves the impression that technological flexibility has not had the attetion it deserves in the understanding of long-term demand and supply.

It is also hard to argue that the IEA's *World Energy Model* meets the requirements of a macroeconometric model. To many variables are exogenous and to many coefficients are calibrated based on professional judgment. Econometric equations are also short on documentation, and the IEA (2015b) includes information on coefficient estimates or model diagnostics. Consequently, evaluation is virtually impossible for this important aspect of the model. At the same time, the wide range of model restrictions, exogenous assumptions, fixed coefficients, and constant trends raise a suspicion that any future development can be supported by a suitable choice of input variables.

Empirical models of energy economics and climate change should open for the endogenisation of economic activity. For the IEA's *World Energy* Outlook, this could allow variation in energy prices and policies to imply corresponding variation in economic growth between the different scenarios. Moreover, uncertainty could be spanned by a variety of sector-specific technology shocks, or even through stochastic modelling of technological progress both for traditional and unconventional energy carriers. The cost of such a development would possibly be a loss of detail and granularity, which is key to the current version of the model. However, the net benefit would most probably still be positive.

This review has illustrated that the task faced by the IEA in modelling long-term energy market developments is both important and very complex. Analyses and projections of energy and climate developments will have to draw on insights from geology, technology, and economics – and are also a political mine field. Any conclusions and outlook will therefore raise discussion, among academic, industry leaders, politicians, and in the public. The IEA's *World Energy Outlook* should therefore be regarded as a voice in this debate, rather than bible in its own respect. Consequently, all parties relating to this type of information are advised to take both the IEA's analyses and competing views on the energy world with a suitable grain of salt.

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