Benchmarking the EU reference scenario 2016: An alternative bottom-up analysis of long-term energy consumption in Europe

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Abstract
Long-term scenarios of future energy demand are a major prerequisite when planning future energy systems and policy intervention. A prominent example of this is the recently published 'EU Reference Scenario 2016', which supports the European Commission's policy decision-making process via model-based energy system analysis until 2050 using the PRIMES energy system model. In terms of modelling energy demand, the EU Reference Scenario is analysed on sector level based on non-linear optimization routines and econometric functions. Due to the high relevance of the PRIMES results for the political discussion on a European level, we use the data published by the European Commission to compare and benchmark the projection of energy demand with the results of our own bottom-up analysis. The goal of this comparison is to critically reflect upon the results provided by the EU Reference Scenario on the one hand and to better understand the forces driving energy demand on the other hand. The applied modelling platform FORECAST aims to develop long-term energy demand scenarios of individual European countries. FORECAST is designed as a simulation-based bottom-up modelling approach, which considers the dynamics of technologies and socio-economic drivers on a high level of granularity. This includes vintage stock modelling for space heating equipment, household appliances and industrial steam systems, among others. To ensure a high level of comparability, we use similar framework assumptions (GDP, population, energy prices, etc.) as those provided in the EU Reference Scenario. The model results for final energy demand in the EU27 are compared by sector and country up to 2035, focusing on the residential, tertiary and industry sectors. The comparison focuses particularly on the role and contribution of bottom-up energy demand modelling and the driving forces of energy demand in the three sectors.

Introduction
Long-term projections of energy demand are a major prerequisite when planning future electricity systems. The European Commission regularly publishes the 'The European Reference Scenario' (Capros et al. 2016), which includes an estimate of how Europe's energy demand will evolve until 2050. This following study uses framework data published by the European Commission for a sector overarching bottom-up analysis using the FORECAST model to benchmark study outcomes with the results of the European Reference scenario and discuss potential model differences and driving forces of final energy demand. We apply the modelling platform FORECAST, which aims to develop long-term scenarios of future energy demand for individual European countries until 2035. FORECAST is based on a bottom-up modelling approach considering the dynamics and inertia of technological change as well as socio-economic drivers. The model allows various research questions related to energy demand to be addressed including scenarios for the future demand of individual energy carriers like electricity or natural gas, the calculation of energy saving potentials and the impact on greenhouse gas (GHG) emissions as well as abatement cost curves and ex ante policy impact assessments. The major advantages of using such a detailed bottom-up ap-

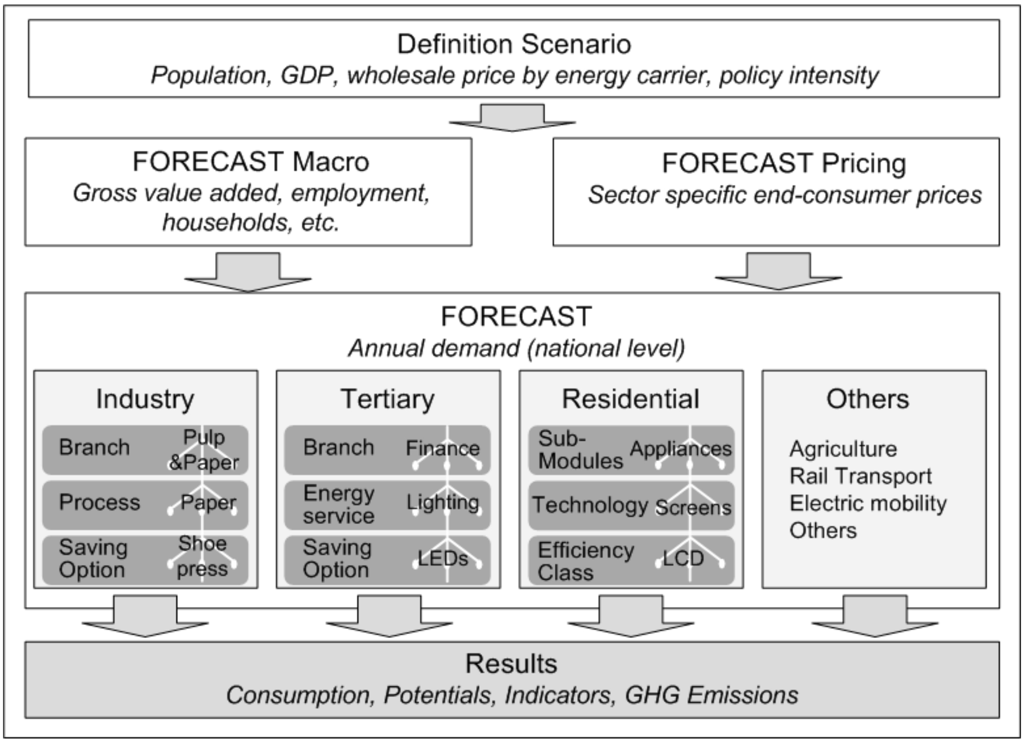

Figure 1. Overview of FORECAST model structure. Source: Fraunhofer ISI.

proach are - due to its high level of technological granularity – the detailed evaluation and modelling of technology-specific policies as well as modelling explicit technology and innovation developments taking structural changes into account.

Modelling future energy demand

INTRODUCTION

The following section describes the bottom-up simulation model FORECAST (FORecasting Energy Consumption Analysis and Simulation Tool), which is used to derive long-term projections for the future annual energy demand in individual European countries. FORECAST is designed to simulate the dynamics of technologies and socio-economic drivers, distinguished by the individual demand sectors on a high level of granularity. In addition, the model also considers factors such as weather conditions, the impact of past and prospective economic situations including socio-economic trends, technology change and energy efficiency policies. The projections of final energy demand can be evaluated for individual energy carriers, of which the most significant are electricity, gas, heating oil, district heating, solar thermal and biomass. The model system has been developed for the EU-28 plus Norway, Switzerland, and Turkey up to 2050, and has already been applied in international studies for Brazil and Taiwan. FORECAST is based on earlier work by Fleiter et al. (2011a, 2011b, 2012, 2013), Jakob et al. (2012, 2013), and Elsland et al. (2013, 2014a, 2014b, 2016). Even though FORECAST is able to generate results with a high level of granularity, the comparison here has to take place on a more aggregated level – that of final energy demand – in order to match the publicly available information from the EU Reference Scenario 2016 (EU Ref 2016).

MODELLING APPROACH

The FORECAST modelling platform comprises four individual models, each representing one sector in line with the Eurostat energy balances: industry, services/tertiary, residential and others (agriculture and transport; see Figure 1). While all sector models follow a bottom-up methodology, they also consider the particularities of each sector like technology structure, actor heterogeneity and data availability.

This heterogeneity is reflected in the list of selected input data and provides a first idea of the level of detail of each module (see Table 1). In the industry sector, activity data are used for the demand scenario. Industrial production in physical tonnes (especially of energy-intensive industries) is used here to forecast demand. In the tertiary and residential sectors, in contrast, the demand scenarios are based on more population-related drivers (e.g. number of employees, number of households). Furthermore, end-consumer energy prices play a significant role in each sector and are distinguished by energy carrier (e.g. electricity, natural gas, light fuel oil, etc.).

The third group of input data relate to technology characteristics and also reflect data availability in the individual sectors. While in the industry and tertiary sector the model works with so called energy-efficiency measures (EEMs) which represent all kinds of actions that reduce specific energy consumption, in the residential sector the stock of alternative appliances and the market share of different efficiency classes are modelled by alternative devices. In all cases, energy savings can be calculated and traced back to technological dynamics including cost considerations. To obtain the full final energy demand at the end, data for the transport and agricultural sectors are usually taken from external sources.

THE TERTIARY SECTOR

The tertiary model has been developed by Jakob et al. (2012, 2013) based on Fleiter et al. (2010). It distinguishes 8 sub-sectors (trade, hotel and restaurants, traffic and data transmission, finance, health, education, public administration, other) and 17 end-uses including for example lighting, electric heating, ventilation, cooling, refrigeration, cooking, data centres with servers and others. To derive future energy demand, an annual energy service driver is multiplied by the annual specific energy demand per unit of driver. For example, the electricity demand for space cooling can be calculated using the specific energy demand per m^2 floor area cooled and the quantity of the given driver, here the share of cooled floor area per employee. This is in turn driven by employment in the tertiary subsectors, which depends on the development of gross value added in the service sector, demographic trends (e.g. working population) and GDP per capita. The diffusion of EEMs depends on the cost-effectiveness of efficiency alternatives or efficiency add-on measures. Costs are calculated based on a Total Cost of Ownership[1] (TCO) approach including capital costs (derived from investment costs), maintenance costs and energy costs. In contrast to the Life Cycle Cost (LCC) approach, the end-of-life disposal of technologies is not considered here. Lower and upper boundaries (terminology autonomous and technical diffusion) are defined for the diffusion path depending on historically observed trends and derived from typical lifetime or re-investment cycles of technologies and appliances. (Jakob et al. 2013).

THE INDUSTRIAL SECTOR

The industrial model is based on the works of Fleiter et al. (2011a, 2011b, 2012, 2013). It distinguishes 8 sub-sectors (iron and steel, non-ferrous metals, paper and printing, non-metallic minerals, chemicals, food and drink and tobacco, engineering and other metal, other non-classified), 64 process technologies (e.g. primary aluminium production, secondary aluminium production, paper production, cement production, electric arc furnace steel production, blast furnace steel production) and a variety of cross-cutting technologies (e.g. lighting, electric motors). Compared to the other sectors, the industrial sector shows the highest degree of heterogeneity with regard to technologies and energy users (i.e. companies). This poses a huge challenge to a bottom-up model, which always needs to focus on large homogeneous groups of energy uses/services. At the same time, the number of energy uses should not be too high as gathering input data is very time and resource intensive. Similar to the service sector, energy demand is calculated using the annual specific energy demand per unit of activity driver, which is the physical production by process in combination with the value added by sub-sector in the case of industry. The production of energy-intensive materials depends on several factors such as economic development, changes in net imports (including assumptions about fixed domestic production capacities or shrinking production capacities), material efficiency and substitution, as well as saturation effects of basic products (e.g. cement). The diffusion of technical EEMs depends on their payback time and the respective profitability requirements of firms. The payback time in turn is determined by end-consumer energy prices, European Union Allowance (EUA) prices and the saving potential. For the diffusion path, lower and upper boundaries (terminology autonomous and technical diffusion) are defined that depend on historically observed trends, the lifetime of technologies and the resulting technology stock turnover. Fleiter et al. (2011a, 2011b, 2012, 2013).

THE RESIDENTIAL SECTOR

The residential model has been developed by Elsland et al. (2013, 2014a, 2014b, 2016). It separates household energy demand into 4 sub-groups (appliances and lighting, sanitary hot water, space heating, new and others), which are reflected by 27 end-uses (e.g. air conditioning, computer screens, dishwashers, dryers, lighting, modems, stoves, televisions, washing machines, etc.). The end-uses are further broken down into technologies, and each technology is distinguished by various efficiency classes. The calculation of energy demand in the residential sector is structured as follows: The majority of final residential energy demand is attributed to space heating. The useful heat demand is calculated in a first step based on a detailed representation of the European building stock. The model is designed as a vintage stock model that captures the number of end-uses in the market in combination with their age distribution. For heating systems, the vintage stock is represented by market shares. Technology diffusion depends on the relative cost advantages of substitution alternatives. The cheaper an alternative is, the larger its market share in the corresponding year. In line with the other sectors, the costs are calculated based on a Total Cost of Ownership (TCO) approach including the investments, maintenance and energy costs. Due to the fact that the residential model is designed as a vintage stock model – with detailed techno-economic parameters of energy end-uses – stock turnover is determined by the length of the reinvestment cycles. (Elsland et al. 2013).

MODEL VALIDATION

Validating long-term bottom-up models based on empirically observed data is challenging due to two main reasons. First, long time series are required and, second, bottom-up models require a huge quantity of input data, which needs to be available for the entire time series. Given these restrictions, we propose an approach to validate the FORECAST model based on shorter time series, in this case beginning in the year 2008. Here, the main challenge is that the factors influencing energy demand are very different in the short term (1-5 years) than in the long term (5-30 years). In the short term weather and business cycles are more important, while in the long term the economic structure, technology change, climate change and others are more relevant.

Thus, in order to allow for ex-post modelling of the recent past, also short-term effects need to be considered in FORECAST. Such ex-post analysis allows calibration of input factors and results in better model quality and understanding. To implement both effects, a climate correction factor using heating degree days and temperature levels is introduced as well as an approach to model past business cycles via a capacity utiliza-

1. Total cost of ownership is used to evaluate the cost of investment goods including operation and maintenance costs as well as energy costs. The Life Cycle Cost approach is broader in the sense that additional cost factors such as disposal costs as well as use costs are also considered in such analyses.

Table 1. Overview of input parameters for FORECAST.

	Tertiary	Residential	Industry
Main drivers	No. of employees by sub-sector Floor area per employee by sub-sector Heating degree days	No of households Building area by type of building [m²] Heating degree days	Physical production by process [t/a] Value added by sub-sector [Meuro/a] No. of employees by sub-sector Heating degree days
Prices	Energy prices	Energy prices	Energy prices EUA Prices
Technology data	**Energy Services:** Technology driver Installed power Annual full load hours **Saving options:** Saving potential Costs Lifetime Diffusion	**Appliance data by efficiency class** Market share Specific energy cons. Lifetime Standby power Standby hours **Building related data:** Insulation levels Heating system efficiency Heating and lighting technology shares	**Processes:** Specific energy consumption **Saving Options:** Saving potential Costs Lifetime Diffusion

Source: Fraunhofer ISI

Table 2. Framework data EU27.

EU 27	2010	2020	2030	2040
Population (million)	496	506	512	517
Gross domestic product (MEuro'13)	12,849	14,501	16,627	19,364
Industry value added (MEuro'13)	1,748	1,937	2,155	2,395
Tertiary value added (MEuro'13)	8,701	9,946	11,523	13,599
Number of Households (million)	188	200	200	196
Household size (inhab per household)	2.6	2.5	2.6	2.6

Source: Capros et al. 2016.

tion indicator in industry. These methodological improvements have been used to benchmark the model results with available statistics from 2008 to 2012. The two methodological extensions are described briefly below:

- *Weather*: Effects such as weather (temperature, radiation) mostly are of fluctuating nature. Here, long-term average climate data has been complemented by up-to-date actual data of each year in the short-term past (temperature data weighted by population, averaging hourly data to monthly data).
- *Capacity utilization*: The energy consumption pattern of buildings, production plants, and others often is characterized by constant base load consumption on the one hand and of a variable consumption on the other hand. Whereas the latter depends on output indicators such as occupancy or industrial production, base load consumption is independent of such indicators.

Scenario definition

EU REFERENCE SCENARIO 2016

The following results are based on the latest EU Reference Scenario of the European Commission (Capros et al. 2016). Published framework data like gross domestic product, population, number of households as well as sectoral value added for industry and the tertiary sector have been used as major drivers for the simulation to enable maximum comparability (Table 2[2]). The EU Ref 2016 (Capros et al. 2016) is defined to reflect the development of energy demand, taking into account past dynamics but also future developments regarding current economic development and energy policies. Present policy targets and actions, which have been already decided or implemented, are reflected in this scenario.

2. Tertiary value added: Including agriculture.

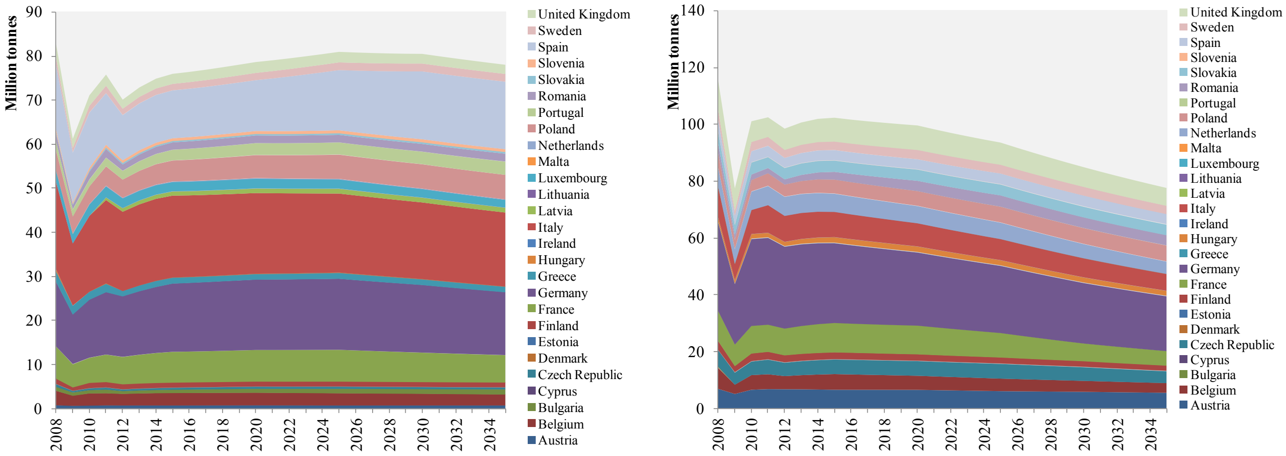

Figure 2. Electric arc furnace steel (left) & basic oxygen steel (right) production projection by country (2008–2035). Source: Fraunhofer ISI (2017), World Steel Association various issues.

However, as FORECAST is a bottom-up simulation model with a high level of granularity, a further breakdown of the economic and demographic drivers in Table 2 is required to receive activity related drivers like square metre per employee or physical production of energy-intensive products to calculate future energy demand (as shown in Table 1).

Figure 2 illustrates such physical drivers of energy demand for the iron and steel industry. Current European steel production is dominated by two production routes: the energy-intensive basic oxygen furnace (primary production) and the less energy-intensive electric arc furnace (secondary production), which are calculated endogenously within the model by a sub-module called FORECAST-Macro (Herbst et al. 2012, 2014, 2016). When modelling future steel production based on the economic development of the steel industry provided by the European Reference Scenario, intra-industrial structural changes like trends to higher gross value added (e.g. higher quality products), process switches (primary to secondary), material efficiency (e.g. less prompt scrap) and material substitution (e.g. aluminium) have to be taken into account (see also Herbst et al. (2012, 2014, 2016)). On a process level it is assumed that basic oxygen furnace steel production continues its downward trend, and has already passed its production peak (see Figure 2). Due to continued population growth and future refurbishment actions, a slight increase in electric steel production returning to pre-crisis level up to 2035 has been assumed (mainly simple construction steel).

Selected Results

The results on how final energy demand will develop are analysed on sector level for the EU27[3] up to 2035. Results were calculated on an annual basis up to 2035 commencing in 2012. As the results for the EU Reference Scenario are not available on a yearly basis, values had to be interpolated between available years.

Final energy demand in the **tertiary sector** (including agriculture and services to comply with the definition in EU Ref 2016) shows a decreasing trend up to 2035 (-0.5 % p.a.; from 1801 to 1619 TWh, Figure 3). The strongest decrease with -1.3 % p.a. takes place in public offices followed by education (-1 % p.a.), agriculture (-0.7 % p.a.) and trade (-0.6 % p.a.). Demand more or less stagnates in the other services sector as well as traffic and data transmission, while it decreases moderately in the finance and health sectors, in hotels, cafes and restaurants (by approx. -0.4 % p.a.).

The shape of the demand curve is explained by a continuation of the upward trend in the number of employees, associated floor area and diffusion of energy services in the near future. However, saturation effects are also expected in most countries and sectors for demographic reasons. Indeed, the number of potential employees is limited by an ageing population, which is only partly compensated by increased immigration, and the employment share of the tertiary sector then reaches a saturation level. Moreover, electricity demand is curbed by autonomous energy-efficiency improvements and policy measures such as the EU Ecodesign Directive, National Energy Efficiency Action Plans (NEEAP), the amended Energy Performance of Buildings Directive (EPBD), and others. Many of these policy instruments need time to be implemented, and may take even longer in the tertiary sector than in households and appliances. Thus, the impacts of these policy measures will become more pronounced in the next seven to ten years and beyond. This time lag contributes to the deferred demand saturation.

The tertiary sector's (services and agriculture) demand in the EU Ref 2016 decreases by -0.4 % p.a. between 2012[4] and 2035. However, part of this decrease is probably triggered by developments in the agricultural sector – which is probably also the main reason for the large deviation in absolute values, as FORECAST is calibrated using actual Eurostat data for the year 2012. Compared to the FORECAST results, it seems that

3. Croatia as part of the EU28 is not covered in the analysis.

4. Interpolated value 2010 to 2015.

Contents Keywords Authors

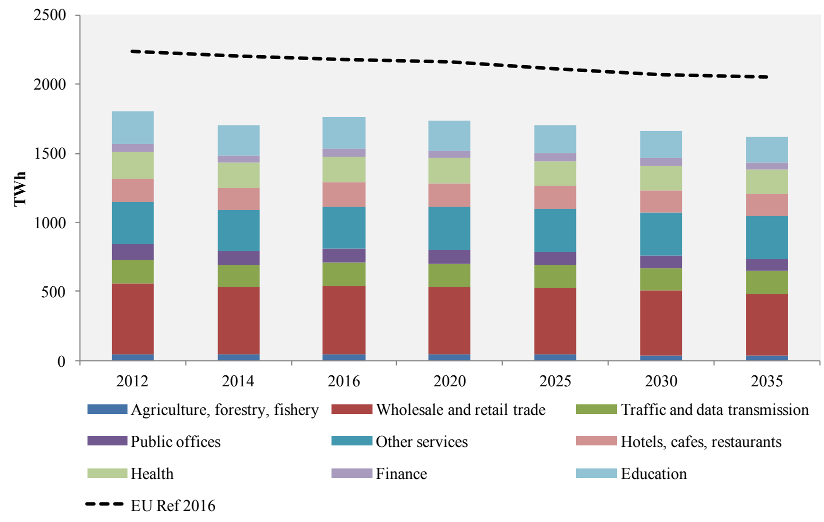

Figure 3. Final energy demand TERTIARY and AGRICULTURE, EU27 (2012–2035). Source: TEP (2017), Capros et al. 2016.

Figure 4. Country comparison absolute %-change in final energy demand TERTIARY (2012 to 2035). Source: TEP (2017), Capros et al. 2016.

the European Reference Scenario results tend to have slightly higher estimates for future tertiary EU27 energy demand. Possible reasons for these different estimations could be:

- The use of the more aggregated driver gross value added in the EU Ref 2016 (e.g. less ambitious efficiency gains, using energy intensity as the main indicator neglecting structural changes like reduced floor area per employee).
- Included temperature effects in FORECAST (e.g. higher future average temperature levels will lower the need for space heating, but increase the need for ventilation and cooling although at lower levels in the health and finance sector for example; temperature effects can be seen exemplarily between the 2012 to 2016 model results with fluctuating energy demand (see Figure 3)).
- FORECAST includes autonomous energy efficiency improvements based on existing regulations, which will be fully implemented in the coming years (e.g. no time lag contributes to deferred demand saturation).

Final energy demand in the **industrial sector** shows only a slightly decreasing trend between 2012 and 2035 (-0.1 % p.a.; from 3205 to 3134 TWh, Figure 5). The strongest decrease with −1 % p.a. takes place in the iron and steel industry triggered by the above mentioned continued production shift to electric steel and a continued trend towards higher gross value added (decoupling of economic value and physical production).

Comparing growth in the energy-intensive and non-energy-intensive industry sectors between the two approaches shows that FORECAST projects a less ambitious decrease in final energy demand for energy-intensive industries (-0.4 % p.a. between 2015–2035) than the EU Ref 2016 (-0.9 p.a.; Capros et al. 2016). In the non-energy-intensive industries, a slightly positive trend is observed in the FORECAST model results (+0.3% p.a. compared to -0.1 % p.a. from 2015 to 2035 in the EU Ref 2016; Capros et al. 2016). This suggests that the overall assumptions on energy intensity reductions in industry are more ambitious in the EU Ref 2016 than in the bottom-up model FORECAST - particularly between the years 2020 and 2030 when the EU Ref 2016 assumes the ‘implementation of new productive equipment including significant energy efficiency technologies’

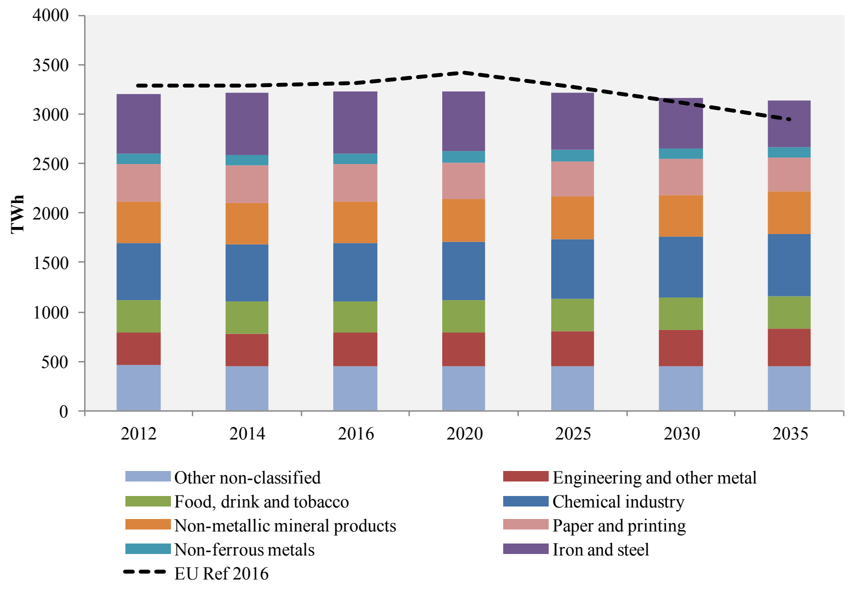

Figure 5. Final energy demand INDUSTRY, EU27 (2012-2035). Source: Fraunhofer ISI (2017), Capros et al. 2016.

(Capros et al. 2016, p. 52). Based on the information available in the public report[5], assumptions for the different industry sectors are compared in more detail.

An obvious difference is the already mentioned higher growth/less ambitious reduction in the non-energy-intensive sectors in FORECAST - engineering, food, drink, and tobacco, other non-classified (see Figure 6) – mainly driven by economic growth in these sectors. Especially in the medium term (2020 to 2030), this is in contrast to the negative growth assumed by Capros et al. (2016) with growth rates of -0.7 % p.a.[6] and lower (see Capros et al. 2016, p. 52). In the energy-intensive industries, growth assumptions in the short term (2012–2020) diverge strongly for the non-metallic mineral products (driven by cement and clinker production), the non-ferrous metals (driven by aluminium production) and the iron and steel industry, where the FORECAST model projects a still slightly positive growth in final energy demand (also driven by the recovery of activity drivers and presumably less pronounced reductions in energy intensity). In the medium term, energy demand reductions in the non-ferrous metals and the non-metallic minerals sectors between 2020 and 2030 are significantly stronger in the EU Ref 2016 scenario (approx. -1.7 % p.a. and -1.5 % p.a.) compared to FORECAST (-0.8 % p.a. and 0 % p.a.) and are probably due to the above mentioned ambitious implementation of efficiency technologies in the EU Ref 2016 (see Figure 6).

The iron and steel industry seems to be the only sector in which the FORECAST model results are more ambitious – due to the strong assumptions about structural changes, as shown in Figure 2. The strong decrease in basic oxygen furnace production – which is much less energy-intensive than electric arc furnace steel – leads to more ambitious energy demand reduction compared to EU Ref 2016. The EU Ref 2016 reports average annual changes of energy consumption in the iron and steel industry of approximately +0.25 % p.a. between 2010 and 2020, -1 % p.a. between 2020 and 2030 and -0.6 % p.a. between 2030–2050 (Capros et al. 2016, p. 52) compared to +0.3 % p.a. (2012–2020), -1.6 % p.a. (2020–2030) and -2.1 % p.a. (2030–2035) in FORECAST.

On a country level, the differences are more heterogeneous. For most of the countries the absolute %-changes in final energy demand – comparing 2035 to 2012 – in the EU Ref 2016 Scenario show a higher reduction or less growth in industry demand than the FORECAST model results. Only in France and Germany the energy demand reduction between 2012 and 2035 in the EU Ref 2016 is lower compared to FORECAST (see Figure 7).

In comparison to the FORECAST results, it seems that the European Reference Scenario results tend to have lower estimates of future industrial energy demand. Possible reasons for this different estimation could be:

- More ambitious diffusion of energy efficiency technologies in the EU Ref 2016 (implementation of new productive equipment including significant energy efficiency technologies between 2020 and 2030, Capros et al. (2016, p. 52)).
- FORECAST assumes less ambitious decrease in energy intensity in primary industry as energy savings above 10 % in that industry would mean that radical steps towards energy efficiency improvements would have to take place. From the FORECAST point of view this is not very likely to happen until 2030 in a reference scenario, as breakthrough technologies would be needed to achieve this. For this reason the industrial energy demand up to 2030 in FORECAST has a stronger focus on available technologies in primary industries. After 2030 it is more likely that new innovative technology (e.g. low carbon cement, green hydrogen or HIsarna based steel production) will enter the market.

5. Detailed sub-sector and energy carrier results were not publicly available as excel download. Numbers had to be estimated from the report.

6. Own estimates from Figure 17 in Capros et al. 2016, p. 52. Intervals 2010–2020, 2020–2030, 2030–2050.

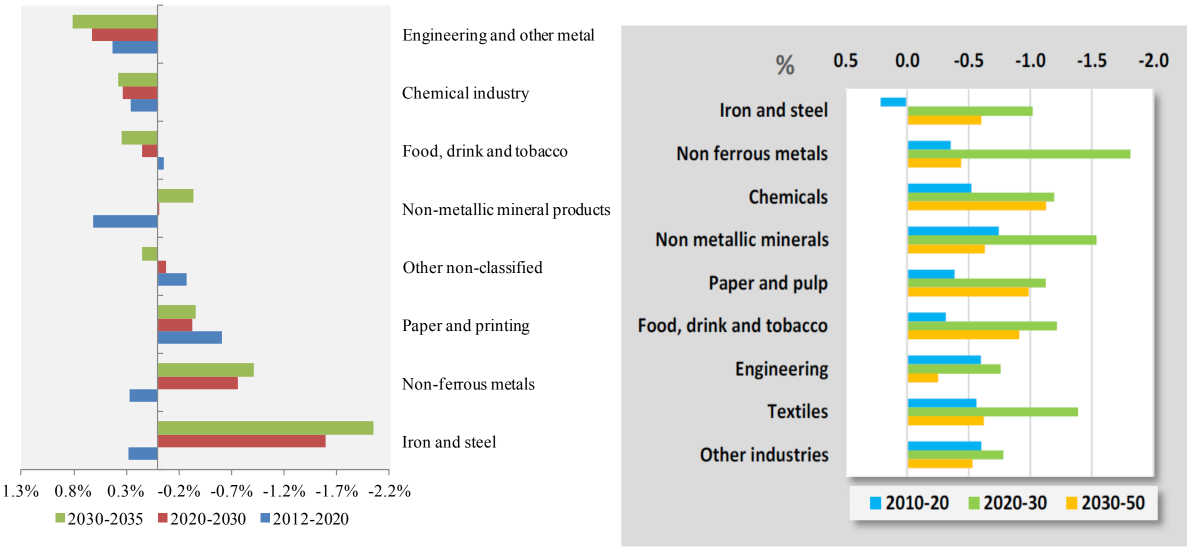

Figure 6. Average annual change of final energy demand in industry for the EU27 (FORECAST left, EU Ref 2016 right). Source: Fraunhofer ISI (2017), Capros et a. (2016, p.52).

Figure 7. Country comparison absolute % -change in final energy demand INDUSTRY (2012 to 2035). Source: Fraunhofer ISI (2017).

Final energy demand in the **residential sector** shows a decreasing trend between 2012 and 2035 (-0.8 % p.a.; from 3405 to 2852 TWh, Figure 8). The strongest decrease with -1.4 % p.a. takes place in space heating followed by sanitary hot water (-0.7 % p.a.). Appliances and lighting more or less stagnate while the demand for ventilation and 'New & Others' technologies will continue to increase by 9.8 % p.a. (but low absolute value) and 1.8 % p.a., respectively. New & Others is a category that captures small appliances (e.g. smart phones), which cannot be modelled in a typical bottom-up way due to restricted data availability. However, as these appliance types have shown the most dynamic development regarding electricity demand in the residential sector over the last two decades, this category captures this demand-side trend in a more aggregated manner. As the number of households and the size of each household (inhabitants per household) remains on a similar level for the projection horizon (see Table 2), the change of energy demand can be traced back to technology structure.

When breaking down the total electricity consumption of the household sector into the main end-uses (see Figure 8), it appears that the trend here is the result of two opposing tendencies: on the one hand, there is a decrease in the demand for heating and hot water generation that is mainly based on the improved thermal efficiency of the existing building stock, essentially driven by the Energy Performance and Buildings Directive (EPBD), and on the replacement of old and inefficient heating systems by condensing boilers and heat pumps. On the other hand, there is a notable increase in the demand of IT-related appliances that is captured by the category New & Others.

These results are the consequence of the combined effects of EU energy policies and the already consolidated autonomous energy-efficiency trends on the one hand and the influence of consumers on the consumer goods market and end-user behaviour on the other hand. EU energy policies, in particular those concerning the eco-design standards, labelling directives and the building sector, shape the scenario by increasing the

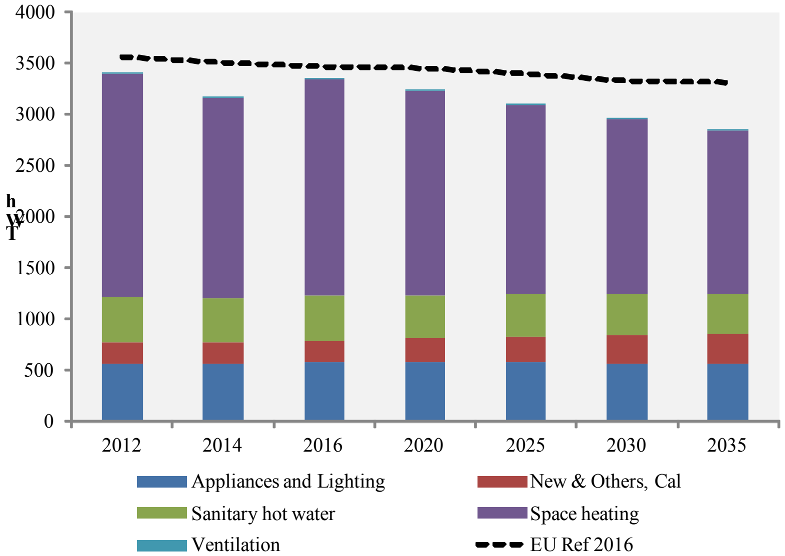

Figure 8. Final energy demand RESIDENTIAL EU27 (2012–2035). Source: Fraunhofer ISI (2017), Capros et al. 2016.

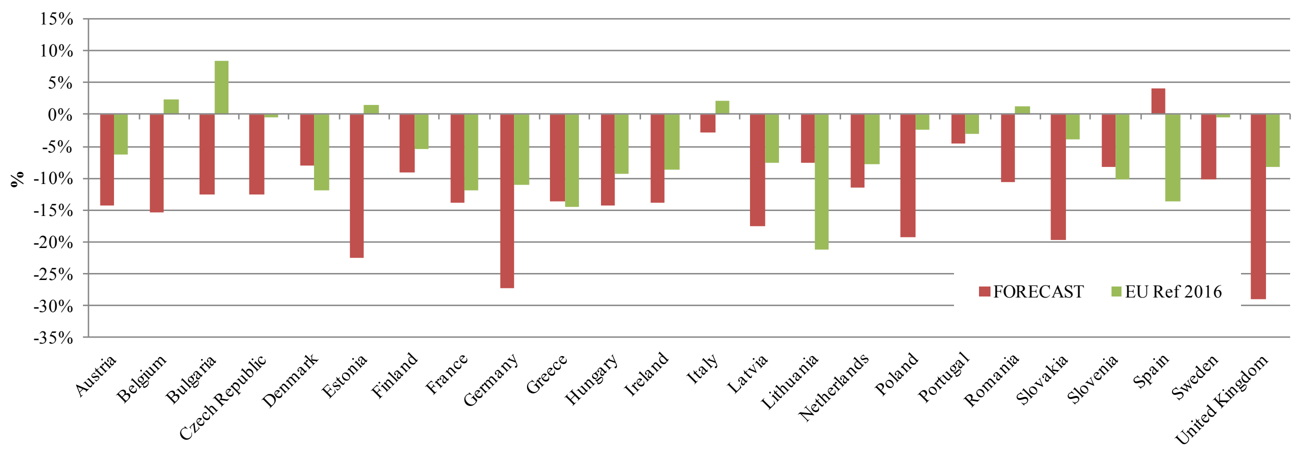

Figure 9. Country comparison absolute %-change in final energy demand RESIDENTIAL (2012 to 2035). Source: Fraunhofer (2017), Capros et al. 2016.

energy efficiency of the energy-using products and transforming the market structure at the same time. This policy framework, modelled in FORECAST, has an impact on heating demand, the electricity consumption of large appliances such as white consumer goods, and lighting systems.

The residential demand in the European Reference Scenario 2016 decreases only slightly by -0.3 % p.a. between 2012[7] and 2035. As FORECAST uses actual Eurostat data for the calibration year 2012, there is also an absolute difference in the base year of 158 TWh. Nevertheless, trends between model results can be compared. In comparison to the FORECAST results, it seems that the European Reference Scenario results tend to have higher estimates of future residential energy demand. This can have several explanations:

- More ambitious autonomous efficiency improvements in FORECAST (e.g. covered via the modelling of Ecodesign directives, labelling, building standards, etc.)
- Included temperature effects in FORECAST (e.g. including temperature levels and heating degree days has a significant influence on energy demand in the residential sector. This can be seen for example in the model results for 2014 which was a rather warm year)
- More ambitious replacement of heating systems in FORECAST (e.g. strong diffusion of heat pumps, replacement of constant and low temperature boilers by condensing boilers).

7. Interpolated value 2010 to 2015.

Conclusions

This paper analysed future energy demand trends based on the framework data of the European Commission's European Reference Scenario 2016 and presents a bottom-up modelling approach on country, sector, sub-sector and process level including the explicit modelling of policies and technology developments for the EU member states. Despite the high degree of technological detail considered in FORECAST, it must be noted that these model results are subject to a variety of uncertainties and assumptions.

Nevertheless, it was possible to make an overall comparison of the model results and identify potential points for discussion. While in the **tertiary sector** FORECAST uses EEMs based on historical developments to calculate future energy demand and determine energy efficiency gains, the European Reference Scenario uses different discount rates to "mirror the changes in the decision-making conditions and constraints" (Capros et al. 2016) as well as white certificates "reflecting the marginal costs of reaching energy savings obligations" (Capros et al. 2016). For the **industrial sector** FORECAST assumes a less ambitious increase of energy efficiency based on current available technologies in the primary industry sector. Higher potentials have to be supported by more innovative breakthrough technologies, which will probably not enter the European market in large scale before 2030. For the **residential sector** more ambitious efficiency improvements and more ambitious replacements of heating systems are assumed in the FORECAST model.

Scenario and model comparisons are an important method to improve the robustness of energy models. In order to make even more use of them, the following suggestions for future research are made.

- Comparisons are a lot more powerful, when the scenario design and the model runs are specifically aiming for this comparison. E.g. targeted sensitivity analyses of individual input parameters would allow more insights into model behaviour. This, however, requires substantial time and resources.
- In case such a controlled "model experiment" is not feasible, the comparison conducted in this study could be improved by aligning more FORECAST assumptions and input data to the EU Reference Scenario. While this was done for the macro-economic development, already important drivers as industrial production in the basic materials industries is not publicly available.
- Furthermore, modelling energy demand is still much less standardized than it is for energy supply. Both, data sources and simulation routines are very diverse and scattered. More standardisation would greatly improve comparability of models and in the end also the reliability and acceptance of model results.

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