REVISED VERSION

Renovation of the EU buildings stock: an opportunity to reduce the EU gas dependency

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Abstract

The buildings sector consumes 38 % of the EU 27 total gas consumption which makes the sector play a pivotal role in gas dependency and energy expenditures of European countries.

Over the past twenty years, the European Union has adopted a set of directives (Energy Performance of Buildings Directive (EPBD), Ecodesign Directive, and Labeling Directive) with the aim to improve energy performance of buildings. As the main challenge in the EU is the renovation of the existing buildings stock, the European Energy Efficiency Directive introduced in 2012 an obligation to conduct energy efficiency renovation in 3% of public buildings owned and occupied by central government every year. The implementation of the directives is supported by different financial instruments targeting individual consumers.

The European Parliament has recently stressed "that the current rate and quality of building renovation needs to be substantially scaled up in order to allow the EU to significantly reduce the energy consumption of the existing building stock by 80 %, relative to 2010 levels, by 2050" and calls "Member States to adopt ambitious, long-term building renovation strategies as required by the Energy Efficiency Directive".

To assess the renovation rate and its impact on the economic activity, the IEA developed a new bottom-up model called SBC (Sustainable Buildings Centre) model.

SBC model is an overall performance model and consist of three sub-models, namely a) a thermal building simulation model to estimate the deepness of the renovation, b) a building stock model to estimate the renovation rates, and c) an economic model that estimates the impact of the renovation on economic activity.

This paper presents the methodology used by SBC model and the modelling results for France and the Netherlands. For France, the paper also discusses the inconsistency between the energy reduction target and current policies. Finally, the authors make policy recommendations to enable the 80 % energy savings target by 2050.

Introduction

In 2010, the total final energy consumption (TFC) in Europe reached 1194[1] Mtoe with 39 % consumed by the buildings sector. The residential sub-sector remains the largest consumer of energy with 26 % of TFC. Space heating is by far the largest end-use in the residential sector (more than 50 % of primary energy consumption in most countries).

The buildings sector accounted for 38 % of the total EU gas consumption and most of this gas was imported from non-EU countries. Eastern and Central Europe is overwhelmingly dependent on Russian gas [Austria (67 %), Czech Republic (88 %), Estonia, Finland and Slovak Republic (100 %), Hungary (70 %) and Poland (90 %)], while Southern Europe is dependent on imports from Middle East and North Africa countries [Portugal (100 %), Spain (90 %), Italy (65 %), France (40 %)].

1. Unless otherwise stated, data included in this paper are from the IEA statistics internal database.

In most EU countries, the buildings sector's consumption of imported gas has a significant impact on their balance of trade and residential energy expenditures represent an important share of their GDP [Slovak Republic (3.8 %), Germany (3.3 %), Spain (2.5 %)].

From a policy perspective, the EU has developed a comprehensive energy efficiency policy package. It includes the Energy Performance of Buildings Directive (EC, 2010a) which introduced mandatory minimum energy performance requirements for existing large buildings (currently those with more than 500 m^2) when they undergo major renovation, the Energy Performance Certificate (EPC) each time a building is sold or rented and the inspection of heating and cooling systems. Appliances and equipment are regulated under the Ecodesign and the Labeling directives (EC, 2009) and (EC, 2010b). To scale-up the deployment of low energy buildings and efficient technologies, numerous streams of financing are put in place at the EU level.

At the national level, the transposition of the EPBD directive led Member States to introduce more stringent energy requirements in building energy codes and their expansion to existing buildings when they undergo major renovation, the implementation of EPCs for each building segment and the design of several financial instruments (mainly grants) to support the renovation of the existing buildings stock.

As the main challenge in the EU is the renovation of the existing buildings stock, the EU introduced last year through the Energy Efficiency Directive (EC, 2012) the obligation to every year conduct energy efficiency renovations of 3 % of public buildings owned and occupied by central government.

This paper describes the SBC (Sustainable Buildings Centre) methodology to estimate the deepness of the renovation, the renovation rates, and their impact on the economic activity. Estimates are made for France and the Netherlands considering that each country has to meet the EU target of 80 % energy reduction by 2050.

The paper highlights the inconsistency between the renovation targets and the existing policy instruments for France. Finally the outcomes discussed in the paper are summarised in the conclusion and the authors make policy recommendations to enable low building stock by 2050.

Modelling methodology

A number of existing models present the features necessary to answer each of our research questions (deepness of the renovation, renovation rates needed to achieve the energy savings targets and the economic activity a national renovation program may generate) separately.

Stock models are the most common approach to conduct energy efficiency policy impact assessment (Mundaca, Neij and Worrell, *et al.* 2010). In the context of the buildings sector, examples include the IEA's Energy Technology Perspective model (IEA, 2012a), modelling exercises conducted using the Long-range Energy Alternatives Planning System (LEAP) such as Kadian, Dahiya and Garg (2007) and Yanbing and Qingpeng (2005), or the buildings component of the International Panel of Climate Change (IPCC) Global Energy Assessment Model (Urge-Vorschatz *et al.*, 2012). In these models, the buildings stock is represented directly in terms of floor area broken down by building segments. When data allow, the breakdown goes further, using construction periods and climate zones. Yet building energy consumption is often considered for some end-uses only (notably space heating and hot water), and is represented by a single value for each sub-segment, usually annual kWh consumed per square metre. This approach does not allow to model different energy renovation measures and their interactions, such as insulation or windows replacement.

Modelling energy renovation measures directly requires the use of another type of energy model, sometimes termed physics-based models (Mundaca & Neij, 2010). Existing applications in the buildings sector include the Canadian Residential Energy End-Use Model (Farahbakhsh, Ugursal & Fung, 1998), the Building Research Establishment's Housing Model for Energy Studies (BREHOMES) in the UK (Shorrock, Henderson & Utley 2005), an application of ECOFYS' Built Environment Analysis Model (BEAM[2]) to the EU27 (Boermans & Grözinger, 2011) or Huang and Brodick (2000) in the US. At the aggregate level, these models also use a stock approach; however, each sub-segment, identified by a combination of building segment, construction period and in some cases climate zone, is represented by a reference building. The physical characteristics of these reference buildings are fully described, including geometry, construction materials, U-values, and the efficiency of HVAC equipments. The expected energy consumption is then calculated using a thermal simulation tool, under the weather conditions of the building's climate zone.

Physics-based models offer a distinct advantage: the impact of the interaction of different renovation measures can be estimated, which allows for a selection of the most optimum solution technically feasible.

To estimate the impact of the renovation on economic activity, two families of economic models are described in the literature: computable general equilibrium (CGE) models, and input-output (IO) models. Recent applications of a CGE model to assess the macro-economic impacts of energy efficiency policies include the use of the OECD ENV-Linkages model in combination with the IEA World Energy Outlook model and its Efficient World Scenario (IEA, 2012b).

A number of joint energy-IO models have been used to evaluate energy efficiency policies from an economic perspective: ADEME and OFCE's Three-ME model (OFCE, forthcoming), GWS's PANTA RHEI model (Lehr, Lutz & Pehnt, 2012), or Cambridge Econometrics E3ME model (EC, 2011). The use of an IO model facilitates the inclusion of sector-specific knowledge (Lutz, 2012). They are thus better suited for the sector-specific analysis presented in this paper.

To our knowledge, no existing model has tied together the physics, stock and economic components in a cohesive model specifically designed for and focused on the buildings sector. This is what the SBC model proposes to achieve.

Structure of the SBC model

The SBC model is a bottom-up overall performance model. It consists of three sub-models, namely a) a thermal building simulation model, b) a building stock model, and c) an economic model (Figure 1).

The thermal building simulation sub-model aims at selecting the combination of energy renovation measures that will maximise the overall performance of the building. The combinations of renovation measures vary per building type and are defined using reference buildings, construction periods, building segments, climate zones and technologies available in the country. For each country and each climate zone, the model runs an hourly thermal simulation on a number of reference buildings that represent the national buildings stock.

The characteristics of the reference buildings considered include the surface area of the building, number of floors, window area, U-values of walls, roofs, windows and doors, roof's inclination, efficiency level of the installed HVAC systems and the annual load profiles as well as energy consumption for hot water, lighting and appliances. The improvements in the insulation of walls, roofs and windows achieved through retrofits can therefore be modelled directly as an increase of their respective U-values. Similarly, the subsequent retrofit of the heating system can take into account the reduced need for heating resulting from the improved insulation.

The key advantage of the thermal simulation sub-model is to allow the modelling of holistic building retrofits which takes into account the interactions between different building components and allows for the selection of the combination of measures that maximises the technical savings potential feasible.

The building stock sub-model integrates stock data obtained from the national housing surveys or censuses to allow for a disaggregated description of the building stock in each country, by building segment, construction period, and climate zone. Input data for the stock sub-model include floor area, number of dwellings and number of buildings in the residential sector, but only floor area and number of buildings in the non-residential sector. Stock data are combined with energy consumption data disaggregated along the same dimensions. Data availability is often a limiting factor at this stage, as very few countries report building energy consumption by construction period or climate zone. Sources for this data thus include one-off surveys, publicly available databases that provide a representative sample of the building stock, and estimates from the literature.

Contrary to many existing models where the savings potential is estimated by considering a single factor to model the reduction of energy consumption over the entire stock (ECEEE, 2011), combining a thermal building simulation sub-model with a building stock sub-model allows for a more accurate estimate of the overall savings potential for each building segment. It also allows to model different pathways for the renovation of the entire stock over time, and to estimate the resulting evolution in the buildings stock energy consumption for each of these scenarios.

Model iterations unfold as follows. The model uses a time-step of one year. Each year, a demolition rate is applied uniformly to all construction periods and all building segments:

$$a_{p,i,t} = (1-\delta)a_{p,i,t-1} \tag{1}$$

where:

$a_{p,i,t}$ is the floor area of construction period p, within segment i, in year t

δ is the annual demolition rate

In each year, in each construction period, part of the stock is already renovated while the remainder is not yet renovated:

$$\forall p, \forall i, \forall t, \qquad a_{p,i,t} = r_{p,i,t} + \overline{r_{p,i,t}} \tag{2}$$

where:

$r_{p,i,t}$ is the floor area already renovated for construction period p, within segment i, in year t

$\overline{r_{p,i,t}}$ is the floor area not yet renovated for construction period p, within segment i, in year t

Each year, a renovation target is to be fulfilled, and is ventilated across the building stock by targeting the most inefficient dwellings first. The floor area renovated each year in each construction period and building sub-segment is calculated using equation 3:

$$r_{p,i,t} = \frac{\overline{r_{p,i,t}}e_{p,i}}{\sum_{segment}\ \overline{r_{p,i,t}}e_{p,i}}R_{i,t} \tag{3}$$

where:

$e_{p,i}$ is the average energy consumption per square metre before renovation for construction period p within segment i

$R_{i,t}$ is the floor area to be renovated in segment i in the year t

The economic sub-model has two purposes: estimating the amount of investments needed to achieve the renovation scenarios designed with the building stock model, as well as assessing the impact of these investments on overall economic activity. The investment needs are calculated using estimated labour and material costs by square metre for deep renovations. These costs are estimated in each country, for both the residential and non-residential sectors based on existing literature and interviews with industry. The economic impact of the renovation programmes is then evaluated through the use of input output analysis. An input-output model represents an economy using a "system of linear equations, each one of which describes the distribution of an industry's product throughout the economy" (Miller, 2009). The aim is to analyse the inter-linkage between different sectors of the economy.

In the SBC model, input-output analysis is used to assess the impact on the broader economy of an increase in the activity of the construction sector that would result from a nation-wide mandatory renovation programme. This allows estimating the impacts on the construction materials industry or on architectural and engineering services. Input-output tables used are those produced by national statistics offices. However, input-output tables only provide a snapshot of the structure of the economy in the year they are produced. In the model, this snapshot is used to calculate multiplying factors that are considered constant throughout the period considered. This is obviously a rough approximation, as the structure of the economy would be expected to be significantly different by 2050 in any of the countries considered. However, analysing such long term dynamic effects would require the use of a computable general equilibrium model, which lies outside the present scope of the SBC model.

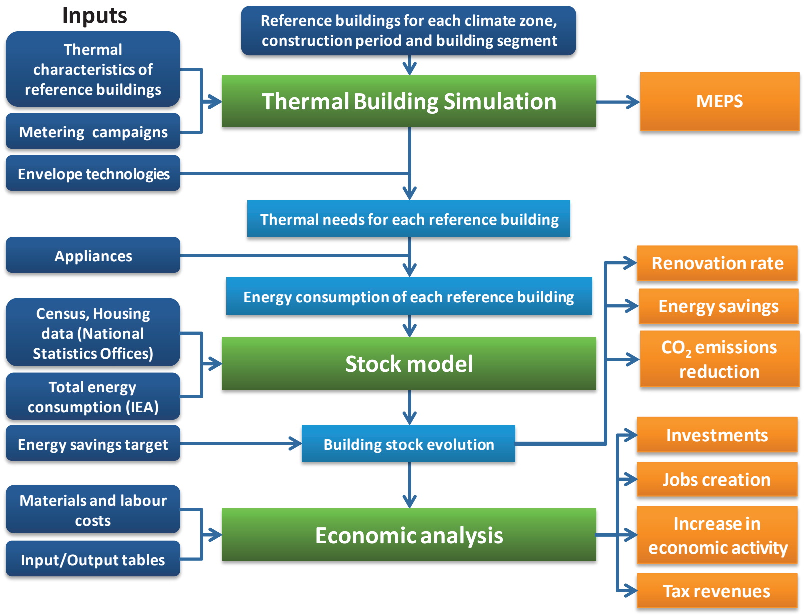

Figure 1. IEA-SBC model chart flow.

Assumptions

To build a precise assessment of the current state of the building stock, the model combines several data sources. Given the availability of these various sources, 2010 was chosen as the base year for the modeling runs. This corresponds to the latest detailed energy consumption data available from the IEA and the ODYSSEE database.

For the purpose of this paper, we considered the French and Dutch residential data only as these are the two countries for which an important progress in data analysis and validation has been made.

The French building stock was modeled using the 2008 Census and construction data over the period 2008–2010, obtained from the French National Statistics Office, INSEE. This allowed estimating the number of dwellings, and their corresponding floor area, by building segment and construction period. Energy consumption data was then gathered from IEA, the ODYSSEE database and ADEME. These datasets were used to calculate the average final energy consumption per square metre in each sub-segment, along with the corresponding share of each end-use.

The Dutch building stock was modeled in a similar fashion, using data from SenterNovem (now called NL Agency), the National Association of Realtors, IEA and the ODYSSEE database.

A summary of these assumptions is provided in the tables below (Table 1 and Table 2). As shown in Tables 1 and 2, single-family dwellings dominate the building stock in both France and the Netherlands, with 69 % of the total residential floor area in France, and 79 % in the Netherlands. While both stocks are quite old, with 28 % of the residential floor area built before World War II in France and 25 % in the Netherlands, a slightly greater proportion of the Dutch building stock is more recent than its French counter-part: 37 % of the residential floor area has been built since 1981 in the Netherlands, while only 34 % has been built since 1982 in France.

The evolution of average energy consumption across the construction period exhibits the impact of building energy codes, notably after the early 2000s when a model-based approach was adopted in both countries. Indeed, French dwellings built before 1989 consume on average 208 kWh/m^2 of final energy, while those built after 2000 have reduced this consumption to 139 kWh/m^2. Similarly, Dutch dwellings built before 1991 consume 204 kWh/m^2 on average, while those built after 2000 only use 131 kWh/m^2.

From an end-use perspective, residential energy consumption is heavily dominated in both France and the Netherlands by space and water heating. These two end-uses account for a combined 79 % of final residential energy consumption in France and 81 % in the Netherlands (Figure 2).

In all scenarios, a demolition rate is applied uniformly to the entire residential stock in both countries at 0.1 % per annum.

To estimate avoided CO_2 emissions, we have calculated the CO_2 intensity of the residential sector based on 2010 emissions. We then consider this intensity constant throughout the renovation period, as modifications to the supply mix in both countries lie outside the scope of this study.

Regarding the cost of renovation, based on interviews with industry experts, we have assumed that on average holistic renovations will incur a cost of 400 EUR per square metre in both countries by 2014. It is then assumed that productivity improvements will drive a 2 % annual reduction in these costs, resulting in 50 % reduction to 197 EUR per square metre by 2050.

Scenarios

In terms of policy development, it is considered that energy renovations would be conducted on a mandatory basis whenever a regular building retrofit is conducted, starting from 2014.

The model includes two scenarios. In the first one, named Business As Usual (BAU), we considered that the renovation rate remains at its historical level of 0.6 % per annum in France and the Netherlands from 2014 through 2050.

In the second scenario, named Low Energy Building (LEB), we consider the European Parliament's objective to renovate

Table 1. French building stock assumptions.

	Single-family dwellings		Multi-family dwellings	
Construction period	**Share of total residential floor area**	**Average annual final energy consumption per dwelling (kWh)**	**Share of total residential floor area**	**Average annual final energy consumption per dwelling (kWh)**
< 1949	21%	22,997	7%	12,715
1949-1974	14%	21,992	12%	14,355
1975-1981	9%	23,208	4%	13,677
1982-1989	8%	20,872	2%	11,634
1990-1998	6%	19,077	3%	9,348
1999-2005	7%	17,907	2%	8,567
2006-2010	4%	17,605	3%	8,317
Total	**69%**	**21,417**	**31%**	**12,520**

Table 2. Dutch building stock assumptions.

	Single-family dwellings		Multi-family dwellings	
Construction period	**Share of total residential floor area**	**Average annual final energy consumption per dwelling (kWh)**	**Share of total residential floor area**	**Average annual final energy consumption per dwelling (kWh)**
< 1905	4%	25,691	1%	16,569
1905-1929	9%	24,395	2%	15,733
1930-1944	6%	24,642	2%	15,894
1945-1959	6%	22,694	1%	14,636
1960-1970	12%	22,299	3%	14,384
1971-1980	13%	23,874	3%	15,405
1981-1990	11%	20,228	3%	13,065
1991-2000	12%	20,864	3%	13,479
2001-2010	6%	18,667	2%	12,064
Total	**79%**	**22,411**	**21%**	**14,451**

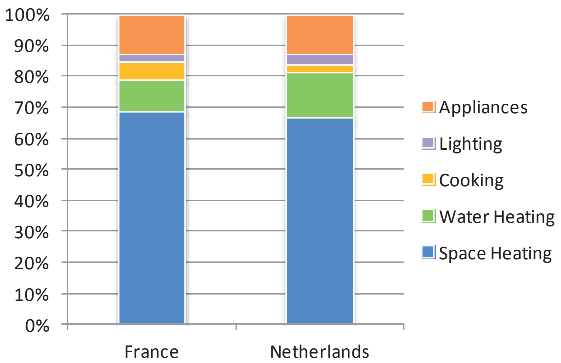

Figure 2. Residential energy consumption by end use in France and the Netherlands.

the entire residential stock by 2050, starting from 2014. To this end, starting from its historical level in 2014, the renovation rate is then progressively increased to reflect the learning curve that would be needed in the buildings industry to adapt to such a massive renovation program. In France, the renovation rate increases to 1 % by 2018 and reaches its maximum at 6 % a year in 2032, while decreasing progressively to 0.6 % in 2049. The residential stock built prior to 2010 is fully retrofitted by 2050. Similarly in the Netherlands, renovation rate increases progressively to a maximum of 6 % in 2032, to then decrease back to 0.6 % in 2049.

Energy savings, CO_2 emissions and investment needs

In the BAU scenario, final residential energy consumption of the existing stock goes down from 42 Mtoe to 33 Mtoe in France from 2010 to 2050, or a 20.4 % reduction. In the Netherlands, residential energy consumption of the existing stock decreases from 12 Mtoe to 9 Mtoe from 2010 to 2050, which represents a 24.2 % reduction (Figure 3 and Figure 5). These energy savings translate into 14.4 $MtCO_2$ of avoided CO_2 emissions in France (4 % of 2010 emissions) and 8.1 $MtCO_2$ in the Netherlands (4.3 %) – (Figure 7 and Figure 8).

The LEB scenario yields substantially larger energy savings: in France, residential energy consumption of the existing building stock is reduced to 11 Mtoe by 2050, a 74.7 % decrease. In the Netherlands, residential energy consumption decreases to 3 Mtoe in 2050, a 73.0 % decrease (Figure 4 and Figure 6). These savings result in 52.8 $MtCO_2$ of avoided CO_2 emissions in France (14.8 % of 2010 emissions) and 24.3 $MtCO_2$ in the Netherlands (13 %) – (Figure 7 and Figure 8).

The investment needs in both scenarios vary greatly. Since the renovation rate remains stable throughout the period considered, investment needs in the BAU scenario only vary with the evolving renovation costs: they average 4.2 billion EUR in France and 1.3 billion EUR in the Netherlands from 2014 to 2050 (Figure 9). In the LEB however, the increasing renovation rate leads to increasing investment needs: while investments average 18.4 billion EUR in France and 5.5 billion EUR in the Netherlands, they reach a peak of 42.4 billion EUR and 12.7 billion EUR in 2031 respectively.

Natural gas is a particularly important energy carrier in the residential sector in both countries. Indeed, residential energy consumption accounts for 47 % of final natural gas energy use in France and 35 % in the Netherlands. In both scenarios, energy savings are broken down across the residential energy mix prevalent in 2010: the model does not consider fuel shifts. Under this hypothesis, the LEB scenario would lead to a reduction in natural gas consumption of 10.2 Mtoe in France and 6.4 Mtoe in the Netherlands annually by 2050.

Discussion

Considering impacts of the LEB scenario on the balance of trade, the reduction in natural gas consumption would have a very different impact in each country. Indeed, while France imports close to 100 % of its natural gas consumption, the Netherlands is a net exporter of gas.

The LEB scenario would allow France to reduce its natural gas imports by 25 % by 2050 (based on 2010 imports obtained from Eurostat international trade statistics). This would help alleviate France's trade deficit, which in 2010 was mostly due to its energy imports, namely oil and gas. Based on 2010 gas import prices in France, such a reduction in consumption would alleviate France's energy bill by 3.6 billion EUR annually. This represents 7 % of France's overall trade deficit in 2010 (Figure 10).

In the Netherlands, reducing domestic natural gas consumption would instead allow an increase in gas exports. Natural gas savings in the LEB scenario by 2050 would represent 15 % of the Netherlands' exports in 2010. Using 2010 gas exports price for the Netherlands, this would translate into an additional 261 million EUR of gas exports annually. This amounts to 0.6 % of the Netherlands' trade surplus in 2010.

In terms of investment needs, the LEB scenario underlines in both countries the magnitude of the renovation rate increase that will be needed to achieve a low energy building stock by 2050. In France, this translates to an additional 14 billion EUR in France and an additional 4 billion EUR in the Netherlands. Besides, peak investments, reached in both countries in 2031, would be larger than the long-term average in the BAU scenario by an order of magnitude. Still, it should be noted that while substantive, this investment peak would only represent slightly more than 2 % of 2010 French GDP. Assuming a 1 % per annum GDP growth, this would be further reduced to 1.7 % of a projected 2031 GDP.

To provide evidence-based of the inadequacy between the energy savings targets and the renovation policies and commitments we compared the energy savings target with the savings potential achievable in France considering the current policies. France is in fact a good illustration of this inconsistency as in the "Grenelle de l'Environnement" law adopted in 2009, the French government committed at the same time to achieve 38 % energy savings in the buildings sector by 2020 and to renovate 400,000 dwellings and 80,000 social housing units every year between 2013 and 2020.

Since the implementation decree is not yet adopted, we assumed that only 100,000 dwellings will be deeply renovated in 2013 and a progressive increase could achieve 480,000 dwellings by 2016 onwards. By doing so, the renovation programme would yield 4.9 Mtoe of energy savings in the existing building stock by 2020 if the most energy-intensive dwellings are considered as a priority. This represents 7.7 % savings, which falls short of the stated objective of a 38 % reduction in 2020 (Figure 11).

Conclusion

The buildings sector puts substantial pressure on gas dependency and expenditures of the EU countries. The European Parliament has therefore set an ambitious energy savings target by 2050.

This paper provides evidence-based analysis showing that achieving 80 % energy reduction in the EU building stock will require a large renovation effort, sustained over a long timeframe, as illustrated in our LEB scenario.

Estimates of investments and impact of the renovation programme on gas imports and expenditures have been presented for the Netherlands and France. They demonstrate the cost-effectiveness of a national renovation programme for the overall

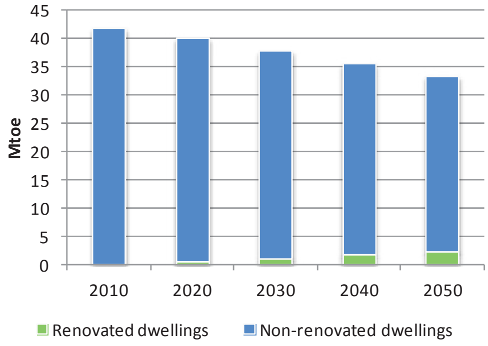

Figure 3. France – Business as usual scenario.

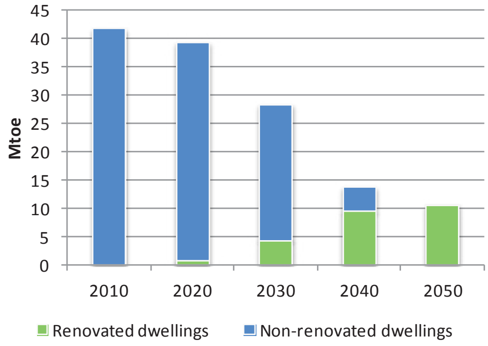

Figure 4. France – Low energy buildings scenario.

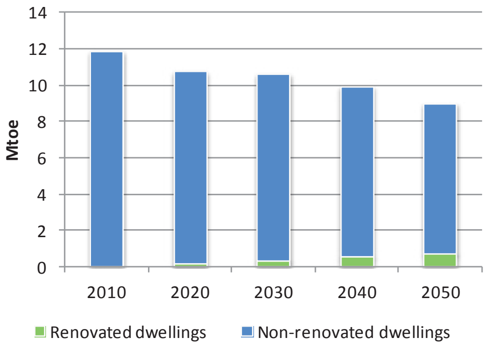

Figure 5. Netherlands – Business as usual scenario.

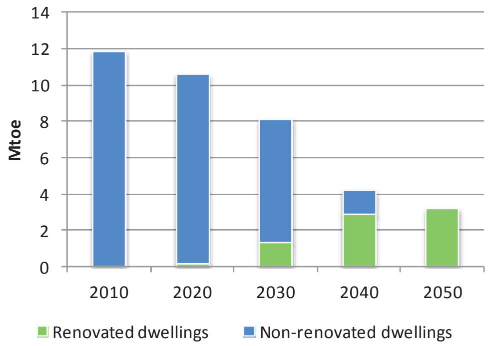

Figure 6. Netherlands – Low energy buildings scenario.

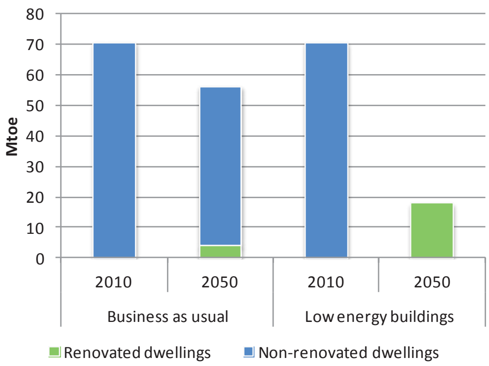

Figure 7. France – CO_2 emissions savings.

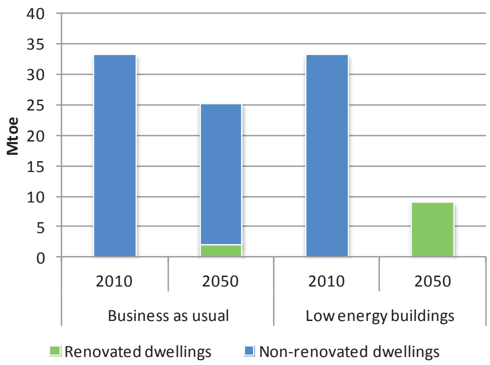

Figure 8. Netherlands – CO_2 emissions savings.

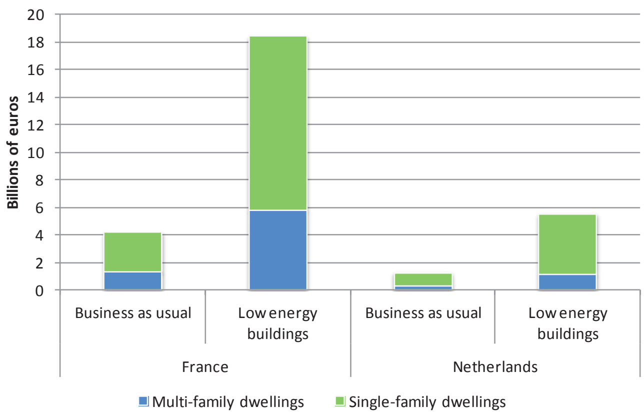

Figure 9. Average investment needs in France and the Netherlands in both scenarios.

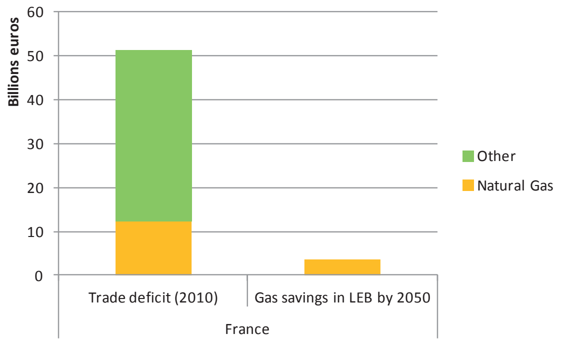

Figure 10. Impact of natural gas savings on France's trade balance.

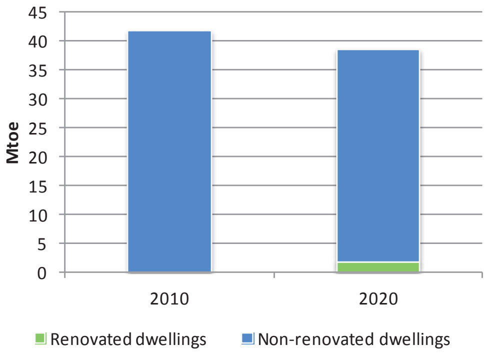

Figure 11. Impact of France's renovation commitments to 2020.

economy of each country. Moreover, in the case of France, the paper shows the inadequacy between the governmental energy savings commitment by 2020 and what is doable in the field considering the current policies.

The French case study demonstrates that there is the risk for the EU to not meet its targets if current policies are not revised. The authors consider that energy renovation will happen at a large scale only if governments decided to make energy renovation mandatory each time a technical renovation is conducted. Market instruments will also be required to address the up-front investment cost and remove the perceived risk by industry. Looking beyond the energy savings of each individual building and including the renovation of the existing buildings stock in the green growth strategy are pre-requisites for the EU to reduce the impact of this sector on energy dependency.

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