REPORT

Cost-benefit analysis of a selection of policy scenarios on an adequate future Belgian power system

Economic insights on different capacity portfolio and import scenarios

February 2017

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Abstract - In this report, different capacity portfolio and import scenarios for Belgium are investigated. They are based on the reports published by the Belgian transmission system operator Elia in 2016. Four scenarios are scrutinized differing in their overall context (level of carbon price) and/or in the choice of the content of their structural block. A fifth scenario is added which constitutes a sensitivity analysis: in this scenario, a considerable amount of new natural gas-fired power plants on top of the structural block is built on the Belgian territory in order to study the impact of a fairly lower level of (net) imports and even explore the net export option. The five scenarios are compared in order to assess potential long-term strategic choices from a societal perspective.

Jel Classification - L94
Keywords - Energy policy, Generation adequacy, Electricity

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Executive summary

This report presents a cost-benefit analysis of policy scenarios consistent with an adequate Belgian power system by 2027. The policy scenarios are based on information contained in two reports published by the national Transmission System Operator (TSO) Elia in 2016. The Elia reports deal with the adequacy and flexibility needs of the future Belgian power system by calculating the need for and the required volume of a "structural block". The structural block is defined as the national volume of adjustable capacity needed to keep electricity supply and demand in balance at all times while satisfying the current legal security of supply criteria. This cost-benefit analysis then looks at the implications of different constitutions of the structural block on a number of social welfare components. It responds to concerns ventilated by a number of stakeholders after the publication of the Elia reports.

More specifically, the Federal Planning Bureau calculates a number of costs and benefits for different power capacity portfolio and import scenarios for Belgium. Four main scenarios are scrutinized differing in the level of carbon price and/or in the choice of the content of their structural block, being natural gas-fired power plants versus decentralised technologies. These four scenarios are however all characterized by a relatively high dependence on foreign electricity supplies. A fifth scenario is added which constitutes a sensitivity analysis: a considerable amount of new natural gas-fired power plants on top of the structural block is built on the Belgian territory in order to explore a situation in which Belgium's electricity trade balance is almost neutral in 2027. The results of the five scenarios are compared in order to assess potential long-term strategic choices from a societal perspective.

One outcome of the analysis is that a decentralised structural block (compared to one solely filled by natural gas-fired power plants) engenders benefits in terms of the production surplus, CO_2 emissions, employment and energy trade deficit. Nonetheless, to secure our future power supply, natural gas-fired power plants are proven to be indispensable in this setting.

The overall positive impact results from a strong increase in the producer surplus that is not being compensated for by a decrease in the consumer surplus. The former effect is triggered by the higher prices at which the different producers can sell their electricity while the latter is caused by higher wholesale power prices that consumers have to pay. CO_2 emissions and CO_2 auction payments are lower because power generation relies more on decentralised carbon-free renewables. The positive employment creation effect is brought about by the higher labour intensities of renewable technologies, whilst the shrinking energy trade deficit can be ascribed to lower imports of natural gas. Required investments, however, are considerably higher and amount to a factor 2.5 compared to a solely gas-filled structural block.

The fifth scenario teaches us that not only investing in decentralisation, but also in additional gas-fired power plants in order to diminish the level of (net) electricity imports (and even reverse it into a net export position) might generate some benefits for Belgium. Compared to (simple) decentral production, the consumer surplus climbs significantly because of a decrease in the wholesale power prices. Above that, the energy trade deficit drops further because of the elimination of net power imports on a yearly basis. On top of that, extra jobs are created because of the additional construction of new centralised generation units in Belgium. But there is a downside: required (additional) investments are substantial, domestic CO_2 emissions skyrocket and the case for Demand Response completely vanishes.

Of course, the realisation of the benefits and costs hinges on external circumstances: if they change, the overall picture changes and these results no longer hold. It is therefore of utmost importance to carefully observe and, where possible, try to influence the external context. This can be done on two levels: European and Member State level. As regards the European level, European climate policy should be steered towards a context which closely resembles the Gas before Coal scenario by having more ambitious carbon prices. Concerning the Member State level, sovereign national decisions that potentially could have a huge impact on other Member States should be duly announced and, by preference, replaced by more intensified regional collaboration and cooperation as is specified in the European Winter Package.

Synthese

Dit rapport stelt een kosten-batenanalyse voor van beleidsscenario's die coherent zijn met een toereikend Belgisch elektriciteitssysteem tegen 2027. De beleidsscenario's zijn gebaseerd op gegevens uit twee rapporten die in 2016 door de nationale transmissienetbeheerder Elia zijn opgesteld. De rapporten van Elia handelen over de nood aan toereikendheid en flexibiliteit van het toekomstig Belgisch elektriciteitssysteem door de behoefte aan een 'structureel blok' en het vereiste volume ervan te berekenen. Het structurele blok wordt gedefinieerd als het nationale volume aan regelbaar vermogen dat nodig is om te voldoen aan de huidige wettelijke criteria qua bevoorradingszekerheid opdat op elk moment productie en verbruik in evenwicht zouden zijn. De kosten-batenanalyse buigt zich dan over de implicaties van verschillende invullingen van het structurele blok voor een aantal componenten van de sociaal-economische welvaart. Ze biedt een antwoord op de bezorgdheid die werd geuit door een aantal stakeholders na de publicatie van de Elia-rapporten.

Het Federaal Planbureau rekent meer bepaald een aantal kosten en baten door van verschillende elektriciteitsproductiepark- en invoerscenario's voor België. Er worden vier hoofdscenario's onder de loep genomen. Die scenario's verschillen op het vlak van het niveau van de koolstofprijzen en/of de keuze van de inhoud van hun structurele blok. Dat structurele blok bestaat uit ofwel aardgascentrales, ofwel decentrale technologieën. Die vier scenario's worden evenwel allemaal gekenmerkt door een relatief grote afhankelijkheid van buitenlandse elektriciteitsleveringen. Daaraan wordt een vijfde scenario toegevoegd dat in feite een gevoeligheidsanalyse is: op het Belgisch grondgebied wordt een aanzienlijk aantal nieuwe aardgascentrales bovenop het structurele blok gebouwd om een situatie te onderzoeken waarin de Belgische elektriciteitshandelsbalans in 2027 quasi in evenwicht is. De resultaten van de vijf scenario's worden vergeleken om de mogelijke strategische keuzes op lange termijn vanuit maatschappelijk oogpunt te evalueren.

Uit de analyse blijkt dat een decentraal structureel blok (in vergelijking met een structureel blok waarin alleen aardgascentrales zijn opgenomen) meerdere voordelen oplevert op het vlak van producentensurplus, CO_2-emissies, werkgelegenheid en de energiehandelsbalans. Niettemin wordt aangetoond dat – zelfs in een decentrale toekomst – aardgascentrales onontbeerlijk zijn om onze toekomstige elektriciteitsbevoorrading te verzekeren.

De globale positieve impact vloeit voort uit een forse stijging van het producentensurplus die niet wordt gecompenseerd door een daling van het consumentensurplus. Het eerste effect is het gevolg van de hogere prijzen waartegen de verschillende producenten hun elektriciteit kunnen verkopen, terwijl het tweede effect wordt veroorzaakt door de hogere groothandelsprijzen die de consumenten moeten betalen. De CO_2-emissies en de aankoopbedragen voor CO_2-emissierechten liggen lager omdat de elektriciteitsopwekking meer gebaseerd is op decentrale koolstofvrije hernieuwbare energiebronnen. De positieve impact op de werkgelegenheidscreatie wordt veroorzaakt door de hogere arbeidsintensiteit van hernieuwbare technologieën, terwijl het dalend tekort op de energiehandelsbalans kan worden toegeschreven aan een krimp in de aardgasinvoer. De benodigde investeringen zijn echter aanzienlijk en zijn een factor 2,5 hoger dan wanneer het structureel blok enkel door gasgestookte centrales zou worden ingevuld.

Het vijfde scenario leert ons dat het voor België voordelig zou kunnen zijn om niet alleen in decentralisatie, maar ook in bijkomende aardgascentrales te investeren om het niveau van de (netto-)invoer te laten dalen (en zelfs om te draaien in een netto-uitvoerpositie). In vergelijking met een (eenvoudige) decentrale productie klimt het consumentensurplus behoorlijk in dit scenario als gevolg van een daling van de groothandelsprijzen voor elektriciteit. Bovendien daalt het tekort van de energiehandelsbalans verder omdat de netto-elektriciteitsinvoer op jaarbasis verdwijnt. Daarenboven worden nieuwe jobs gecreëerd omdat er bijkomende centrale productie-eenheden in België worden gebouwd. Er is echter een keerzijde: de benodigde (bijkomende) investeringen zijn merkbaar hoger, nationale CO_2-emissies schieten de hoogte in en vraagbeheer (Demand Response) lijkt volledig van het elektriciteitstoneel te verdwijnen.

Of die kosten en baten daadwerkelijk worden bereikt, is natuurlijk afhankelijk van externe omstandigheden: als die veranderen, verandert het algemeen beeld ook en zijn de resultaten niet langer geldig. Daarom is het van uiterst belang dat de externe context zorgvuldig wordt opgevolgd en, waar mogelijk, beïnvloed. Dit kan op twee niveaus gebeuren: op Europees niveau en op het niveau van de lidstaten. Op Europees niveau zou het Europees klimaatbeleid in de richting van een context moeten worden gestuurd die nauw aansluit bij het ‘Gas before Coal’-scenario met ambitieuzere koolstofprijzen. Op het niveau van de lidstaten zouden soevereine nationale beslissingen – die mogelijk een aanzienlijke impact kunnen hebben op andere lidstaten – tijdig moeten worden aangekondigd, en bij voorkeur worden vervangen door intensievere regionale samenwerking zoals wordt bepaald in het Europese winterenergiepakket.

Synthèse

Ce rapport présente une analyse coût-bénéfice de plusieurs scénarios compatibles avec l'adéquation du système électrique belge d'ici 2027. Ces scénarios se fondent sur les informations contenues dans deux rapports publiés en 2016 par le gestionnaire du réseau de transport national Elia. Les rapports d'Elia étudient l'adéquation et les besoins en flexibilité du système électrique belge dans le futur ; ils déterminent si un bloc structurel est nécessaire ou non et, le cas échéant, précisent son volume. On définit le bloc structurel comme le volume de puissance nationale réglable nécessaire pour équilibrer à tout moment l'offre et la demande d'électricité selon les critères légaux actuels de sécurité d'approvisionnement. L'analyse coût-bénéfice se penche sur les effets de différentes compositions du bloc structurel sur plusieurs indicateurs du bien-être social. Elle répond à des préoccupations exprimées par un certain nombre de stakeholders après la publication des rapports d'Elia.

De manière plus spécifique, le Bureau fédéral du Plan étudie plusieurs coûts et bénéfices associés à différents scénarios concernant le parc de production électrique et les importations en Belgique. Quatre scénarios sont principalement analysés. Ils diffèrent selon le niveau du prix du carbone et/ou selon le choix opéré quant à la constitution de leur bloc structurel, à savoir les centrales au gaz naturel ou les technologies décentralisées. Tous ces scénarios se caractérisent toutefois par une dépendance relativement élevée aux importations d'électricité. Une analyse de sensibilité est réalisée dans un cinquième scénario où un nombre considérable de nouvelles centrales au gaz naturel sont construites sur le territoire belge et viennent s'ajouter au bloc structurel. Ce scénario a pour but d'explorer une situation de quasi-équilibre de la balance commerciale électrique belge en 2027. Enfin, les résultats des cinq scénarios sont comparés entre eux pour évaluer les orientations stratégiques qui sont possibles à long terme, d'un point de vue sociétal.

L'analyse révèle qu'un bloc structurel décentralisé (par rapport à un bloc constitué uniquement de centrales au gaz naturel) génère des effets positifs en termes de surplus du producteur, d'émissions de CO_2, d'emploi et de déficit commercial énergétique. Néanmoins, même dans un avenir « décentralisé », les centrales au gaz naturel s'avèrent indispensables pour la sécurité future de notre approvisionnement en électricité.

L'impact positif global résulte d'un accroissement important du surplus du producteur qui n'est pas compensé par la diminution du surplus du consommateur. La croissance du surplus du producteur est dû aux prix de vente plus élevés pratiqués par les différents producteurs, tandis que la baisse du surplus du consommateur s'explique par les prix de gros plus élevés de l'électricité à payer par les consommateurs. Les émissions et les enchères de CO_2 diminuent car la production d'électricité repose davantage sur des énergies renouvelables sans carbone décentralisées. Les créations d'emplois sont dues aux plus fortes intensités de main-d'œuvre des technologies renouvelables, tandis que la réduction du déficit commercial énergétique a pour origine la baisse des importations de gaz naturel. Les investissements requis sont, par contre, considérables ; ils sont 2,5 fois plus élevés que lorsque le bloc structurel est constitué uniquement de centrales au gaz naturel.

Le cinquième scénario nous apprend qu'investir non seulement dans la décentralisation, mais également dans de nouvelles centrales au gaz naturel - pour réduire les importations (nettes) d'électricité (ou même viser un solde exportateur net) - pourrait être bénéfique pour la Belgique. Par rapport au scénario misant sur les technologies décentralisées, le surplus du consommateur s'accroît dans ce scénario grâce à la baisse des prix de gros de l'électricité. En outre, le déficit commercial énergétique s'amoindrit en raison de l'élimination des importations nettes d'électricité sur base annuelle. On constate également que la construction d'unités de production centralisées additionnelles en Belgique stimule les créations d'emplois. Par contre, les besoins en investissement sont très importants, les émissions de CO_2 sur le territoire belge s'accroissent et l'effacement de la consommation n'apparaît plus comme une option intéressante.

Naturellement, la matérialisation de tous ces bénéfices dépend de facteurs externes : si ceux-ci évoluent, le tableau qui vient d'être brossé pourrait changer et les effets décrits plus haut ne seraient plus valables. Par conséquent, il est essentiel d'observer attentivement le contexte extérieur et, si possible, d'essayer de l'influencer. Il est possible d'agir à deux niveaux : à l'échelle européenne et au niveau des États membres. En ce qui concerne le niveau européen, il conviendrait de peser sur la politique climatique européenne pour tendre vers un contexte proche du scénario Gaz avant Charbon où le prix du carbone est plus élevé. Pour ce qui est du ressort des États membres, les décisions nationales souveraines susceptibles d'avoir un impact considérable sur d'autres États membres devraient être annoncées en temps utile et, de préférence, céder le pas à une intensification de la collaboration régionale telle que préconisée dans le Paquet Hiver.

Introduction

On December 21, 2015, the Belgian national TSO Elia received a formal request from the federal Minister of Energy to conduct a study on the adequacy and flexibility needs of the (future) Belgian power system for the next ten years (horizon 2027). On April 20, 2016, Elia published its report[1] which was executed in cooperation with the cabinet of the federal Minister of Energy and the Energy administration of the FPS Economy (DG Energy) who, together with Elia, discussed and decided on the methodology and assumptions withheld. After the official release of the study, DG Energy organised a public consultation round regarding the potential introduction of a capacity remuneration mechanism (CRM) in Belgium[2]. On July 18 of that same year, Elia received a new mandate from the Federal Minister of Energy to analyse an "additional scenario"[3] which could be seen as a follow up on the results of the public consultation and the recommendations made by DG Energy in its public document.

Based on these three documents and after a thorough study of the different stakeholder responses, it became clear that a comprehensive cost-benefit analysis for the future Belgian power system was lacking[4]. To respond to the concerns different stakeholders have formulated, DG Energy contacted the Federal Planning Bureau (FPB) to deliver on such an analysis based on a selection of scenarios performed in both Elia studies.

In this report, the FPB documents on its undertakings to perform this cost-benefit analysis for which it received input from both DG Energy and Elia. In concertation with DG Energy, scenarios from the original Elia reports (April and September 2016) were selected and subsequently adapted in order to construct different (diversifying) capacity portfolio and import settings. These frameworks are then compared in order to assess potential long-term strategic choices from a societal perspective.

The content of the cost-benefit analysis not only covers the cost comparisons (of investment costs, marginal system costs, economic surpluses and rents), but it also looks into the energy trade balance and provides some elements as to the national employment outlook.

The ultimate goal of this report is to provide another building block in the construction of an overarching energy vision and, hence, to contribute to a profound discussion on the market design and regulation to be put in place to trigger the required incentives for market participants to implement the desired path. After all, strategic political decisions should benefit from a cost-benefit analysis gathering different elements, different outlooks and different viewpoints.

The structure of the text is as follows: chapter 1 discusses the different methodologies used to perform the cost-benefit analysis which in fact covers three pillars: costs, trade balance effects and employment;

1 Elia (2016a), Studie over de nood aan 'adequacy' en aan flexibiliteit in het Belgische elektriciteitssysteem, Periode 2017-2027, April.

2 AD Energie (2016), Synthese van de antwoorden afkomstig uit de raadpleging inzake de invoering van een capaciteitsvergoedingsmechanisme in België.

3 Elia (2016b), Addendum to the Elia study regarding the "adequacy" and flexibility needs of the Belgian power system for the period 2017-2027: "Additional scenario" and clarifications, September.

4 In fact, to be accurate, an encompassing cost-benefit analysis was not lacking, it was simply not assigned in the mandate Elia received from the Minister.

chapter 2 goes into the different assumptions taken and explains the choice for the five scenarios under scrutiny; chapter 3 describes the results to, afterwards, conclude in Chapter 4.

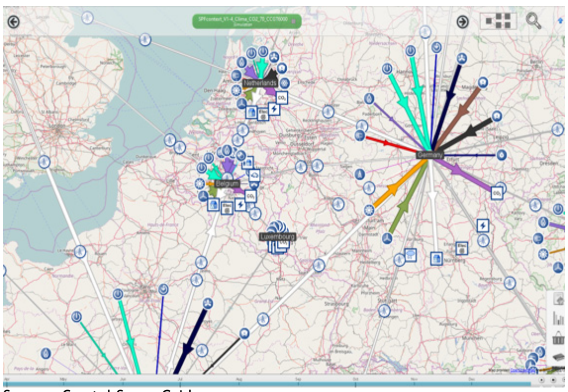
1. Methodology

In order to duly perform the cost-benefit analysis based on a selection of scenarios described in the two reports published by the national TSO Elia (Elia, 2016a and 2016b), the FPB went ahead with a threefold methodology. In fact, this triple methodology concords with the three pillars of the welfare analysis being costs, trade balance and employment. Each pillar necessitates its own approach since there is no single all-embracing model or computational method to perform the impact calculations all at once. The triple methodology consists in using an optimisation model, exploiting energy trade data and applying a multiplier method based on input-output results.

1.1. Costs

The first analysis focuses on costs. The model used is the optimisation tool *Crystal Super Grid* (Artelys, 2015). This model in fact minimizes total system production costs whilst aligning demand with supply. It contains an extensive library of both physical and financial assets (thermal power plants, renewable energy sources, power lines, etc.) which allows a fine-grained level of detail for analyses. The data infeed for the model mainly comes from publicly available databases like ENTSO-E and the International Energy Agency (IEA). More specifically, the demand, the installed capacities and the thermal availabilities are obtained from ENTSO-E, the fuel costs from IEA and the detailed capacity descriptions from the European TSO's individual websites. Powerful optimization solvers are used to calculate the optimal dispatch of generating facilities in the interconnected zones. Results cover e.g. imports/exports between zones (countries or regions), marginal costs of electricity generation and CO_2 emissions.

Graph 1 The interconnected Crystal Super Grid system, illustration



Source: Crystal Super Grid.

Crystal Super Grid runs on JAVA. The computation process is performed by successive optimisation problem resolutions over a rolling horizon. This is done to avoid perfect foresight issues at the end of the projection period. The model computes 14-day period[5] (tactical horizon) problems with 7-day steps (rolling horizon) at each iteration. This way, each new computations' tactical horizon overlaps with the previous one taking into account its decisions and the ensuing state of the system.

The attentive reader might notice that this model differs from the one used by Elia (called *ANTARES*[6]) to perform its adequacy and flexibility needs estimation (as well as its volume determination of the strategic reserve[7]). Nonetheless, both models do have a lot in common in their way of func-

5 For this specific exercise, a tactical horizon of 28 days is chosen in order to address the large penetration of electric vehicles in the system in certain scenarios.

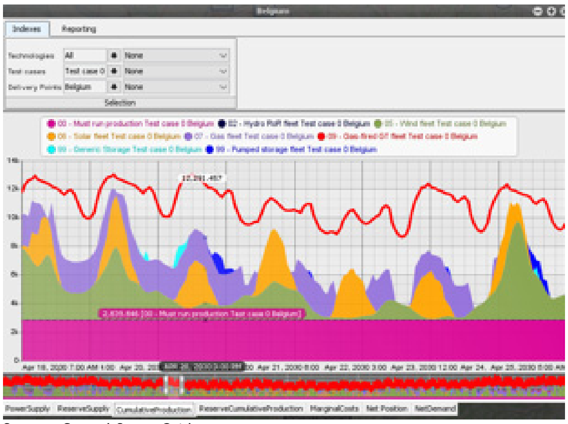
6 Short for 'A New Tool for Adequacy Reporting of Electric Systems'.

7 See for example Elia (2016d), Adequacy study for Belgium: The need for strategic reserve for winter 2017-2018 and outlook for 2018-19 and 2019-20, November 2016.

tioning: both models are economic optimal dispatch tools in which production costs are being minimized when determining how the generation park should be dispatched to cover load at all times. Different, however, is that *ANTARES*, developed by RTE (the French national TSO), uses a probabilistic approach in order to draft security of supply and economic analyses whilst *Crystal Super Grid* uses a (rather) deterministic one[8]. The probabilistic approach allows evaluating a large number of climatological years with the aid of historical/simulated time series or draws according to the Monte Carlo method. *Crystal Super Grid* does not have the Monte Carlo feature but, through design, can operate in a similar manner by simulating an elevated number of test cases and choosing its test cases strategically in such a way that 'extremities' are part of the draw.

In this report, *Crystal Super Grid* with its hourly load profile, power plant ramp-up and emission trading is applied to the European electricity market to study the case of diverging levels of capacity portfolio and import on a number of indicators in Belgium. For this purpose, five scenarios with ten test cases each (to take account of different meteorological years and hence the influence of the weather during a specific year on both demand and solar and wind production) are created within *Crystal Super Grid*. A scenario is a broad description of a state of generating and consuming facilities in 30 countries. The five scenarios differ in their assumption as to the future CO_2 price (climate ambition) and in the way they cover the structural block in 2027.

Graph 2 Hourly load profile and cumulative production in Crystal Super Grid, illustration



Source: Crystal Super Grid.

1.2. Trade balance effects

Changes in the structure (domestic vs. foreign) and energy mix (e.g. natural gas vs. renewables) of electricity supply affect Belgium's (net) energy trade balance. We refer to net trade balance as the value of exports minus the value of imports. A negative net trade balance therefore equals a trade deficit.

The proposed analysis only deals with energy trade related to power supplies. Moreover, as the effects mainly come from (net imports of) natural gas and electricity, the assessment uniquely focuses on these two energy forms[9]. In other words, the trade balance effects encompass the changes, over time and between scenarios, related to the net imports of electricity and to natural gas imports for power production.

8 Another (major) difference concerns the rolling horizon described in the previous paragraph: this feature is not implemented in ANTARES. ANTARES therefore functions under a perfect foresight hypothesis (per discrete time slice).

9 The power sector also relies (and could rely in the future) on imports of oil products and biomass. However, the impact of these fuels on the energy trade balance is much smaller than the effect of natural gas and electricity. Moreover, they do not vary (significantly) between the different scenarios.

Historical data of energy trade are published by the National Bank of Belgium (NBB). Readily available data on the NBB website cover the period 2011-2015 and are split into the different energy products. The reported gas trade balance refers to the total gas supply. To calculate the share related to the power sector, it is assumed that the average gas import price, calculated as the ratio of the gas trade balance and the physically imported gas volumes, applies to the power sector. The 'power' gas trade balance is then calculated as the product of natural gas supplied to the power sector and the average gas import price.

Physical quantities of natural gas used in the power sector and of (net) electricity imports are taken from Eurostat (period 2011-2014), the Energy Observatory of the FPS Economy (2015) or are calculated from the production and average conversion efficiency of gas-fired power plants (2027).

1.3. Employment

As regards the employment effects, it is important to stress that the deployed methodology is partial at best. After a literature review, it appeared very hard to find reliable figures to sketch the full impact of a decentralised future in terms of job creation. Therefore, it was decided to only zoom in on the job creation potential of more 'traditional' and well documented chains, knowing that this would largely underestimate the total impact of a decentralised power future.

To calculate the job creation potential of renewables and natural gas, the multiplier approach as described in Devogelaer (2013) was applied. This approach is based on an analytical job creation model for the US power sector detailed in Wei et al (2010). The model synthesizes data from 15 job studies covering renewable energy (RE), energy efficiency (EE), carbon capture and storage (CCS) and nuclear power. The paper employs a consistent methodology of normalizing job data to average employment per MW installed capacity and per MWh energy produced over plant lifetime. Job losses in the natural gas industry are modelled to project net employment impacts. The resulting model is used for job projections under various capacity portfolio and import standards.

2. Scenarios and assumptions

As regards the assumptions, the reader is referred to the respective publications from the national TSO Elia (Elia, 2016a and 2016b). Nonetheless, some assumptions are specific to this study, notably when it comes to defining the ‘content’ of the structural block.

The horizon that is looked at is the year 2027. In a joint decision, it was decided not to perform the simulations for all the intermediate years covered in the Elia analysis, basically because of resource and time constraints, but also because 2027 is the only year in which a (significant) structural block pops up. Without the presence of a structural block, it makes not much sense to discuss the potential benefits and costs of new investments in the Belgian power system since the installed capacities in all scenarios will be exactly the same (only the economic indicators might be different). Moreover, one of the objectives of this study is to determine which technologies will be particularly suitable to cover the structural block as such results might shape future policy and regulatory decisions. Therefore, the year in which we are especially interested is the year in which the structural block should be covered, that is 2027.

2.1. The scenarios

The choice of the scenarios for this study was made based upon a decision jointly taken by the FPB and DG Energy as to the scenarios of the Elia studies that are the most interesting from a cost-benefit point of view. In this report, five scenarios are constructed based on two “contexts”. These “contexts” are

– On the one hand, a context that is very similar to the Base case scenario (Elia, 2016a) but with some updated hypotheses as described in the Addendum (Elia, 2016b). Basically, the exterior (foreign) context of the Base case is combined with the updated hypotheses on domestic capacity as described in the Addendum. The annual electricity consumption growth rate therefore attains 0.6% per year (instead of 0% per year), the capacity of biomass is assumed to be constant, CHP is increased by 1000 MW, … The Additional scenario from the Addendum (Elia, 2016b) was not entirely withheld as such because of the explicit valuation of Elia as to that scenario having an ‘extreme character and low likelihood’ of occurring[10]. Therefore, it was decided not to mimic the Additional scenario in the welfare analysis, but to integrate some of its (national) assumptions, specifically the ones that were also signalled by different stakeholders during the stakeholder consultation as organised by DG Energy (AD Energie, 2016);

– On the other hand, the Gas before Coal context from Elia (2016a). The latter is chosen in order to take account of the evolutions that seem to be most in line with what the future holds in terms of climate change mitigation (basically, a higher future CO_2 price).

Starting from these two “contexts”, five scenarios are built that differ in the way they cover the structural block. The size of the structural block reaches 4000 MW by the end of the period (year 2027) in both contexts. The assumptions for the structural block (hence, the choice for the five scenarios) are described in part 2.2.

[10] Basically because of anticipative security of supply measures taken by the different Member States.

2.2. The assumptions

Regarding the assumptions that were taken to cover the structural block in 2027, two options were chosen:

– Option 1 is to fill the structural block with newly built gas-fired power plants. Basically (apart from cogeneration), there are two gas-fired power generation technologies, being open cycle (mainly used to cover peak demand) and combined cycle gas turbines (rather flexible as they can be easily ramped up and down). It is important to recall that the assumption of Elia on the availability of the structural block equals 100%. In reality, this is not the case because of maintenance, planned and unexpected outages (overhauls), reserve bids, … This means that to guarantee a 100% availability of say 4000 MW with gas-fired power units, approximately 4400 MW should be installed.

– Option 2 is to fill the structural block with more decentralised generation and storage. Because of the intermittency of most decentralised generation, a mix of different sources is proposed including solar PV, wind, batteries and electric vehicles. Remark that this resembles an evolution that agrees with what is described in the Winter Package 'Clean energy for all Europeans' by the European Commission (European Commission, 2016) which puts the consumer at the centre of the energy transition.

Based on these two options, five scenarios can be created. A scenario is in fact a broad description of a state of generating and consuming facilities in the countries belonging to the CWE (Belgium, France, the Netherlands, Luxemburg and Germany), complemented with the available capacities and load in 25 other countries. Out of the five scenarios, four are in fact a combination of the two contexts described above (see part 2.1) with the two options (1 and 2), the fifth scenario being a sensitivity performed on the fourth scenario. Keep in mind, however, that the five scenarios have an identical external context (to Belgium) as regards power capacity additions and withdrawals.

To recapitulate,

1) Scenario **"Base Gas"**: based on the Base Case defined in Elia (2016a and 2016b) with a structural block of 4000 MW filled with newly built CCGT/OCGT assumed to be 100% available. Two additional assumptions have to be decided on:

   a) *The 'real' availability rates*: a technology that is 100% reliably available does not exist. This is due to limitations on the output power of power plants because of non-usable capacity, maintenance and overhauls, outages and system services (ENTSO-E, 2014). Therefore, the technology specific availability rates from work Elia performed during its determination of the Strategic Reserve 2017-2018 (Elia, 2016c and 2016d) are used.

   b) *The share of CCGT and OCGT in the future structural block*: although the current share of OCGT in the total gas-fired generation park is rather low (around 15%), we expect it to increase in the course of the next decade because of the ability of OCGT's to quickly follow (peak) load. The future allocation evolves towards 75% CCGT-25% OCGT (based on expert judgment).

   Consequently, the structural block will be composed of 3200 MW CCGT with average availability of 91.8% and 1200 MW OCGT with average availability of 84.8%.

2) Scenario **"Base Decentral"**: the structural block is filled by a selection of different technologies:

   a. Solar: 568 MW additional solar, mounting the total solar capacity to 5556 MW in 2027.

This is based on the High RES scenario from Elia (2016a);

b. Wind: 2275 MW additional wind, adding up to 8129 MW in 2027, also based on High RES in Elia (2016a);

c. Electric vehicles: penetration of 500 000 battery electric vehicles driving on Belgian roads by 2027 (growing from 4368 EV's in 2016). This means that approximately 10% of the total car stock in 2027 will be electrically propelled. This also means that between 2022 and 2027 around 22% of the new car sales (or 1 out of 4 newly sold cars) will be an electric one. These EV projections are based on results obtained in the context of a Working Paper from the FPB (Devogelaer and Gusbin, 2015). This figure seems to be in line with a recent study performed by the University of Ghent (Albrecht et al., 2016) in which the same hypothesis for a similar horizon is taken.

d. Generic storage: 'home' batteries of 5 kWpeak and 15 kWh energy installed in 500 000 families (around 10% of the projected number of households in Belgium (FPB, 2016)) totalling a battery storage capacity of 7500 MWh. The home battery hypothesis is taken in conjunction with the 500 000 EV owners assuming that those people are more likely to install a home battery as well.

When these figures are integrated in the model, we notice an average LOLE of 385 hours, which is significantly higher than the legally defined cap of 3 hours. Therefore, some CCGT and OCGT should be installed as well. To conform to the legally defined LOLE criterion, 2400 MW of CCGT's and 500 MW of OCGT's are conjointly being built in this setting[11].

3) Scenario **"Clima Gas"**: the same assumptions as in the scenario "Base Gas" hold (hence, the same structural block), with one exception: the CO_2 price is raised to 57.45 €/ton[12] (according to Elia, 2016a).

4) Scenario **"Clima Decentral"**: the same assumptions (and structural block) as in the scenario "Base Decentral" hold, with one exception: the CO_2 price is raised to 57.45 €/ton (according to Elia, 2016a).

5) Scenario **"Clima Decentral and new Gas"**: this fifth scenario in fact builds on the previous **"Clima Decentral"** scenario but has way more gas-fired power plants at its disposal: a total of 6000 MW of CCGT is supposed to be operational in Belgium by 2027. This 6000 MW of CCGT can be split into the preservation of the current CCGT's (3200 MW) and the construction of new ones (2800 MW). However, no new investments in OCGT's are foreseen compared to "Clima Decentral". This scenario is built to investigate how welfare related indicators change when more natural gas units are added to the system. Its main interest is that it plots the costs and the benefits of a scenario in which Belgium by 2027 does not rely on net electricity imports anymore (and even displays a small amount of net exports).

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11 An even more ambitious scenario in terms of renewables in which 10 000 MW of solar together with 10 000 MW of wind was installed in 2027, was run as a sensitivity. Battery storage was increased to 5000 MW (storage capacity of 15 000 MWh). Even under these conditions, LOLE reached highs of 212 hours. To decrease the LOLE to anywhere below 3 hours, 2000 MW CCGT and 400 MW of OCGT are needed.

12 For a further explanation on the CO_2 price, the reader is referred to part 5.1.

3. Results

The results described in this part cover different aspects of a cost-benefit analysis, namely costs, trade balance and (some elements of) employment. We start with the (general) cost analysis in section 3.1.

3.1. Costs

Although the title of this chapter is ‘costs’, its content covers more than only economic costs and in fact has a broader perspective than a purely financial one. This part collects all results related to the scenario analyses and not only describes differences in investment costs or potential price differences, it also zooms in on CO_2 emissions, net imports and surpluses on the consumer and producer(s) side. A comprehensive table compiling all quantitative results is given at the end of this document (part 4, Table 10).

As already mentioned in part 2, results are only documented for the final year, being the year 2027 (no intermediary results). Also worthwhile to keep in mind: these results are only valid for the settings as described in Elia (2016a), meaning that we take the international contexts of the Base case and the Gas before Coal case as given. Of course, if external circumstances change and (some) countries start to heavily invest in gas-fired power plants or extend the operational lifetime of certain units for security of supply reasons, the current overcapacity will pertain and benefits as described in this section (particularly in part 3.1.3) might be lost in good part.

3.1.1. Base scenarios

First, the Base case is scrutinised. Recall that the Base case is a close approximation of the Base case dissected in the Elia report (2016a) but with some updates on certain hypotheses (e.g. demand, biomass, …). The Base case gathers two scenarios linked to two assumptions (options) as to the content of the structural block (SB in what follows). On the one hand, one can distinguish the “Base gas” scenario in which the SB is provided by gas-fired technologies, on the other hand, “Base Decentral” mimics a future state in which power production (and consumption) is way more decentralised and the SB is taken care of by a mix of different technologies, accompanied by battery storage and a significant penetration of EVs. The results of these two Base scenarios are compared in what follows and discrepancies are documented.

a. Marginal costs

Let’s start by looking at the average[13] “price” difference between the two scenarios. In the decentralised environment (“Base Decentral”), the marginal cost (which can be interpreted as a “price[14]” in an energy-only market system) is 2.28 €/MWh higher than in “Base Gas”, a fact that has an immediate repercussion on the ensuing consumer surplus (see part 3.1.1.b). The higher price can be attributed to

[13] Average meaning averaging out over all the hours of the year (not weighted by demand).
[14] Meaning the price for the commodity, not the bill the end consumer receives at the end of the billing period.

- a different merit-order curve (MOC)
- more congestion
- a higher use of the Demand Response option.

The first part of the explanation is the different MOC, or the MOC effect of the integration of more variable renewable energy sources in the electricity system. This leads to an overall (European-wide) lower use of coal, gas (CCGT), lignite and nuclear when producing power, but to an increased use of OCGT which do tend to set CWE prices more often in "Base Decentral".

The second explanation has to do with more congestion in "Base Decentral" (see also part 3.1.1.d). In case of congestion, prices are set in the isolated Belgian pricing zone and tend to be higher.

Graph 3 Demand Response, Base Decentral, year 2027
MW

Source: Crystal Super Grid.

The third (and most important) part regards the practice of Demand Response (DR). In "Base Gas", DR is called upon for 2 consecutive hours, representing a total volume of 1 GWh[15]. In "Base Decentral", DR is activated during 78 hours, representing a total volume of 65 GWh.

Given that the assumed price of Demand Response is set at, on average, 400 €/MWh[16], this largely adds to the explanation of the higher average price in "Base Decentral". This price assumption is coherent with Fraunhofer ISI and FfE (2014) who claim that minimal prices triggering industrial DR are to be situated within an interval of 100 to 400 €/MWh. The same interval, albeit a bit broader, can also be found in Rooijers et al (2014). DIW Berlin confirms by advancing that the variable costs of industrial DR are usually high but stay below 500 €/MWh (Stede, 2016).

b. Consumer surplus

A second indicator is the (difference in) consumer surplus. The consumer surplus is defined as the surface being made up of the demand curve and the horizontal line representing the marginal cost (defined as the intersection between demand and supply). The difference in consumer surplus can be seen as the difference in (negative) marginal costs between the "Base Decentral" and "Base Gas", multiplied by the total demand. Because of the higher prices to be paid by the different consumer categories in "Base Decentral", the cost of the system increases for the consumer, hence the consumer surplus decreases and is 280 M€ lower in this scenario than in the "Base Gas" scenario.

[15] The total market volume that reacts to prices and that is taken into account in this study, amounts to 1096 MW in 2027 (Elia, 2016a).

[16] This is an assumption based on the report of the national regulatory authority CREG (2016) in which the Belpex clearing price on September 22, 2015 reached €448,7/MWh which was attributed to a Demand Response bid.

c. Production surplus

As regards the production surplus, the situation is markedly different. The production surplus is defined as the effective production of a certain technology times the marginal cost (proxy for the equilibrium price) minus its total production cost (which equals the sum of the variable operation & maintenance costs, the purchase cost of consumed energies and, where applicable, CO_2).

Producers (including prosumers) in "Base Decentral" are expected to gain and earn higher revenues in this future setting. This effect is triggered by the higher prices at which the different producers can sell their energy. Overall, the producer surplus in this scenario is expected to be 509 M€ higher than in "Base Gas". All production technologies tend to increase their surpluses: solar by 45 M€, wind by 396 M€, OCGT by 4 M€, cogeneration and biomass by 57 M€ and battery storage by 20 M€. The only 'losers' are the CCGT's which see their surplus decrease by 14 M€ because of a markedly lower production (see also part 3.1.1.f).

d. Net imports

In the "Base Decentral" future, the production of power occurs primarily at a decentralised level. The total amount of domestic power production amounts to 66.1 TWh, whilst "Base Gas" produces 63.6 TWh. The demand in the two scenarios is almost identical, the difference being made up by the consumption provoked by the electric passenger transport in "Base Decentral" (500 000 EV's cruising the Belgian roads by 2027). This additional demand in "Base Decentral" sums up to 1.5 TWh.

The difference between demand and domestic production is balanced by imports or exports. Because the additional generation in "Base Decentral" more than covers the additional demand, an increase in exports (+1 TWh) can be observed. Net imports equal 29 TWh in "Base Decentral", which is 1.1 TWh less than in "Base Gas".

Table 1 Imports and exports, Base scenarios, year 2027

	Base Gas	Base Decentral
Imports	32.9	32.8
Exports	2.8	3.8
Net imports	30.1	29.0

Source: Crystal Super Grid.

e. Congestion revenues

Although net imports are lower in "Base Decentral", congestion revenues are higher meaning that transmission lines are more congested in this setting. The difference between the two scenarios as regards the congestion revenues equals 170 M€[17].

[17] Congestion revenues should in fact be divided by two because they have to be equally split between the respective national TSO's.

f. CO_2 emissions

The above also has an influence on the CO_2 emissions emitted in the Belgian (and European) power sector. Although the power sector is part of the EU ETS which is a cap-and-trade system, it is instructive to see which future state of the SB will lead to the lowest CO_2 emissions, all things being equal. According to the model results, we notice a significant difference in CO_2 emissions between the two scenarios: in "Base Decentral", Belgium emits 1.66 Mt less CO_2[18] than is the case in "Base Gas". Knowing that the future CO_2 price in the Base case equals 17 €/tCO_2 (Elia, 2016a), this lower emission in "Base Decentral" boils down to an amount of 28.2 M€ that does not have to be spent on the purchase of emission quota compared to "Base Gas".

The lower emissions can be attributed to the lower capacity (utilisation) of the gas-fired technologies. "Base Decentral" has only 2400 MW CCGT installed (whilst "Base Gas" counts on 3200 MW CCGT) and they are slightly less used: "Base Decentral" has 138 less CCGT full load hours, adding up to 4639 full load hours (or a CCGT load factor of 53%) in 2027. The CCGT power production difference between the two scenarios amounts to 4.2 TWh. OCGT produce 0.5 TWh less in "Base Decentral" but they have more full load hours (+57 more FLH). The total number of FLH in "Base Decentral" amounts to 836h, leading to an OCGT load factor of almost 10%.

Table 2 Some production indicators for gas-fired power plants, Base scenarios, year 2027

	Base Gas			Base Decentral		
	Production (TWh)	FLH (hours)	Load factor (%)	Production (TWh)	FLH (hours)	Load factor (%)
CCGT	15.3	4777	55	11.1	4639	53
OCGT	0.9	779	9	0.4	836	10

Source: Crystal Super Grid.

Interestingly, this difference in CO_2 emissions in Belgium is not the end of the story. The operation of the Belgian power park has an influence on total emissions in Europe through the levels domestically produced and imported and exported abroad (hence the emissions originating in the country from and to which Belgium imports and exports electricity). We then note a difference in CO_2 emissions on the European level of around 2.41 Mt CO_2. This higher effect can be attributed to the fact that Belgium needs slightly less imports but has higher exports in "Base Decentral", leading to lower fossil fuel based power production in e.g. the Netherlands, UK and Germany, the latter two countries with which we will be interconnected in the next decade. An example: in 2027, less production from coal-fired power plants in Germany (-0.5 TWh) and the Netherlands (-0.1 TWh) and from CCGT in the UK (-0.3 TWh) is observed. These levels are replaced by exports from Belgium which at that moment employs a less carbon intensive mix.

g. Investment costs

Finally, let's look at the overall cost picture in terms of investments. Investment costs are in both options significant. When the SB is being entirely provided by newly built gas generation units ("Base Gas"),

[18] In 2013, the total net CO_2 emissions in Belgium amounted to 97.8 Mt of which 16.5 Mt were emitted by the public production of electricity and heat (UNFCCC). CO_2 emissions represent around 85% of total GHG emissions in Belgium.

the investments total somewhere between 11 and 12 billion euros by the year 2027[19]. Capital expenditures in "Base Decentral" are 15 to 20 billion euros higher and can be situated within the interval 26 to 32 billion euros, or up to a factor 2.6 higher.

Two considerations have to be made:

– One should be aware of the fact that the type of actor that makes the investment differs hugely between the two scenarios. In the "Base Gas" case, utilities will invest in the 8 new CCGT's and in the 1200 MW required OCGT capacity. In "Base Decentral", on the other hand, the capital expenditures are also undertaken[20] by decentralised customers (households and SME's) which choose to invest in their own energy provision and management through the purchase of (the combination of) batteries, solar panels, electric vehicles, …

– Another point of attention is that in this calculation, we assumed that the 3.2 GW ("Base Gas") and 2.4 GW ("Base Decentral") are newly built CCGT's with investment costs that can be found in Annex (Table 12 and Table 13). If we were to take another assumption, namely not building new ones, but keeping the current stock of CCGT's online, the total investment cost would go down considerably[21]. Of course, the units that are currently operating will not, for a myriad of reasons[22], stand another ten years without any form of capacity remuneration mechanism (be it a strategic reserve, a decentralised or centralised capacity auction, what have you). Therefore, a sensitivity was run assuming that the 3264 MW current CCGT capacity are kept operational but receive a capacity 'fee' of 26.7 €/kW[23] for the next ten years. This would lower the total 'investment cost' of CCGT to 870 M€ (compared to 2720 M€ when investing in new units). For the OCGT, investments in new units will still be necessary since only 238 MW is available for the winter 2017-2018 (Elia, 2016d). Total investment costs for the entire time horizon for a system implementing a remuneration scheme to keep old gas-fired plants available[24] would go down to 10 billion euros in "Base Gas" and to somewhere between 25 and 30 billion euros in "Base Decentral".

3.1.2. Climate scenarios

The difference between the Base and Clima case primarily resides in the fact that EU CO_2 prices are significantly raised in the latter (going from 17 to 57.45 €/tCO_2 in 2027). This of course has an immediate repercussion on the height of the system marginal costs (hence, the consumer surplus), but also other indicators will be impacted. Main discrepancies are described in this part.

19 In this calculation, investments are assumed to be lump sums paid in full in the year 2027. In reality, to have the unit up and running by 2027, investments (and (partial) payments) should be undertaken quite some time in advance. Moreover, the time lag between an investment decision and the moment the unit comes online should be taken into account. That is why it is crucial if one or the other scenario is deemed interesting from the point of view of overall welfare, to start building the future as quickly as possible, meaning that the appropriate regulatory framework has to be put in place, that certain facilitating political decisions should be taken without delay, etc.

20 Nonetheless, utilities still have a role to play in this scenario in providing the investments in large (offshore) wind farms and in the 6 required CCGT's (and 500 MW OCGT).

21 It is important to recall that extending the operational lifetime of the current CCGT's instead of building new ones will not only impact the investments, it will also have an influence on other indicators like the net imports (see e.g. Elia (2016a), p. 58).

22 One of them being the low profitability prospects as described in Elia (2016a), part 5.5.

23 This is the clearing price (equalling 22.5 £/kW) of the third capacity auction held in the UK in December 2016 to cover the period 2020/2021, see http://uk.reuters.com/article/britain-electricity-auction-idUKL1N1E31N7.

24 The cost of remunerating other available technologies through this capacity scheme (e.g. batteries) is not taken into account.

a. Marginal costs

The impact of raising the CO_2 price in the power generation sector (or, more generally, the EU ETS) does not go unnoticed. In the Clima case which represents the Gas before Coal scenario from Elia (2016a), we see that the marginal costs increase by 37%. The "Clima Gas" scenario has an average marginal cost of 97.3 €/MWh in 2027, whilst "Clima Decentral" demonstrates a marginal cost of 99.7 €/MWh. The price difference between the two Clima scenarios is not that different from the delta calculated between the two Base scenarios: it amounts to 2.44 €/MWh.

b. Consumer surplus

Because the price difference between the Clima scenarios is quite similar to the delta observed between the Base scenarios, consumer surplus discrepancies are also quite close: the consumer surplus in "Clima Decentral" is 290 M€ lower than its counterpart in "Clima Gas" (compared to 280 M€ in the Base scenarios).

c. Production surplus

The difference between the two Clima scenarios as regards the production surplus is significantly higher than could be observed in the Base scenarios: it amounts to 670 M€ (compared to 509 M€ in the Base case). Split up per technology, we see that the producer (and prosumer) surplus increases by 63 M€ for solar in "Clima Decentral" compared to "Clima Gas", by 578 M€ for wind, by 61 M€ for cogeneration and biomass and by 16 M€ for battery storage, basically because of the higher prices at which they can sell their energy. The producer surplus for the gas-fired power technologies on the other hand decreases by 50 M€ because of the lower gas-based production in "Clima Decentral" (see also part 3.1.2.f).

d. Net imports

In the "Clima Decentral" future, the domestic production of power majorly occurs at a decentralised level: it amounts to 72.6 TWh in 2027. In "Clima Gas", the total power production equals 72.5 TWh, the difference therefore is marginal. Demand between the two scenarios, however, differs because a large penetration of EV's is integrated in the "Clima Decentral" setting augmenting its annual demand by 1.2 TWh[25].

Consequently, net imports have to cover the additional consumption. "Clima Decentral" notes higher imports (+1 TWh) in 2027 compared to a more centralised "Clima Gas" future state. Exports, on the other hand, are exactly alike: 10.3 TWh is being exported to interconnected countries in both scenarios. Net imports reach 21.8 TWh in "Clima Decentral" and 20.8 TWh in "Clima Gas".

[25] The average efficiency (consumption) of the fleet of EV's is supposed to increase (decrease) in the Clima setting due to favourable development conditions triggered by higher carbon prices (and taxes): the average consumption decreases from 20 kWh/100 km in "Base Decentral" to 16 kWh/100 km in "Clima Decentral".

Table 3 Imports and exports, Clima scenarios, year 2027

	Clima Gas	Clima Decentral
Imports	31.1	32.1
Exports	10.3	10.3
Net imports	20.8	21.8

Source: Crystal Super Grid.

Box 1 Difference in cross-border flows between the Base and Clima scenarios

In this box, we take the net import analysis a step further and compare production and cross-border flows in the Clima scenarios with those in the Base scenarios.

First important finding: the net electricity production in the Clima scenarios is significantly higher than in the Base scenarios. The difference ranges between 6 (Decentral) and 9 TWh (Gas).

Second finding: although the level of imports seems quite similar, the level of exports is significantly different. In the Base scenarios, the latter hovers around 3 TWh whilst in the Clima scenarios, it equals 10 TWh. The additional Belgian production will therefore serve to cover foreign demand. This can be explained by the fact that coal and lignite power plants lose ground in the Clima scenarios because of the penalizing CO_2 price. Their generation will be replaced by an increase in the production of CCGT's all over Europe. Countries that have natural gas in their capacity portfolio, will augment its production. Belgian gas-generated power will therefore increase, raising CCGT load factors and will flow to Member States that burn coal like the Netherlands and Germany. On the other hand, Belgium will export less to the UK that possesses its own gas-generated park.

Another consequence: although the level of imports seems untouched, its composition changes. Belgium will import less from the Netherlands and Germany but will increase its imports from France and the UK.

e. Congestion revenues

We notice that congestion (hence, congestion revenues) in "Clima Decentral" is significantly higher than in "Clima Gas", pointing to the fact that transmission lines are more congested in a decentral setting. The difference between the two scenarios as regards the congestion revenues equals approximately 150 M€[26].

f. CO_2 emissions

The above also has an influence on the CO_2 emissions emitted in the Belgian (and European) power sector. Although the power sector is part of the EU ETS which is a cap-and-trade system, it is instructive to see which future state of the SB will lead to the lowest CO_2 emissions, all things being equal. According to the model results, we notice a significant difference in CO_2 emissions between the two scenarios: in "Clima Decentral", Belgium emits 2.4 Mt less CO_2[27] than is the case in "Clima Gas".

[26] Congestion revenues should in fact be divided by two because they have to be equally split between the respective national TSO's.

[27] In 2013, the total net CO_2 emissions in Belgium amounted to 97.8 Mt of which 16.5 Mt were emitted by the public production of electricity and heat (UNFCCC). CO_2 emissions represent around 85% of total GHG emissions in Belgium.

Knowing that the future CO_2 price in the Clima case equals 57.45 €/tCO_2 (Elia, 2016a), this lower emission in "Clima Decentral" boils down to an amount of 137.3 M€ that does not have to be spent on the purchase of emission quota compared to "Clima Gas".

The lower CO_2 emissions can be attributed to the lower capacity (utilisation) of the gas-fired technologies. "Clima Decentral" has only 2400 MW CCGT installed (whilst "Clima Gas" counts on 3200 MW CCGT) and they are slightly less used: "Clima Decentral" has less CCGT full load hours (-83h), adding up to 7580h full load hours (or a CCGT load factor of 87% which puts them in the baseload category) in 2027. The CCGT power production difference between the two scenarios amounts to 6.3 TWh. OCGT produce 0.5 TWh less in "Clima Decentral" but they have more full load hours (+28h FLH). The total number of FLH in "Clima Decentral" amounts to 830h, leading to an OCGT load factor of almost 10%.

Table 4 Some production indicators for gas-fired power plants, Clima scenarios, year 2027

	Clima Gas			Clima Decentral		
	Production (TWh)	FLH (hours)	Load factor (%)	Production (TWh)	FLH (hours)	Load factor (%)
CCGT	24.5	7663	87	18.2	7580	87
OCGT	1	802	9	0.4	830	10

Source: Crystal Super Grid.

Also here, we notice that there is a European CO_2 effect, albeit smaller than was the case in the Base scenarios: CO_2 emissions on the European level are only 1.3 Mt CO_2 lower in "Clima Decentral" compared to "Clima Gas" (whilst emissions on the Belgian level are 2.4 Mt lower). The difference we observe between the Belgian and European emissions in the Clima case can be attributed to

- the fact that Belgium imports more in "Clima Decentral"
- the high(er) CO_2 price in the Clima scenarios which automatically favours gas before coal so the most polluting coal and lignite fired power plants are already less solicited in both scenarios.

g. Investment costs

Since the Clima and Base case only differ in the price they are putting on emitting CO_2 (which is set at 57.45 €/tCO_2 in the former and at 17 €/tCO_2 in the latter scenario, see Elia (2016a)), the investment cost difference between the two will level up to exactly zero[28].

One might however assume that in a more climate ambitious outset, learning curves for environmentally friendly/CO_2 low/CO_2 neutral technologies will be descended faster, which would lead to lower (total) investment costs by the end of the next decade. That is why the capital expenditures published in Table 13 are more likely to occur in the Clima case. This then would entail an investment expenditure of 11 billion euros in "Clima Gas" and 26 billion euros in "Clima Decentral", or a factor of 2.5 of difference. Also here, the remarks made in part 3.1.1.g are valid and should be borne in mind when interpreting the investment amount.

[28] Since we assumed that the structural block is filled with exactly the same (installed capacity of) technologies as was chosen in the Base case scenarios.

3.1.3. No net import case

As a fifth scenario (and in fact, as a response to one of the concerns ventilated in the stakeholder consultation document published by DG Energy (2016)), we thought it to be interesting to have a look at a particular outset, namely a scenario in which the ample presence of natural gas-fired power plants would enable the Belgian power system not be a net electricity importer anymore, and even to become a net exporter, albeit small, by the end of the horizon. This could be the case if, when all the assumptions taken in "Clima Decentral[29]" are integrated, an additional amount of natural gas-fired power plants is made available. The total volume of natural gas-fired units in this scenario will attain 6000 MW, to be split into a set of currently existing ones (3200 MW CCGT) that are to be kept online through a form of CRM and an investment in 2800 MW new CCGT's (7 newly built CCGT's). An overview of what happens to the different indicators when we compare this scenario to "Clima Decentral" is provided in this part.

a. Marginal costs

When we compare the Clima Decentral scenarios ("Clima Decentral and New Gas" with "Clima Decentral"), we notice the marginal costs taking a dive: they dwindle by 4.72 €/MWh. This can be attributed to the fact that more domestic production alleviates the isolated price zone phenomenon and CWE prices are more often set in the Belgian price zone due to the new gas investments.

Also worthwhile to mention: in the "Clima Decentral and New Gas" scenario, there does not seem to be any DR left. The 65 GWh provided by DR in the "Clima Decentral" case is washed away by abundant (cheaper) supply.

b. Consumer surplus

Of course, when the costs for the consumer decrease, the consumer surplus increases. The difference between the two Clima Decentral scenarios amounts to 519 M€.

c. Production surplus

Production surplus increases by 108 M€. More interestingly, we see that this time, only the CCGT units stand to gain: their surplus increases by 319 M€, whilst all other technologies lose out: biomass and cogen by -117 M€, batteries by -5 M€, OCGT by -10 M€, PST by -4 M€, solar by -16 M€ and wind by -58 M€.

d. Net imports

As already stated, the "Clima Decentral and New Gas" scenario turns Belgium into a net exporter: net exports will reach 2.1 TWh by 2027.

[29] This scenario is chosen as the basis for building the "Clima Decentral and New Gas" scenario because: 1) it mimics the Gas before Coal setting from Elia (Elia, 2016a): new natural gas-fired power plants only make sense when they precede coal in the CWE merit-order curve; 2) it integrates the decentral part which seems to be most in line with what is communicated in the European Winter Package (European Commission, 2016).

Table 5 Imports and exports, Clima Decentral scenarios, year 2027

	Clima Decentral and New Gas	Clima Decentral
Imports	21	32.1
Exports	23.1	10.3
Net imports	-2.1	21.8

Source: Crystal Super Grid.

Above that, Table 5 shows that the additional generation produced by the CCGT's (which amounts to +24 TWh compared to "Clima Decentral") can be split into a higher level of exports (+12.8 TWh) and a lower level of imports (-11.1 TWh). The latter points to the diminished need to appeal to neighbours to satisfy the domestic demand because of the additional power production of the CCGT's. Nonetheless, it is important to stress that imports are still necessary and are not all together eliminated.

As regards exports, more detailed analysis demonstrates that the bulk of the increased exports is directed towards Germany and the Netherlands, not surprisingly two countries in which coal makes up an important part of the (future) electricity mix. In "Clima Decentral & New Gas", these two Member States will further substitute part of their coal-fired power with gas-generated Belgian imports.

The situation in the two other interconnected neighbours (France and the UK) is also interesting to look at. Since their power mix is fundamentally different (not only of each other, but also from the Netherlands and Germany), they will react differently.

France with a rather small amount of thermal power plants compared to its nuclear units, will not be that much affected by the larger offer of gas-generated electricity in Europe. Consequently, its power generation will stay almost identical. Nonetheless, it will feel the impact through the lower import needs of Belgium, so it will react through augmenting its exports to countries that burn coal, i.c. Germany, Spain and Italy. The lost import volume to Belgium (around 6 TWh) will be compensated by an increase in French exports (about 4 TWh) to other countries and a decrease of 2 TWh in imports (or transit) from abroad.

The UK, on the contrary, will see its power production decrease because of the more efficient gas based production in Belgium. This lower domestic production will be compensated by higher imports (from France and Belgium) and lower exports (basically to Belgium, France and Norway).

e. Congestion revenues

We notice that congestion (hence, congestion revenues) in "Clima Decentral and New Gas" is significantly lower than in "Clima Decentral". Transmission lines are obviously less congested when a large part of production is being produced domestically. The difference between the two scenarios as regards the congestion revenues equals approximately 130 M€[30].

[30] Congestion revenues should in fact be divided by two because they have to be equally split between the respective national TSO's.

f. CO_2 emissions

Although consumer and production surplus both seem to benefit from the increased domestic production, this comes at a considerable cost: the surge in the production by CCGT (+24 TWh), hence natural gas as a means to produce power, causes CO_2 emissions in Belgium to rise. “Clima Decentral and New Gas” will emit 7.8 Mt CO_2 more than is the case in “Clima Decentral”.

Knowing that the future CO_2 price in the Clima case equals 57.45 €/tCO_2 (Elia, 2016a), this higher CO_2 emission in “Clima Decentral and New Gas” boils down to an amount of 449.3 M€ that has to be spent on the additional purchase of emission quota compared to “Clima Decentral”.

The additional electricity production in “Clima Decentral and New Gas” can be split into generation by the “old” CCGT’s and by the newly constructed CCGT’s. The old CCGT’s will generate 20.4 TWh whilst the new ones will produce 22.2 TWh. The old CCGT’s will run for 6375 hours a year whilst the new ones will operate during 7930 hours (FLH), meaning that they have a load factor of 73% and 91% respectively, placing them in the baseload category.

Table 6 Some production indicators for CCGT in “Clima Decentral and New Gas”, year 2027

	Installed Capacity (MW)	Net production (TWh)	Efficiency (%)	Load factor (%)
"Old" CCGT	3200	20.4	56%	73%
"New" CCGT	2800	22.2	59%	91%
Total	6000	42.6		

Source: Crystal Super Grid.

For Europe as a whole, the CO_2 emission picture is different: EU emissions will decrease by 11 Mt CO_2 in “Clima Decentral and New Gas”. This is because the EU import/export picture changes as a consequence of the different MOC in the CWE zone triggered by the cheaper Belgian CCGT’s. An example was already stated in 3.1.2.d: the Netherlands and Germany will increase their imports from Belgium and decrease their own domestic production. More specifically, the latter will decrease its coal produced power by 3.7 TWh, its OCGT generation by 1.5 TWh and its lignite based production by 2.8 TWh. Its emissions feel the immediate effect: they contract by 7 Mt CO_2. The former will diminish its coal use for power production (-2 TWh), its OCGT’s (-0.4 TWh), CCGT’s (-0.3 TWh) and will see its domestic CO_2 emissions dwindle by 2 Mt.

Throughout Europe, a difference in coal- and lignite-based production of respectively 8.6 TWh and 6.8 TWh can be observed.

g. Investment costs

In order to construct the production park described in “Clima Decentral and New Gas” consisting of both decentralised (solar, wind, etc.) and centralised (CCGT) generation units by 2027 in Belgium, additional investments have to be undertaken. These amount to an extra 1100 M€ in comparison to the “Clima Decentral” case. This calculation takes into account a sort of CRM put in place to keep the currently existing (“old”) CCGT available until 2027[31]. To build the new CCGT’s, it can be expected that potential investors will also need an incentive (remuneration, subsidy scheme, state guarantee, …) in order to start building.

[31] With the same assumptions as described in part 3.1.1.g.

3.2. Trade balance effects

Before going into the analysis of the impact of the different scenarios on Belgium's energy trade balance in 2027, it is instructive to have a look at the recent trends in electricity and natural gas (for power) (net) trade balances (Table 7). To alleviate the text, the words in parentheses are skipped in what follows.

Table 7 Electricity and natural gas net trade balances, 2011-2015
Billion euros of 2014

	2011	2012	2013	2014	2015
Electricity	-0.14	-0.49	-0.46	-0.65	-0.82
Natural gas	-1.18	-1.30	-1.24	-0.86	-0.89
Electricity + natural gas	-1.32	-1.79	-1.70	-1.51	-1.71

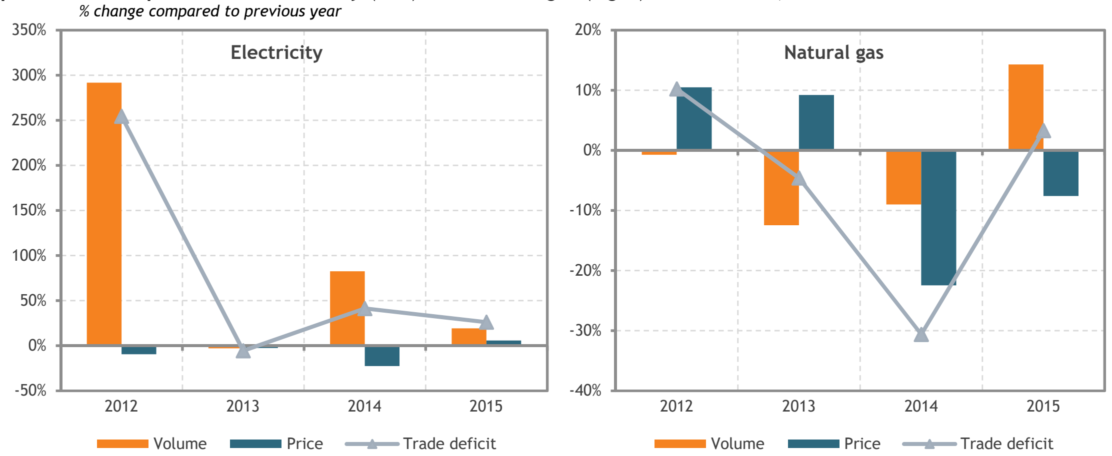
Source: NBB, Eurostat, Energy Observatory (FPS Economy), FPB calculations.
Note: The figures for natural gas only concern gas supplies to the power sector.

Notwithstanding the deterioration of the energy trade balance by 40% over the period 2011-2015, electricity and natural gas trade balances demonstrate rather opposite trends. The value of electricity imports increased significantly, whereas gas supplies first increased slightly in 2012 and then dropped to reach a level in 2015 which is below the level of 2011. Consequently, the relative shares of these two energy forms in the 'total' energy trade balance changed substantially: from 10% for electricity and 90% for natural gas in 2011 to 50% for both in 2015.

The above trend implies a radical change in Belgium's power supply dependence and vulnerability to energy price shocks and energy supply disruptions. Indeed, it translates into a move from dominating extra-EU energy imports towards more balanced intra/extra-EU energy imports.

The following graph shows a decomposition of the evolution of the electricity and natural gas trade deficit into a volume and a price effect. For electricity, the volume effect leads the changes in the trade balance, whereas the price effect plays a more important role for natural gas.

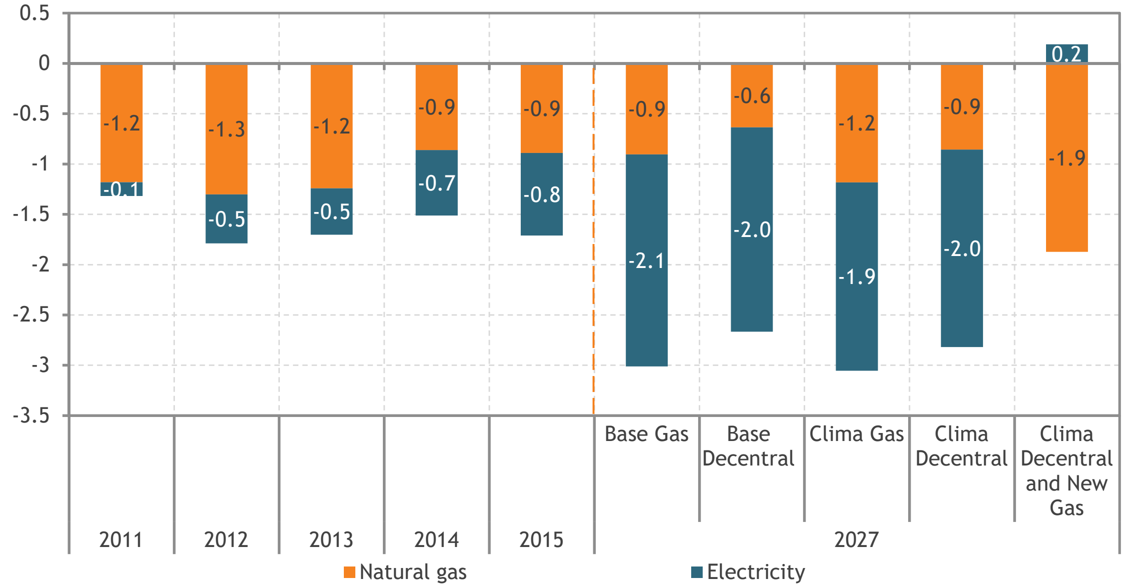
Graph 4 Decomposition of electricity (left) and natural gas (right) trade deficit, 2011-2015
% change compared to previous year



Source: NBB, Eurostat, Energy Observatory (FPS Economy), FPB calculations.

Further changes in the energy trade balance of the power sector are expected by 2027. These changes depend on the trade-off between domestic and external power supply, on the one hand, and on the energy mix of power generation, on the other hand. The five scenarios described in the previous section illustrate this variability. The trade balance effects are depicted in Graph 5.

Graph 5 Electricity and natural gas trade balances according to the scenario, 2011-2015 and 2027
Billion euros of 2014



Source: NBB, Eurostat, Energy Observatory (FPS Economy), Crystal Super Grid, FPB calculations.

In 2027, all scenarios but the “Clima Decentral and New Gas” show a significant increase in the energy trade deficit (almost a doubling) compared to 2015. In the latter scenario, the energy trade deficit is the same as in 2015.

In the first four scenarios, the increase is mainly due to electricity whereas the gas trade balance is comparable to values recorded in the period 2011-2015 (around 1 billion euro). By contrast, the rise in the fifth scenario comes exclusively from natural gas; the value of gas supplies is twice the level of recent years (2011-2015).

The electricity trade balance for the year 2027 is calculated as the product of the net electricity import[32] and an average import price. The net electricity import level in the different scenarios is reported in section 3.1: it ranges between 20 and 30 TWh in the first four scenarios and is slightly negative in the “Clima Decentral and New Gas” scenario in which Belgium becomes a net exporter of electricity (2.1 TWh). The average import price of electricity is assumed to be close to the marginal production cost in Belgium. It is taken to be equal to 70 €/MWh in the Base scenarios and to 90 €/MWh in the Climate scenarios. Sensitivity analyses to the price of imported (or exported) power have been performed, the results of which do not change the overall picture.

Similarly, the gas trade balance in 2027 is calculated as the product of natural gas quantities used in the power sector[33] and the natural gas import price. The consumption of natural gas in the five scenarios is derived from power production figures for CCGT and OCGT and corresponding average conversion

32 With a minus sign.
33 Ibid.

efficiencies as computed with *Crystal Super Grid*. The results are presented in Table 8. By way of comparison, natural gas supplies for power production amounted to 42.5 TWh in 2015.

Table 8 Natural gas consumption for power generation according to the scenario, year 2027
TWh

	Base Gas	Base Decentral	Clima Gas	Clima Decentral	Clima Decentral and New Gas
Natural gas consumption	30.2	21.2	47.3	34.3	74.9

Source: Crystal Super Grid, FPB calculations.

The gas import prices in 2027 are taken from the Elia study (which uses figures from two scenarios of the World Energy Outlook 2015, namely '*Current Policies*' and '*450*'): 7.95 €/net GJ in the Base scenarios and 6.28 €/net GJ in the Climate scenarios.

As shown in Graph 5, the absolute value and relative shares of (net) electricity and natural gas imports change significantly in 2027 compared to the current situation and vary widely according to the scenario. These variations translate into different pictures of Belgium's power supply dependence to foreign energy supply.

In the first four scenarios, despite being a lot more dependent on external supplies than today, Belgium's additional trade deficit is (almost) exclusively with respect to EU countries, in the form of growing electricity imports. In these cases, Belgium's vulnerability is primarily linked to possible power supply disruptions in the neighbouring countries. Factors that can mitigate these risks include the further integration and development of electricity markets and the level of interconnection of the electricity grids.

By contrast, in "Clima Decentral and New Gas" Belgium's (net) dependence on foreign supplies is comparable to the current situation. However, its (net) dependence in this setting only concerns natural gas which is imported from non-EU countries. Belgium's power supply then becomes more vulnerable to gas price shocks while risks related to gas supply disruption are moderated by highly diversified gas supply sources and routes.

3.3. Employment

As regards employment, this analysis only highlights some elements of the subject. Due to missing data and inaccurate estimates on the employment impact of new to be developed services like battery operations and enhanced grid coordination in a decentralised setting, certain analyses could not be performed and the impact of certain scenarios therefore is incomplete. This has to be borne in mind when adding these results to the results already obtained in part 3.1 and 3.2.

The variation in job creation (expressed in full-time equivalents or FTE's) between the Decentral and the Gas scenarios is calculated using a multiplier approach as described in Devogelaer (2013). There is however a small difference in methodology between the FPB job impact study (Devogelaer, 2013) and this study: in the former, the job intensities are expressed in GWh of electricity produced whilst the latter uses intensities relative to the capacity installed (in MW). This choice was inspired by two reasons:

- The employment multipliers in Wei et al. (2010) are based on US capacity factors which are traditionally higher than the ones observed in Belgium;
- If a certain plant diminishes its running hours (hence, its GWh produced), it does not immediately mean that all of its personnel gets sacked. An example can be found in the generation power plants that are part of the Belgian strategic reserve (hence only dispatchable between November 1 and March 31): they still keep their regular work force during the entire year (but allocate it in a different way).

The results of the calculation are depicted in Table 9.

Table 9 Annual job-years created in the Decentral scenarios wrt the Gas scenarios[34], total FTE's, year 2027

Decentral vs Gas	Direct	Indirect	Total
Solar PV	2117	1905	4022
Onshore wind	681	613	1294
Offshore wind	3271	2943	6214
Natural gas	-229	-206	-436

Source: FPB calculations based on Wei et al (2010).

Knowing that the value chain for renewables is longer than the value creation chain for centralised technologies (Kammen et al, 2004[35], Devogelaer, 2013), it comes as no surprise that choosing for a decentralised future (the Decentral scenarios) moulds more jobs than is the case in a scenario in which the structural block is being filled by gas-fired power plants (the Gas scenarios). According to our calculations, 11 000 additional jobs[36] may be created in the Decentral scenarios compared to the Gas scenarios. Moreover, we can expect these figures to be an underestimation of the real job creation potential since some of the filières

34 This holds for both the Base and the Climate scenarios since the installed capacities are identical in the Decentral cases and in the Gas cases (see part 2.2).

35 The renewable energy sector generates more jobs per megawatt of power installed, per unit of energy produced and per dollar of investment than the fossil fuel-based energy sector (Kammen et al., 2004).

36 In the second quarter of 2014, the employment in NACE 35110 (production of electricity) amounted to 6904 employees according to the National Accounts (NBB). If we take on more branches (NACE 35110, 35120, 35130, 35140) also covering the transmission, distribution and trade of electricity, the employment totals 16 080.

- either lack the necessary data to sketch the full employment picture (grid development, battery operation, …)
- or do have a known employment multiplier but are prone to even more uncertainties. This is the case for car manufacturing (SUT 29A): if we were to assume that the 500 000 electric vehicles that would be driven by Belgian customers would all be produced in Belgium, 36 000 jobs (both direct and indirect) could be generated[37]. Since we are absolutely not sure if Elon Musks European expansion plans would include Belgium as a potential production site (or any other major car manufacturer for that matter) and also because domestic jobs would be lost in the manufacturing of non-electric cars, 36 000 jobs seems a particularly high number. But even if a (small) portion of these cars are to be assembled in Belgium, this adds to the 11 000 calculated in Table 9. As an illustration, the Belgian technology federation Agoria recently announced many job openings linked to local EV manufacturing[38].

Also interesting is to put the "Clima Decentral and New Gas" scenario next to the "Decentral" scenario. We then observe an additional increase in employment of around 900 FTE's (on top of the ones already created in "Decentral").

In the box below, an additional light is thrown on the matter by presenting an in-depth analysis of the domestic job creation triggered by an investment in a new natural gas-fired power plant in Belgium. This additional analysis is performed with the input-output methodology developed within the Federal Planning Bureau.

37 This calculation is based on the employment multipliers of the final demand in Belgium for 2010 from the FPB (http://www.plan.be/databases/database_det.php?lang=en&ID=57&tab=1). They have been calculated with data from the 2010 current price input-output tables (published in December 2015). A trade margin of 8% is taken into account.

38 http://www.agoria.be/nl/Voertuigindustrie-zoekt-600-nieuwe-medewerkers-in-ons-land

Box 2 Employment creation provoked by gas-fired power plant investment in Belgium

Within the framework of the National Accounts Institute, the Federal Planning Bureau is responsible for drawing up the five-yearly input-output tables for Belgium. These tables constitute the core of the national accounts along with the supply and use tables from which they are derived and the institutional sector accounts. Input-output tables provide detailed and consistent information on production activities and transactions in products of the Belgian economy: structure of production costs, flows of goods and services produced in Belgium and flows of goods and services with the rest of the world. As such, these tables are a valuable statistical and analytical tool. One of the analytical applications of this input-output methodology is the calculation of the domestic employment creation due to an investment shock in Belgium.

In this part, the introduction of such a shock is simulated by an investment in a new gas-fired power plant type CCGT in Belgium. Data from the 2010 current price input-output tables which were published in December 2015 are used. These tables have been constructed following the ESA 2010 and the Nace Rev.2/CPA 2008 industry and product classifications.

First, the activity chain triggered by the investment or, more specifically, the composition of products and services needed to build and operate a CCGT has to be established. Sectors like the construction of utility projects (Nace 42), manufacture of engines and turbines (Nace 28), manufacture of steam generators (25) and many others are involved. Information from the sector allowed us to draw up this product map. But the story does not end there: not only the above mentioned sectors will be influenced by the investment shock, also their suppliers and subcontractors will be since the former needs products and services from other (non-related) sectors. An example: when investing in a new centralised unit in Belgium, components have to be moved towards the building lot. Therefore, the sector of freight transport by road (Nace 49) will benefit. This chain is exactly what can be traced through input-output analysis.

Next, knowledge of the share of the investment that is flowing out of the Belgian economy and, hence, is dedicated to foreign contractors is indispensable. In other words, the share of the total investment that will go directly to foreign companies has to be unravelled and, by doing so, the share that is destined for the national (Belgian) enterprises can be deducted. For each of the sectors (or products), the average share of import has been calculated. Adding this up for the total investment results in an overall import share of 45%. This means that of the total investment amount of 400 M€, 180 M€ will directly leak out of the Belgian economy to benefit foreign companies. This is called the 'investment leak'. 220 M€ will then flow to Belgian companies and will give rise to local employment.

The next step is to calculate the employment induced effect of an investment shock of 220 M€ in the Belgian economy. The total employment triggered by this shock collects employment generated both directly (initial effect in the concerned sectors) and indirectly (through the chain of suppliers of these sectors and their subcontractors). According to our calculations, we see that investing in a new CCGT in Belgium opens up a total of almost 1900 direct and indirect jobs. This also means that investing in 7 new gas-fired power plants (as was simulated in the «Clima Decentral and New Gas» scenario) would lead to a job creation of around 13 000 Belgian jobs.

Recall however that these jobs are created during the construction of the unit, say during a period of 2.5 to 3 years. This explains the difference between this result and the calculations performed above as regards natural gas-fired units. The numbers in Table 9 hence differ because

– they are averaged out over the operational lifetime of the unit (30 to 40 years)

– they include employment related to running the power plant (28 to 30 persons).

4. Conclusions

This study was requested by DG Energy following their public consultation round organised at the occasion of the apparition of the adequacy and flexibility needs study performed by the national TSO Elia. It responds to some of the concerns that different stakeholders have formulated by presenting a cost-benefit analysis of a selection of policy scenarios established in the Elia reports.

In this analysis, the FPB investigates different (diversifying) capacity portfolio and import scenarios for Belgium. Four scenarios are scrutinized differing in their overall context (level of carbon price) and/or in the choice of the content of their structural block. A fifth scenario is added which constitutes in fact a sensitivity analysis: in this scenario, a considerable amount of new natural gas-fired power plants on top of the structural block is built on the Belgian territory in order to diminish the level of (net) imports and even explore the net export option. The five scenarios are then compared in order to assess potential long-term strategic choices from a societal perspective.

Some of the main conclusions of this study are that

- Higher carbon prices favour the domestic production of CCGT and induce significantly higher production surpluses;
- Choosing for a decentralised future engenders multiple benefits in terms of employment, CO_2 emissions, production surplus and energy trade deficit; the consumer surplus, on the other hand, is markedly lower and required investments are significantly higher;
- Even in a decentralised future, natural gas-fired power plants are, according to the current legal framework, indispensable to secure our future supply of electricity.
- Even in a scenario in which the electricity trade balance is (almost) neutral, Belgium structurally depends on imports from other countries.

When it comes to decentralisation, some remarkable findings are that, although decentral production tends to raise prices thereby decreasing consumer surplus, it augments producers' revenues (hence, production surplus). The latter effect outperforms the former. Above that, CO_2 emissions (hence, CO_2 auction payments) are lower, employment is way higher and the energy trade deficit shrinks considerably: less imports of natural gas are needed in a decentralised future. Capital expenditures, however, more than double compared to a uniquely gas-based structural block.

The fifth scenario teaches us that not only investing in decentralisation, but also in additional gas-fired power plants may initiate a number of advantages: compared to (simple) decentral production, the consumer surplus climbs notably (majorly because of lower consumer prices), the energy trade deficit drops further (because of the elimination of net power imports on a yearly basis) and additional jobs are created (because of the construction of new centralised generation units). But there is a trade-off: national CO_2 emissions skyrocket, the (additional) investments are considerable and Demand Response becomes completely redundant.

Of course, the realisation of the benefits and costs hinges on external circumstances: if they change, the overall picture changes and these results no longer hold. It is therefore of utmost importance to carefully observe and, where possible, try to influence the external context. This can be done on two levels: European and Member State level. As regards the European level, European climate policy should be steered towards a context which closely resembles the Gas before Coal scenario with more ambitious carbon prices. Concerning the Member State level, sovereign national decisions that potentially could have a huge impact on other Member States should be duly announced and, by preference, replaced by more intensified regional collaboration and cooperation as is specified in the Winter Package.

The tables below synthesize some of the key results that came out of this study.

Table 10 Summary of key results, part 1, year 2027

	Base Gas	Base Decentral	Clima Gas	Clima Decentral	Clima Decentral and New Gas
Net production (TWh)	64	66	72	73	96
Marginal Costs (€/MWh)	71.1	73.4	97.3	99.7	95.0
Net electricity imports (TWh)	30	29	21	22	-2
Energy trade deficit (M€'14)	3000	2700	3000	2800	1700
CO_2 emissions (Mt CO_2)	5.6	3.9	8.6	6.2	14.0
ETS auction payments (M€)	95	66	494	357	806
Investments (B€)	11-12	26-32	11	26	28
Annuities 4% (B€)	1.4-1.5	3.2-3.9	1.4	3.2	3.3
Annuities 10% (B€)	1.8-2.0	4.2-5.2	1.8	4.2	4.4

Source: Crystal Super Grid, FPB calculations.

Note: Annuities represent the annual cost of capital (interests included) for the investments as calculated in the different scenarios. The investments are being annualized over a period of 10 years (time horizon of the study) with a WACC (weighted average cost of capital) of 4% in the first case, 10% in the second case. Payments and WACC are assumed to be constant over the time horizon.

Table 11 Summary of key results, part 2, year 2027
M€

	Base Decentral vs Gas	Clima Decentral vs Gas	Clima Decentral and New Gas vs Clima Decentral
Consumer surplus	-280	-290	+519
Producer surplus	+509	+670	+115
Congestion revenues	+170	+150	-130
Energy trade deficit	-346	-235	-1136
Additional job increase (FTE)	+11000	+11000	+900

Source: Crystal Super Grid, FPB calculations.

Note: Additional jobs should be interpreted with care since these figures are prone to many uncertainties. On the one hand, they do contain jobs like the construction of solar panels which are not (anymore) performed in Belgium, on the other hand, they do not include the entire value chain of either grid development or battery manufacturing and operation.

5. Annex

5.1. Differences with respect to the modelling software

As already stated in part 1.1, the models used by the FPB (for the 'cost' part of its welfare analysis) and Elia (for its adequacy study[39]) do show major similarities but are also different, basically because of the level of data ANTARES[40] is able to integrate. That is why it was not possible to simply copy the Elia scenarios into *Crystal Super Grid*: they had to be reconstructed. Due to resource and time constraints, it was not possible to mimic in full detail the exact assumptions as were taken by Elia in (Elia, 2016a) and (Elia, 2016b), but we tried to stay as close as possible to the original scenarios and hypotheses.

One of the things that differ between the two exercises is the modelling of the international context (all modelled countries besides Belgium). In *Crystal Super Grid*, assumptions from the TYNDP 2016, scenario V1 ("slowest progress") were adopted (ENTSO-E, 2015). This was done because, after careful consideration, V1 was considered to be the closest to the scenario Elia described in its Base case (Elia, 2016a).

Another difference lies within the production cost assumptions used in both models. Because of these disparities, the height of the CO_2 price in the two models to simulate the Gas before Coal scenario should also be different. In the modelling done by the FPB, the CO_2 price therefore amounts to 70 €/tCO_2 in order to trigger the coal to gas switch in power generation.

5.2. Hypotheses on investment costs

When it comes to investment costs, one should be aware that significant uncertainties are inherent to long term forecasts since numerous factors influence the evolution of the costs, e.g. learning rates, energy policy support decisions, global and national economic growth, … A decent reference for future investment estimations was found in the ETRI 2014 report (JRC, 2014). In fact, for every technology, three evaluations for capex estimations are published: a *reference* value, which is bound by a *low*er and a *high*er value, constituting an interval of potential future investment costs.

In our analysis, the reference and low estimate are used. The reference value is seen as quite a trustworthy estimation of future capex whereas the low estimate can be interpreted as less confident because the uncertainties surrounding this estimate are rather large and the sources to back it are less abundant.

The two tables below sketch the investment cost hypotheses of the different technologies used to fill the structural block. Table 12 describes the assumptions as to the reference estimate from ETRI 2014 (JRC, 2014), Table 13 sketches its low estimate counterpart.

39 As well as for the determination of the need for a volume of strategic reserves.

40 ANTARES being developed by RTE (the French national TSO) disposes of a vast amount of detailed input data (e.g. on congestions in certain zones in France) which allows a more fine grained level of modelling.

Table 12 Capex assumptions for some key technologies, Reference, year 2030

	Investment cost (€/kW)
CCGT	850
OCGT	550
Solar	990
Onshore wind	1300
Offshore wind	2580
Stationary batteries (per kWh)	390
Electric vehicle (per car)	25000

Source: Elia (2016a), JRC (2014), MIT (2009).
Note: Solar relates to residential solar PV<100 kW.
The assumptions on EV are based on expert judgment and do not have the same source as the other technology estimations.

Table 13 Capex assumptions for some key technologies, Low, year 2030

	Investment cost (€/kW)
CCGT	700
OCGT	400
Solar	850
Onshore wind	1000
Offshore wind	2280
Stationary batteries (per kWh)	205
Electric vehicle (per car)	22000

Source: JRC (2014).
Note: Solar relates to residential solar PV<100 kW.
The assumptions on EV are based on expert judgment and do not have the same source as the other technology estimations.

6. References

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