Drivers, trends, and uncertainty in long-term price projections for energy management in public buildings

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Abstract

Buildings are responsible for almost 40% of energy consumption and CO_2 emissions in the EU (EC 2010). Improving the energy efficiency of buildings is a vital step towards achieving the EU climate and energy objectives. Directive 2010/31/EU outlines measures specifically focused on the energy performance of buildings. Incentives are created for building operators to optimise their energy sub-systems in a more robust, energy-efficient, and cost-effective manner. The challenge is to choose efficient energy-supply portfolios accounting for technological and market deregulation and risks. Decision support tools for energy management in public buildings using future scenarios of market and technological developments would be beneficial. The aim of this paper is to discuss the drivers and uncertainties in the recent and future energy market trends and prices, including

technological progress and developments in fossil-fuel markets. This discussion is relevant for researchers and policymakers in general, and in particular, as an input for scenarios used in the development of decision support systems.

Keywords: energy price trends, technological progress, energy efficiency in buildings, strategic decision making.

1 Introduction

Improving energy efficiency is a key element of the EU strategy to enhance the economic competitiveness of its member states. The Energy Efficiency Plan 2011 (EC 2011a) favours multiple goals, including energy supply security and sustainability. Directive 2010/31/EU (EC 2010) outlines measures that require Member States to set minimum requirements and develop methods for determining energy performance of buildings. Ambition levels vary by building type and depend on the type of project considered. By the end of 2018, all government-occupied and -owned buildings should consume nearly zero energy, and per ultimo 2020 all new buildings. There is more leeway, however, for existing buildings. In this context, the concept of Zero-Energy Buildings (ZEB) refers to the net energy balance of a building over a period of time. If the renewable generation is as large as the building's consumption, then it can be considered a ZEB (Marszala et al., 2011).

EU Member States must draft lists to enhance the transparency of political and financial incentive schemes for improving energy performance. Energy performance certificates should provide information relevant to building buyers and renters and increase awareness and knowledge of the general public regarding energy consumption and efficiency. Also, heating and cooling systems in buildings should be inspected regularly.

Lowering energy consumption of buildings is a concern not just in the EU but also in countries such as the USA, China, and Norway. In 2009, the U.S. Congress supported a mandatory reduction of energy consumption for federal buildings, including a target of zero fossil-fuel consumption by 2030 for newly constructed buildings (ARRA, 2009). Brown et al. (2008) show that there is much potential for energy savings in U.S. buildings. In fact, achieving savings of all electricity and natural gas use of approximately one third relative to a business-as-usual case by 2030 would require investments with payback periods of less than three years. However, Andrews and Krogmann (2009a,b) argue that not so much costs, but the comfort and quality objectives of users, may be the main determinant in energy technology choices. To save energy, passive design features should be used and building operating and maintenance practices improved (Andrews and Krogmann 2009a). Additionally, energy-efficient technologies are most likely to be adopted by the owners of new, large energy-intensive buildings (Andrews and Krogmann 2009b).

Several recent papers discuss the need and potential for improving energy efficiency of buildings in China, where building energy consumption has been growing by more than 10% annually (Yan-ping et al. 2009). In existing buildings, the occupants' behaviour is a large driver of energy usage and savings. Regulatory and voluntary instruments can be used to encourage energy-efficient behaviour and environmental awareness (Lee and Yik 2004). New policies and building codes aim to lower the energy intensity of public buildings (Cai et al., 2009). Yan-ping et al. (2009), Dai et al. (2009), and Jin et al. (2009) discuss policy regulation as well as energy measurement and management systems for public buildings and their potential to decrease the growth in energy consumption. Jiang (2011) discusses why policy measures and efficiency standards by themselves will not suffice to reach the targets set by the national and regional governments.

Several authors discuss that cost effectiveness and very short payback periods do not provide enough incentive for measures to be implemented. The consulting company McKinsey (2009) shows that many energy-saving and CO_2-emission-reduction measures have a large positive net present value. However, various thresholds exist for taking action. A major one is that often the entity who should make the upfront investment is not the entity benefitting from the lower operational costs. This is an example of what is known in the literature as the principal-agent problem (Grossman and Hart, 1983). Building constructors and owners can be hesitant to invest in energy-saving measures not knowing if the future buyers will remunerate them to reward the anticipated lower operational costs. Ryghaug and Sørensen (2009) discuss gaps in Norway between the communicated government energy-efficiency ambitions and the measures taken. Although the societal awareness relative to energy cost seems to have increased, the necessary follow-up is lacking. Existing government action, such as providing information and economic incentives, is not backed up by stricter building codes or by using its own position as a large building owner to push development in the right direction. Clearly, economic benefits alone do not provide enough incentives, and there is a need for additional stimuli to overcome the barriers to taking action.

Research can help to provide a means to overcoming these barriers. Alongside policy development fostering energy and sustainability goals, the European Commission (EC) stimulates research activities through its so-called framework programmes. In recent years, research projects have been executed to support achieving the goals outlined in the energy and climate directives. These projects covered areas from standardizing energy certificates and monitoring energy performance to suggesting energy-efficiency measures and distributed power generation (for an overview, see EC 2012a). Most projects focus on one or just a few aspects of energy management; however, meeting EU ambitions requires an integrated approach to improve energy management of public buildings and achieve the objectives laid out in the directive 2010/31/EU. Taking such an approach, in October 2010, nine organizations commenced the project “Energy Efficiency and Risk Management in Public Buildings” (EnRiMa) to develop decision support tools for energy and risk management in public buildings. Models are developed to manage energy flows in buildings with reduction of costs and/or risks involved, while providing a desired comfort level for the building users. The aspects that are considered in such models range from the thermodynamics of energy flow in buildings and the dispatch of various electricity and heat generation options to spot and contract purchases of energy. A major contribution of EnRiMa is to consider explicitly long-term developments and strategic decisions as well as the potential risks due to short-term price and demand uncertainty.

Regarding the time horizon, two types of decisions must be made: short-term operational management decisions and long-term strategic decisions. The short-term decisions cover aspects such as the on-site power and heat generation dispatch, off-site energy purchases, and contracts. The operational considerations include how to balance comfort and costs, and how much can the building occupants' behaviour be steered.

Long-term decisions relate to investments and contracting. Investments in on-site generation capacity may include renewable options such as solar photovoltaic or solar boilers, and energy-efficiency enhancing measures such as heat pumps, insulation, and CHP.

Figure 1 illustrates how strategic and operational decision variables (DV) are interrelated in the EnRiMa Decision Support Systems (DSS). Strategic decisions need to balance risks, should take into consideration operational aspects, and allow for recourse decisions by hedging against various scenarios.

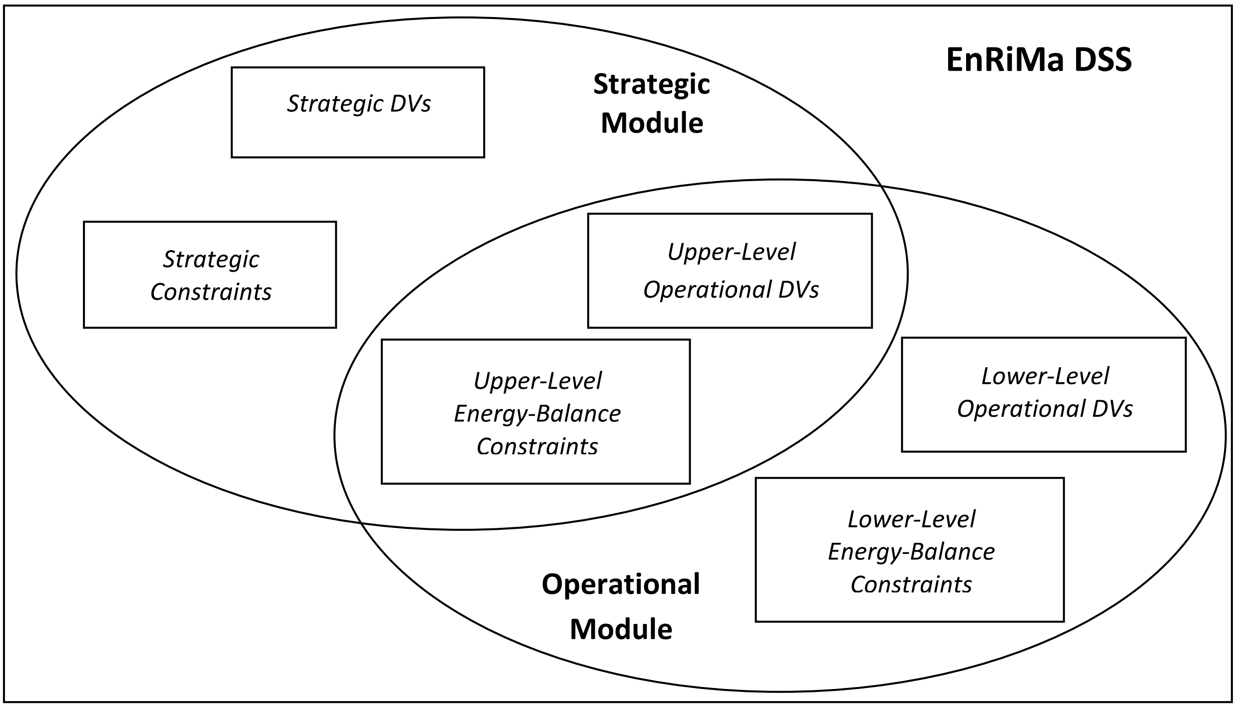

Figure 1 Interplay between operational and strategic decisions (EnRiMa)

As this discussion shows, there are many short-term and long-term considerations to managing energy supplies and costs. This paper focuses on long-term energy-economic aspects relevant to strategic decision making in public building energy management. Specifically, factors driving energy prices and uncertainty, and the modelling of these factors, are discussed. Our main findings include: 1. Small differences in technological progress can have large impact on competitiveness of technologies in the mid and long term, especially for new technologies. 2. Fossil fuel price projections are very unreliable. For natural gas, the fossil fuel with the largest share in the fuel mix for buildings (directly and indirectly as input for power generation), price projections in the past have been off more than for other fossil fuels. 3. Efficiency gains and shifts in the merit order for electric power production can lower future electricity prices significantly. 4. To address the complexity and uncertainty related to building energy management to balance comfort, cost, climate and risk objectives quantitative decision support tools are necessary. Given the magnitude of the uncertainties, wide enough bandwidths for stochastic parameters should be accounted for.

The remainder of this paper is organized as follows. Section 2 discusses technological progress and consequences for long-term investment costs and energy prices. Section 3 observes trends in fossil-fuel prices with a focus on natural gas. Section 4 explores electricity prices addressing various generation sources and types of exposure to price volatility. Section 5 examines the consequences of technological progress and energy price trends for making strategic building energy management decisions. Section 6 concludes and offers directions for the next phase in the research.

2 Technological progress in decentralized and renewable electricity generation

Technology developments affect the future cost of energy supply options and play a major role in strategic investment decisions regarding cost-efficient, reliable future energy supplies (Sagar and Van Der Zwaan, 2006). Hence, future efficiency and costs of various supply options are important inputs for a strategic energy management decision support tool. In this section, we discuss the concept of technological progress and discuss some methods and literature for estimating and forecasting technological progress.

According to Schumpeter (1912), *progress in the methods of production* is one of five key factors that explain economic development. The concept is also referred to as learning curve, learning rate, progress rate, and experience curve. A simple approach to learning assumes a constant relative cost decrease for every doubling of a specific measure (e.g., installed capacity or produced quantity). This implies that young technologies learn faster than mature ones. Let C_t denote the cost per unit at time t, δ_0 the cost of the first unit, CAP_t the total installed capacity, and ε_L the learning elasticity. Then: $C_t = \delta_0 CAP_t^{\varepsilon_L}$, or equivalently $ln\, C_t = ln\, \delta_0 + ln\, CAP_t \ + \varepsilon_L$ is the one-factor learning curve (or Henderson's Law) (Jamasb and Köhler, 2007). This expression captures *learning by doing.* Including an additional explanatory variable results in a two-factor learning curve. For instance, adding the knowledge stock K_t (*learning by searching)* gives $ln\, C_t = ln\, \delta_0 + \varepsilon_L ln\, CAP_t \ + \varepsilon_K ln\, K_t$ (Söderholm and Sundqvist, 2003). Whereas learning by doing represents the consequences of gaining experience, learning by searching represents the positive effects of research on technological progress.

In contrast to the above, it is also possible to assume that young technologies do not learn quickly. Typically, in the first period after a new technology is invented, considerable effort (time and money) is needed to improve the cost and efficiency. After the initial hurdles are taken, progress speeds up until the physical limits for improvement come nearer and progress slows down. When plotted against time (or investment amounts), the shape of the curve looks like an S, hence the name, S-curves. Two expressions for this kind of non-constant technological progress are the Gompertz curves and the logistic curves (Bengisu and Nekhili, 2006). Denote location by α and the shape of curve by β, and let L be an asymptotic (physical or theoretical) maximum value of the forecasted variable C_t. The Gompertz curve is then described by $C_t = Le^{-\alpha e^{-\beta t}}$ and the logistic curve by $C_t = \dfrac{L}{1+\alpha e^{-\beta t}}$. How to choose which of these two S-curves should be used in a particular situation can be investigated by using a statistical regression model (Bengisu and Nekhili, 2006).

Anderson and Tushman (1990) describe an alternative two-stage learning perspective as a cycle of an unpredictable breakthrough of a new technology followed by a period of incremental technical change where the most useful parts of the new technology are adopted and copied. Schumpeter (1912) presents the cycle of technological progress as invention (new ideas), innovation (implementation and improvement upon ideas), and diffusion (of knowledge and products). Boston Consulting Group (1968) describe four phases: development, price umbrella, shakeout, and stability. In the development phase, a supplier may set prices below costs to gain a market share. When the market grows, more suppliers enter the market. At first, the initial supplier benefits from the lead position and lower costs. This period is denoted as the price umbrella. When the new entrants see their costs decrease, the market becomes more competitive. This is the shakeout phase after which the market eventually stabilizes.

The stages that need to be addressed depend on the research objective and the time horizon. A period of about 25 years is often not considered long enough for a completely new technology to break through and gain a significant market share. For instance, the World Energy Model (WEM) covers a time horizon until 2035 (IEA 2010). The WEM captures technological progress through a constant learning rate based on produced outputs by a technology. In contrast, the model that is used for various energy projections for the EC, the POLES model, incorporates two-factor learning and covers learning by doing and learning by searching (Criqui, 2001; Rynikiewicz and Criqui, 2005). In the POLES application for the World Energy and Technology Outlook 2030 (EC 2003), only incremental technological change is considered, whereas WETO 2050 (EC 2006), with a 20 year longer time horizon, considers technological breakthroughs, too.

Many researchers have estimated learning rates for energy-supply technologies. Söderholm and Sundqvist (2003) discuss that estimates for different learning rates depend on how many and which explanatory variables are included in the analysis. Some factors that are typically difficult to account for explicitly are spill-over effects of learning, e.g., between countries or between technology fields. Notably, ICT developments have positive effects on many other technologies through more efficient monitoring and calculations. In regard to wind power in several European countries, Söderholm and Sundqvist (2003) find values for learning by doing ranging from 1.8% to 8.3% and for learning by searching up to 16.4%.

Goldemberg et al. (2005) provide numerical evidence for the learning curve in Brazilian ethanol production and discuss the results in the context of values for cost reductions for wind energy, solar photovoltaic, and combined-cycle gas turbines in Europe. McDonald and Schrattenholzer (2001) report that the majority of the learning rates for energy technologies calculated based on time windows ending after 1985 are in the range of 18% to 25%. Jamasb and Köhler (2007) survey the modelling of learning curves for technological progress related to energy. Their review results in a general learning rate of 20% applicable to many different technologies. Data for specific technologies range from 3% to 35%. Although the general learning rate they find is within the same range as reported by others, the bandwidth of values for separate technologies is larger than for instance in McDonald and Schrattenholzer (2001). In sum, careful attention is needed when determining the technology learning rates values to use in a specific analysis.

Clearly, a strategic decision support tool should consider learning as it effects the optimal timing of investments. Models that forecast technological progress endogenously usually apply curves (like the ones discussed above) based on some explanatory variables that project a cost decrease per unit output. Explanatory variables are usually aggregate production volume or installed capacity and sometimes R&D expenditures. When economies of scale are used as an additional dependent variable, the learning rate values found tend to be significantly lower (Söderholm and Sundqvist 2003). However, it is generally difficult to estimate and forecast the separate impacts of learning by doing, learning by searching, and economies of scale. Unfortunately, especially for new technologies a few percentage point difference in the learning rate can have a large impact on future costs, but for older technologies the impact will be smaller because the aggregate installed capacity already in place is much larger, and hence not likely to double several times over the planning horizon. A section in IEA (2000) shows how a two-percentage point change in learning rates for photovoltaic (PV) power generation affects the cumulative capacity, and changes the moment in time that PV would break even with fossil-fuelled power generation by several years.

Decentralized (renewable) power generation technologies are in various stages of their development and deployed at different scales, which affects the potential for future technological improvements. Notably, the deployment of solar and wind power has increased rapidly over the last decade. Typically, production and installation costs have decreased dramatically, but the picture is not always clear. Investment costs depend heavily on project characteristics such as the construction location. For instance, new offshore wind turbines have larger capacities but are constructed on increasingly deeper sea beds, which is more costly. Remoteness from the power transmission grid is favourable for the economic competitiveness of PV

It is not feasible to model the complete global development of solar PV or any other technology in a decision-support tool for a public building energy management. From the building manager's perspective, technological progress is exogenously given when she is considering investments and refurbishments. However, uncertainty in costs and efficiency projections should be accounted for. The decision-support tools developed, e.g., in EnRiMa, should not only account for the uncertainty in the *future* cost and efficiency developments but also have up-to-date information available on all the relevant technologies to provide the best starting points for future projections.

In this section, we have discussed that cost and efficiency developments of distributed and renewable technologies for on-site power and heat generation are important when making strategic investment decisions for public building energy management. However, according to Atkinson et al. (2009), energy price trends are the largest determinant when it comes to investments that improve the energy efficiency and decrease CO_2 emissions of existing residential and office buildings. The next sections discuss drivers and trends in energy prices.

3 Drivers and trends of future energy prices

In this section, we discuss various aspects that are relevant for the development of future energy prices, focussing on natural gas. The IEA (2012) reports energy consumption in public buildings as part of Commercial and Public Services. In 2009, the EU27 consumption in that category totalled 140.5 million tons of oil equivalent, accounting for about 12% of total EU27 energy consumption. Figure 2 breaks down the total supply by energy source. Electricity makes up 47% of the total and natural gas provides 30%.

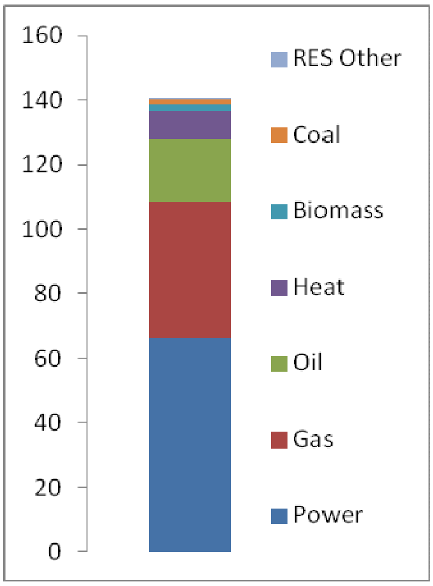

Figure 2 Energy supply to commercial and public services (IEA 2012)

Considering that almost 25% of electrical power and 42% of heat in 2009 in the EU27 originated from natural gas (IEA 2012), it is the fossil fuel with the largest share in the fuel mix of public buildings. Additionally, natural gas is considered to be the marginal fuel in electricity production, often determining the electricity spot price. Therefore, the discussion focuses on natural gas supply and price trends.

A major driver of the developments in the natural gas market in the last years has been the developments in unconventional natural gas in the USA and the consequences for its LNG trade. In 2005, the net US LNG imports amounted to 16 billion cubic meter (bcm). In the Annual Energy Outlooks (AEO) in the years 2005 to 2008, the Energy Information Administration (EIA) projected large increases of the LNG imports in the period until 2030.

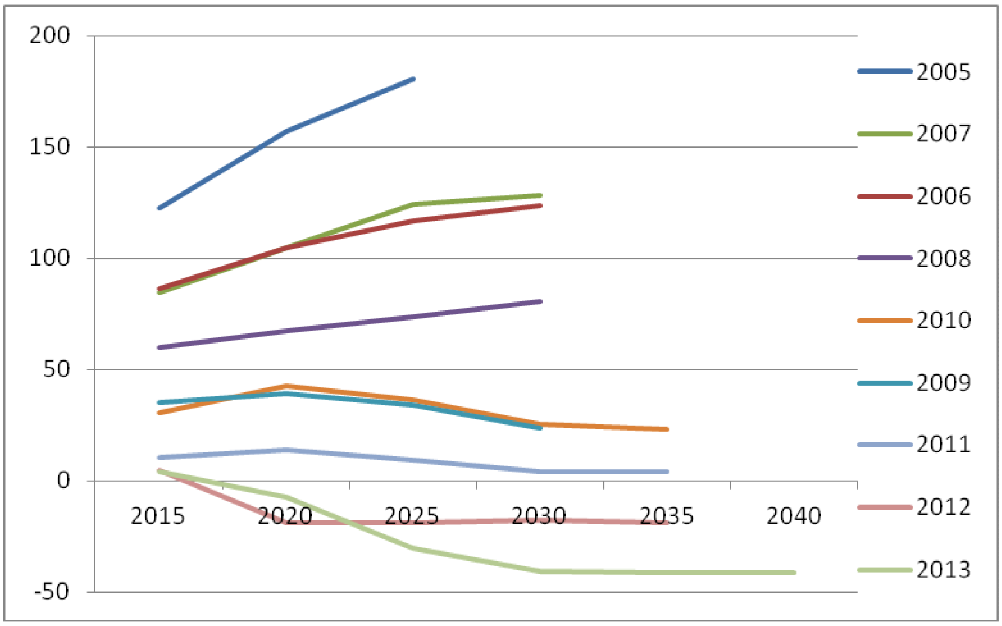

Figure 3 Projected Net LNG imports (bcm/y). (Own compilation based on EIA 2005a-2013a)

However, due to huge technological innovations in shale gas production, the picture has shifted dramatically. In the AEOs of 2009 to 2011, the projected LNG imports all but diminished. In the last two projections of 2012 and 2013, EIA foresees that the USA will be a net exporter starting in 2020. The 210 bcm difference for 2020 between the projection of 2005 (180 import) and 2012 (30 export) is huge, compared to the current market size of 330 bcm (BP 2012).

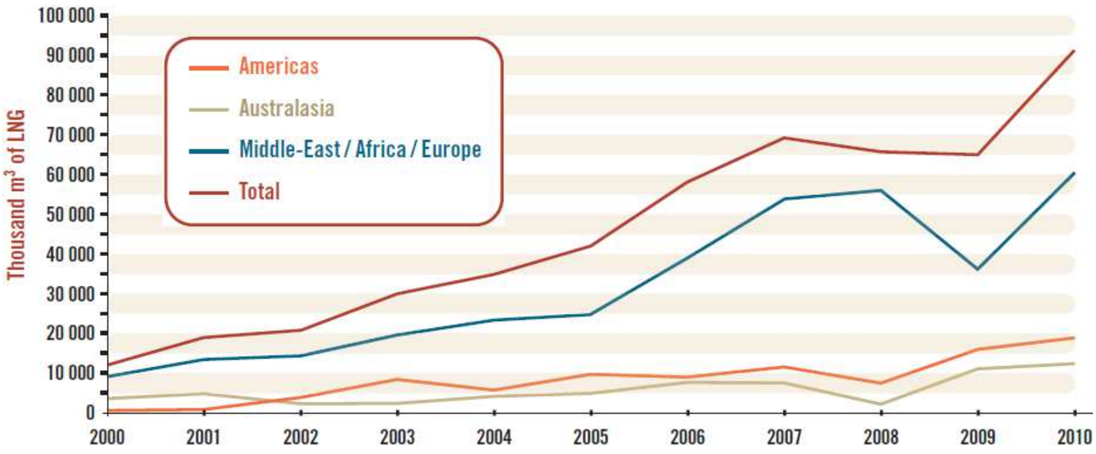

Figure 4 Short-term and spot trade (GIIGNL 2010)

In the global picture, Qatar has expanded its liquefaction capacity enormously in recent years. According to GIIGNL (2011), Australia and many other countries are constructing and planning new liquefaction capacity. LNG trade is growing rapidly and that is likely to continue. This will improve the liquidity in global LNG and gas markets, including short-term trade opportunities. LNG spot trade has increased even faster than trade under long-term contracts (Figure 4). This is favourable for countries that are increasingly dependent on gas imports and their options for additional short-term supplies in times of sudden demand increases.

In long-term energy price projections, the crude oil price is a major factor. Among the IEA, EC, and the EIA, none of them forecasts oil prices. Oil price projections are often an important and critical assumption for energy market and other forecasts. From one year to the next, the oil price assumptions may change considerably. The last few years IEA (2011), EIA (2011b), and others project an oil price around $120/bbl for 2030-2035 (in current prices).

Rather than just looking at the absolute values of natural gas price projections from the various organizations as s given, it is informative to look whether they are determined endogenously by the forecasting models or just taken as a fixed percentage of the oil price. For instance, the IEA (2009) uses a fixed, but over time changing, ratio between gas and oil price. EC (2009) takes a fixed ratio in early years but increasing gas-to-gas competition later on. EIA assumes gas-to-gas competition throughout the time horizon. As a consequence, even given very similar oil price projections, the gas price projections differ considerably. EC projects a large price increase, but the price increase IEA (2009) is much smaller in magnitude. EIA (2011a) projects relatively low future gas prices.

Natural gas prices vary by geographical location, the level in the supply chain, the type of transaction considered, etc. When considering investment options in energy technologies, as in the strategic decision support tool developed, e.g., in EnRiMa, relevant natural gas prices are those paid by an occupant of a moderate to large-sized building. The prices paid by such an organization include not only the gas commodity costs but also transportation and distribution charges, environmental and other taxes, profit margins of agents in the supply chain, and value-added tax. The larger these additional taxes and charges are relative to the natural gas commodity price, the lower the relative impact of the gas itself is on the price paid by the end user. The yearly consumption of moderately large buildings will be in the 1000-10000 GJ range (25 – 250 thousand m^3) (c.f., Zomer 2011 p. 102). For this group, the EU27 average commodity price + Value Added Tax (VAT) is 62% of the delivered price (C.f., EuroStat 2012, data 2011 Jan-June). (Note that VAT is a percentage and other taxes are usually fixed amounts per energy unit; hence, the VAT adjusted price fluctuates identically to the ex-VAT prices.) Typically, transportation and distribution charges in Europe are regulated. That means that they cannot spin out of control and will not become very large all of a sudden. However, with increasing energy efficiency and lower gas consumption per connection, distribution charges may grow more than the general inflation rate (EIA 2010b). Energy taxes may also rise quicker than the general inflation rate, depending on political preferences and decisions. The next section discusses trends and drivers in centralized heat and power production.

4 Drivers of electricity supply costs

Electricity and heat can be purchased from an external supplier or produced on-site in a decentralized fashion. The total costs and risks of externally purchased energy must be compared to investment and operating costs and risks of onsite generation when determining the optimal energy supply portfolio. The relative price paths of different technologies affect the kind of retrofitting decisions made (Atkinson et al., 2009). The future electricity supply costs depend not only on fuel costs but also on the energy efficiency development in electric power production and the penetration of renewable energy.

The daily, weekly, and seasonal patterns in electricity demand are largely predictable and dependent on the climate, and winter and summer seasons induce heating days and cooling days. Figure 5 shows an example of a country-level aggregate daily load curve. For individual homes and offices the daily variation tends to be higher, dependent on factors such as whether gas, electricity, or district heating is used for space heating.

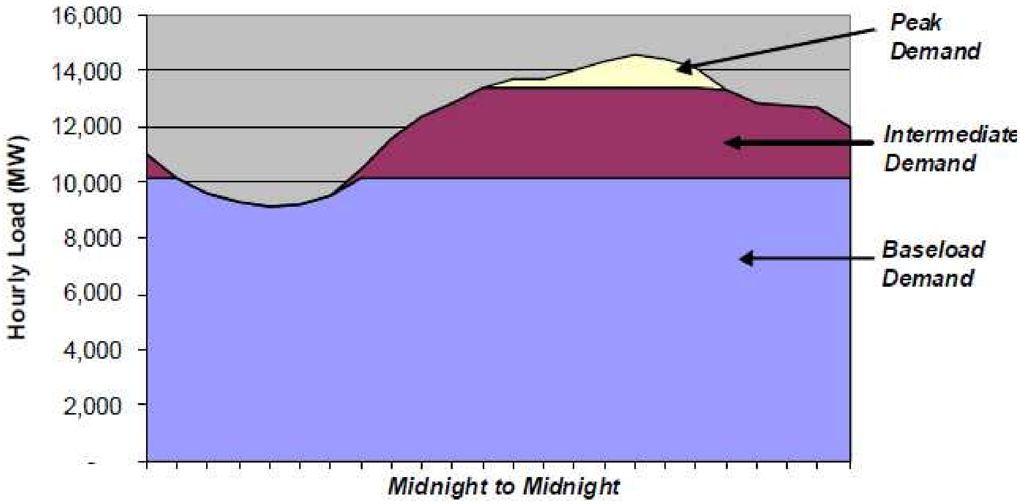

Figure 5 Example of Daily Load Curve (Kaplan 2008)

Figure 6 displays, for the United Kingdom in 2010 – 2011, what percentage of the time the countrywide load was relative to the largest load in the year, demonstrating that a significant part of the generation capacity is needed for a small part of the time only.

[INSERT FIG 6 HERE]

Figure 6 Load Duration Curve for the United Kingdom 2010-11 (National Grid 2011)

The merit order, the order in which electric power generators are deployed to meet demand at a certain point in time, is mostly based on marginal production costs per kWh but affected by operational aspects such as ramping times. Nuclear and coal-fired plants cannot simply be turned off for a few hours. In contrast, gas-fired plants can generally ramp up in less than an hour, and hydro power within minutes. Solar, wind and run-of-the-river hydro power production is lost when not used. Figure 7 shows a typical merit order for dispatching power generation capacity.

[INSERT FIG 7 HERE]

Figure 7 Merit Order Curve (Adapted from GASNET 2012)

Among the natural gas-fired electricity generating plants, many CHP ones provide base load due to heat demand. In contrast, many other gas-fired technologies are much less efficient and used for meeting peak demand and short-term backup supplies only. This phenomenon is why natural gas is considered to be the marginal fuel in power production (e.g., Kaplan 2008). As such, the thermal efficiency of gas-fired power plants is one of the drivers of the electricity price. Simply put, the gas commodity price, adjusted for the conversion efficiency of the least favourable power generation unit dispatched, determines the electricity price.

Naturally, hourly electricity prices correlate with the consumption level. For instance, the day-ahead price for the Netherlands on March 28, 2012 at a delivery hour on March 29 at 12pm-1pm was €69.34/MWh, almost five times as expensive compared to the €14.20/MWh price for 5am-6am.

For large non-industrial consumers, about 40% of the average delivered price in the EU27 is made up by transport charges and other taxes (EuroStat 2012). Since most or all of the additional charges do not apply to on-site generation and VAT may not apply, the decentralized (renewable) power production costs per kWh can be about double the level of central-station generation and still be competitive economically.

Bork (2010), Graus et al. (2007), and Graus and Worrell (2009) compare and discuss efficiency trends in fossil-fired power generation. Many have argued that the addition of renewable resources will push up the merit order – also for base load production - and possibly push out the least efficient generating capacity (e.g., Weigt and Von Hirschhausen, 2008; Weigt, 2009). With adequately high CO_2 prices, the crowded-out technologies should be coal-fired power plants. However, low CO_2 prices in the ETS and abundant supply of coal from the USA has resulted in lower production from natural gas technologies in several European countries, e.g., the Netherlands (CBS 2012).

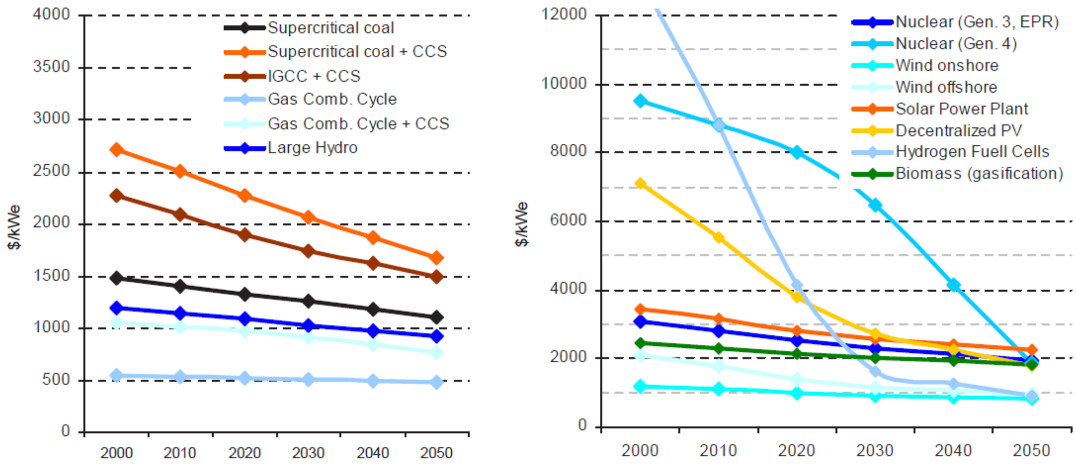

Figure 8: Projected investment cost reductions for power generation (EC 2006)

To assess the potential for technological development EC (2006) uses the TECHPOL data, compiled in a FP6-project, to forecast technological progress (Figure 8). According to these projections, significant investment cost reductions of about 20 to 40% occur over a time span of fifty years, also for conventional technologies. Larger reductions are anticipated for new technologies, such as offshore wind, hydrogen fuel cells, and 4th generation nuclear plants. EC (2012b) provides production cost projections for a range of technologies for 2020. Regarding their annual energy outlooks, EIA (2011b) describes the assumptions for investment cost and operational costs, efficiencies and learning rates for centralized traditional and renewable power generation. The majority of the learning rates for energy technologies reported by McDonald and Schrattenholzer (2001) are between 18% and 25%. These estimates can be used to assess uncertainty margins around the likely progress rates.

5 Discussion

By the end of 2020 existing buildings should be near ZEB, and by the end of 2018 new public buildings should be completely ZEB. This means that building operators should start adjusting their energy supply sources to be more sustainable. In the EnRiMa project, quantitative decision support tools are being developed to support the strategic and operational decisions related to building energy management. The comfort, costs, and risks of options that should be considered for reducing energy consumption and emissions can vary by the type of building concerned, the geographical location, and many other factors. For instance, Zomer (2011) compares systems for providing heating, cooling and hot water to offices, educational buildings, and hospitals. He concludes that CHP systems perform best in regards to economics and avoiding CO_2 emissions, and for hospitals overall. However, in offices and educational buildings in areas with milder climates, heat pumps are more energy efficient.

A building operator should have an integrated, or *portfolio* perspective. Given likely scenarios and uncertainties for investment, fuel, and operational costs for the current and potential energy supply options, investment and operational decisions must be made. Such investments can not be taken without considering the integrated energy supply and consumption situation.

For instance, CO_2 emissions can be reduced by onsite renewable generation, but possibly also by purchasing green power and biogas, or by offsetting CO_2 emissions somewhere else. An intermittent renewable supply resource needs a means to balance and backup the energy supply. This can be an on-site generator, such as fuel cell or biomass CHP, a contract with an energy trader for flexible supplies or feed-in, or a storage option. A small intermittent renewable source might not be enough to meet the building's peak consumption and additional, and flexible supplies will be necessary. In contrast, a large intermittent source would need an accompanying storage or feed-in arrangement. Economies of scale must be weighed against the feed-in tariffs for various contracts. An alternative for reducing CO_2 emissions can be a CHP running on biogas. Clearly, before investing in the CHP unit, it should be clear that the biogas can be obtained or contracted for the life-time of the generation unit.

Today, natural gas is the most important fossil fuel for public buildings. By 2020 when all new-builds need to be nearly ZEB, gas consumption may need to be switched to biogas or compensated by feeding electricity from renewable resources back into the grid. The latter would imply that more on-site renewable generation capacity would be available than needed for meeting the building's own consumption at the expense of higher investment costs. However, from an integrated portfolio perspective – managing costs, risks, and comfort – this could be a viable solution.

The more mature a technology is, the lower the annual cost reduction tends to be. Uncertainty in technological progress has more impact on future cost and efficiency of new technologies than on mature technologies. If a technology needs a large improvement to become competitive, then a few percentage points deviation in the learning rate can mean a difference of years in terms of breaking even. Typical learning rates for energy technologies involve about 20% cost reduction for each doubling of the installed capacity. A stand-alone decision support tool cannot capture factors such as accumulation of production capacity and research expenditures. Hence, rather than modelling endogenous learning curves in a DSS, cost and efficiency projections from the literature can be used. The across the board long-term yearly technological progress is about 1.5% to 2% per year. However, since variation among technologies is what matters most when comparing investment alternatives, one should not take the same value for all the technologies considered.

Although the technology status of conventional fossil-fuel is clear, albeit still improving, the level and uncertainty towards fuel prices has a large effect on the competitiveness of all power generation options. As such, future energy prices are important, but unfortunately impossible to forecast. A wide enough bandwidth should be used for the development of scenarios and uncertainty margins when energy supply options for public buildings are considered. For instance, EIA (2011b) assumes a likely oil price of \$125/barrel, and low and high values of \$50 and \$200. As extreme as that may seem, the 30% margin around a reference oil price that EIA (2000b) assumed for 2020 seemed reasonable at the time, but in 2013 nobody believes that the oil price in 2020 will be in the bandwidth between \$25 and \$46 (even in \$ of 2000).

Building operators and the EnRiMa DSS need to make long-term investment decisions that prevent locking-in. There is a need of flexibility for recourse, including dispatch possibilities, demand-side management measures, using storage and trading in the spot market. To capture short-term uncertainty in a strategic setting, Kaut et al. (2012) present a multi-horizon, dual-level scenario tree structure. In such an approach, the uncertain parameters with a long-term scope in the EnRiMa scenarios, include energy prices, technology efficiencies and costs, and subsidy schemes. Short-term uncertainty includes energy prices, building occupancy, and weather conditions.

Where research subsidies are intended to push research activities and help society through its learning curve, investment subsidies and feed-in tariffs try to achieve the same goal by pulling from the demand side. Subsidy and feed-in tariff schemes have a big effect on pay-back periods by lowering the risk for building operators/investors. As discussed, cost-incentives are often not enough, and it is time for the governments at all levels, EU, national and regional, to use their own position more actively as large building owners to push developments in the right direction and back up energy-efficiency ambitions.

6 Conclusions

Directive 2010/31/EU outlines measures specifically focused on the energy performance of buildings. Integrating long- and short-term decisions in operational building energy management requires processing large amounts of information and balancing costs, comfort, and risks. Having insight in technological progress and the development phases of energy technologies will help to inform better strategic investment decisions for energy management in public buildings. Investing today in mature technologies may give more certainty about costs and efficiencies, but this will lock out near-term investments in newer technologies. New technologies may have a large potential for cost and efficiency improvement, but they cannot readily be invested in to gain from the potential benefits.

A decision support tool for building energy management should have an integrated perspective on comfort, costs, and risks, and consider long-term energy prices and technological progress, and uncertainty therein. These considerations are the basis for the scenarios and DSS developed in the EnRiMA project to support measuring and managing the energy usage and costs of public buildings and making long-term investment decisions for newly built, replacement, and retrofitting equipment.

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