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Long-term effects on investments in electricity markets of renewable energy tender policies under harmonization

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Long-term effects on investments in electricity markets of renewable energy tender policies under harmonization

An agent-based approach

by

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Abstract

The current decentralized support schemes for stimulating renewable energy from electricity (RES-E) in the Member States (MS) of the European Union (EU) cause cost inefficiencies, distort the market and competition and exhibit unclear welfare effects. RES-E policy harmonization, a top-down approach that equalize, support schemes among MS, can improve cost efficiency, decrease market fragmentation and increase overall welfare.

The master thesis explores the long term dynamic effects of policy harmonization on consumer and producer welfare, cost and the electricity market performance. This is tested under the scenarios of infinite interconnector capacity, a tender with technology-specificity, different ambitions of RES-E targets and countries with the exact same RES-E targets.

With the aid of the model EMLab Generation, simulations of the electricity markets in two countries have been carried out from an Agent-Based Modelling (ABM) approach. ABM can deals with market uncertainty and is therefore a novel approach in the field of testing RES-E policy harmonization. Within this modelling environment a tender is conceptualized, which follows the EU Aid state guidelines that recommends to use a competitive bidding process to distribute subsidies for RES-E.

The primary objective is to answer the main research question: *What are effects of RES-E tender support policies on the electricity markets of an interconnected two-country situation in the long run under harmonization?*

Effects of harmonized RES-E tenders Is was found that RES-E tenders stimulates investments in renewable energy technologies that leads to lower electricity prices, creates higher welfare for consumers, but decreases welfare for producers. The lower prices are accompanied with higher volatility.

Furthermore, a rapid development of RES-E creates high yearly generation costs, and high tender clearing prices result in high subsidy costs. Next to the objective of de-carbonisation, it is important for the regulator to deal with technologies that do not participate in the tender, to make sure no high clearing prices occur due to yearly increasing targets.

Effects of high interconnector capacity The increase of interconnector capacity under high penetration of RES-E lowers the overall cost of outages. A country with relative high RES-E energy targets increases the subsidy costs for renewables in the neighbouring country under perfect market integration, and subsequently leads to increased cost burden for society in the importing country. The importing country can offset this by implementing low RES-E targets. However, the consequence is that high differences in RES-E targets between countries, leaves the less ambitious country to serve basically as a ’back-up-country’ for its neighbour.

The research showed that a technology-specific tender leads to lower RES-E target fulfilment when one or more RES-E technologies do not participate in the tender. A technology-neutral tender is thus more effective in stimulating RES-E since the regulator is indifferent of which technologies are participating, as long as these are the lowest cost technologies.

A country can be too ambitious in setting its RES-E target, meaning that if a RES-E target is not met, it results in higher clearing prices and subsequently imposes a burden on society due to high tender subsidies. It also shows that the regulator can control the generation costs to a certain extent by setting the RES-E targets since RES-E is accompanied with high generation costs.

Regarding the regulator, it is concluded that setting the right RES-E target is is of paramount importance but prone to uncertainty due to expectations in renewable generation in the market.

Overshooting expected generation leads to high higher tender quotas than necessary, which leads to over fulfilment of the pre-determined tender targets. Subsequently, it causes higher tender clearing prices which increases the yearly subsidy costs more than needed, which is passed on to society. Moreover, overshooting also affects producer welfare and cash balances negatively, costs in generation and outages rises and electricity prices increase accompanied with more volatility.

While undershooting the expected generation, results in lower RES-E target fulfilments and thus more carbon intensive technologies in the market than demanded. This can be overcome to let the regulator predicts for a shorter interval such that he does not look further into the future than the lead time of a technology. It is concluded that setting the targets wrong will affect the success of the tender or that it imposes a larger cost burden on society than necessary.

objective The secondary objective aimed to find what policy conditions and configurations are most beneficial from an EU and Member State perspective based on the results. It was found that soft policy harmonization and improving market integration i.e. increasing interconnector capacity are the best scenarios for the EU policy maker, while full harmonization is the best scenario configuration on the level of both Member States. This implies that a conflict can arise between the interest of the EU and the Member States.

Moreover, one also needs to take into account that the importance attributed to a certain welfare or cost indicator, can be different among the two national policy makers. Full harmonization would be less feasible if countries do not agree on design variables of tenders, or the priority of certain indicators. Both could lead to different policy configurations, which is in most cases will be moving away from full harmonization. This concludes that full harmonization of RES-E policies is unlikely to succeed.

Key words Electricity Markets, RES-E policy harmonization, Tenders, Agent-Based Modelling,

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Thesis definition

The thesis definition looks into current literature to describe the context, and distillate the problem that serves as basis for this research. Subsequently, the objective of this work, along with the research questions, are presented. The section after that explains the methodology to be used for investigating the proposed research questions. It concludes with a brief presentation of the structure of this work.

1.1. Introduction

One major objective of the European Union (EU) is to achieve a reliable and environmentally sustainable supply of energy. Therefore, it aims at a greenhouse gas emission (GHG) reduction of 20 % in 2020 [7] and 80 % in 2050 [8]. To achieve this, the level of investments in electricity from renewable energy sources (RES-E) should increase from the current volume of 20-53 billion euros to a range of 60-70 billion euros [9]. For Member States (MS), the EU has set national goals for RES-E levels that should be achieved by the year 2020. This should help to achieve the goals of the 80 % GHG reduction in 2050. Figure 1 shows RES-E shares from 2005 – 2012 for the 28 EU countries, and whether they are on track (red bars) to achieve their RES-E targets. These goals are defined in National Renewable Energy Action Plans (NREAP) [2].

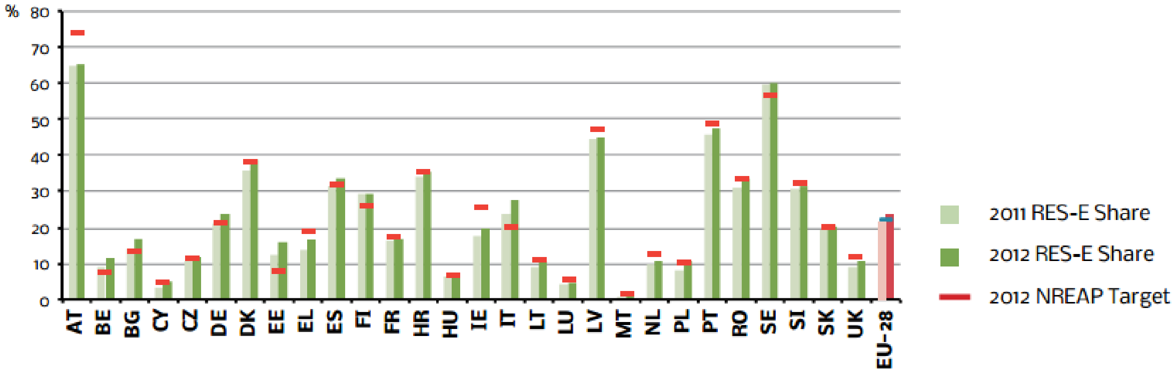


Figure 1.1: RES-E actual and planned shares in the EU-28 from 2005-2012 [2]

Under the previous Energy and Environmental Sate aid Guidelines [10], MS of the EU had the freedom to establish different RES-E support policy mechanisms to encourage investments in RES-E. Support policies for renewable energy in the electricity market are needed due to two reasons. Firstly, the environmental benefit of substantially reduced greenhouse gas emission of RES-E are not reflected in the price of electricity. Thus, the true value of renewable energy is not given and support policies can adjust this by internalizing the value of RES-E. Secondly, policies are needed because most RES-E technologies are not mature yet, which means that in several cases, a full learning process has not been established and economies of scale of RES-E are relatively small. This implies that RES-E have a disadvantage when competing with the well-established fossil fuels. Therefore, incentives are needed to stimulate the integration of RES-E in electricity markets. This can be done publicly by certain support policies [11].

Another ambitious objective of EU energy policy is to create a well-functioning European internal market for electricity, which is derived from Article 2 of The Treaty establishing the European Economic Community (EEC) of 1957 [12]. It states that integration is an important goal of the EU and a well-integrated internal energy market is necessary to achieve the following three goals cost-effectively: affordability and competitively priced energy, environmentally sustainable energy, and secure energy for everybody [13]. At one hand, increasing the interconnector infrastructure to allow for cross-border transmission and balancing energy flows between countries will improve the internal market, which is currently limited and thus indicating imperfect integrated markets. At the other hand, policy coordination and regional cooperation, between the MS, is beneficial towards a single market. However, the establishment of RES-E support policy mechanisms is currently fragmented and thus in conflict with this goal. A recent comprehensive study by the Beyond2020 group suggests that a harmonized RESE-E policy approach is beneficial. This is mainly due to reduced cost inefficiencies and increased market integration [14]. Harmonization in this work is defined as:

”The top-down implementation of common, binding provisions concerning the support of RES-E throughout the European Union” [15].

This definition rules out the cooperation between MS on renewable energy policy that arise from the MS itself like the joint Green Tradable Certificate market in Norway and Sweden [16]. Harmonization is thus not a bottom-up approach. However, the definition leaves room for the degree of harmonization, meaning that harmonization does not necessarily include the choice of support instrument and neither how certain design variables should be implemented. There is thus a continuum of different degrees of harmonization from minimum to full. For this work the classification of different degrees are taken from [17], visible in table 1.1. It is assumed that due to the comprehensive and well known work of the Beyond2020 group, this classification is most clear to researchers and policy makers related to the EU.

Table 1.1: Classification of the degrees in harmonization

Degree of harmonization	**National targets**	**Support scheme**	**Decision on design**
Full	No	EU-wide	EU
Medium	No	EU-wide	EU
Soft	Yes	Same instrument used in MS	MS
Minimum	Yes	MS decision	MS

Full harmonization includes thus EU-wide targets, an EU wide support scheme, harmonization of framework conditions and design elements. Medium is equal to full harmonization with the exception that MS may provide additional support for specific technologies. In the soft case, an EU-wide target exists, like in full and medium, but the targets are on the level of MS in such a way that they are consistent with the EU-wide target. In the case of minimum harmonization, an EU target and a MS target exists, similar to that of the soft case. On top of that the MS can choose its own type of support scheme and decide about the design. Currently, the minimum degree is the status quo of RES-E policy harmonization in the EU [15].

A relevant recent event that will be taken into account for this study, is the adoption of the new (non-binding) Energy and Environmental State aid Guidelines (EEAG) covering the years 2014-2020. It advocates the use of market instruments such as auctioning or competitive bidding processes as RES-E support policy [18].

1.2. Problem definition

After having expressed the current situation and context of RES-E policies in EU electricity markets, this section presents the problem that is related to these polices. A brief overview of the main RES-E policies are given in appendix A. The section ends with a demonstration of proposed solutions to tackle the problem.

1.2.1. Problems with decentralized RES-E policies

From literature three main issues are observed with national support schemes for RES-E:

1. Cost inefficiencies
2. Unclear welfare effects between countries
3. Distortion of market and competition

The following paragraphs discuss these problems in more detail.

Cost effects The main argument leading to cost inefficiencies is the non-optimal resource allocation of RES-E due to uncoordinated national support schemes. Based on natural potentials of the region, one would expect that the most suitable and cheapest technology would be deployed [19]. Figure 1.3 makes this clear by looking especially at solar PV and wind deployment and their difference in costs in Spain and Germany [3]

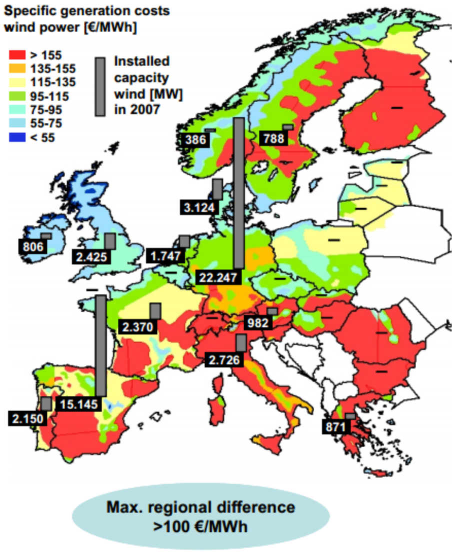


Figure 1.2: Wind deployment [3]

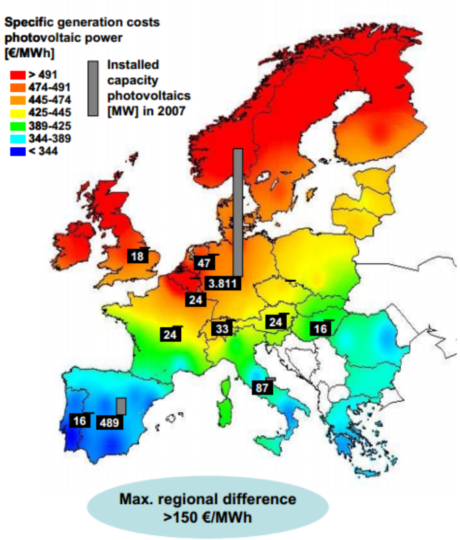


Figure 1.3: Solar PV deployment [3]

Cost inefficiencies are also caused by regulators setting the support level for electricity, which might lead to support overshooting because a fixed support level does not take technology cost reductions over time into account, meaning that more support is given than necessary [18].

Welfare effects International trade increases social welfare when countries remove trade barriers. A trade policy motive arises when policy makers can choose RES-E support schemes that maximizes domestic welfare. Importing countries will choose policies that reduce electricity prices while exporting countries choose policies that increase electricity prices. An electricity importing country is able to increase surplus e.g. by introducing feed-in-tariffs that reduce the import price of electricity. For an exporting country a production tax can be imposed on polluting electricity generators, which increases the export price of electricity and thus domestic surplus. Harmonizing policy support instruments removes the possibility for national policy makers to choose RES-E policies that benefits them more than it benefits the overall level. With the overall level is meant: the combined welfare effects of two or more Member States [20].

In another study it is shown that, for an exporting country, trade redistributes wealth from consumers to producers. Whereas for an importing country, trade always redistributes producers surplus to consumer surplus. Trade barriers like limited interconnection capacity affect the extend of redistribution effects [21],[20].

Unteutsch (2014) states that system-wide social welfare always increases when cooperation for RES-E support is introduced if the countries are perfectly interconnected. However, it is harder to determine welfare effects from trade if countries are not perfectly interconnected. Moreover, the welfare effects also depend on the level of the RES-E target since it will affect the generation costs and consumer expenditures [22].

From the above discussion it is pointed out that welfare effects between to Member States, driven by electricity trading, depends on whether the countries have harmonized RES-E policies or not, on the available interconnector capacity, and on the level of RES-E targets. It is unclear how these three parameters interact and what the resulting welfare effects are.

Distortion of the market RES-E subsidies received by investors, which are not determined in a competitive setting, lacks the effect of a price signal i.e. prices that stimulate investor to invest in new capacity to make a profit. This distorts the competition between electricity producers in the electricity market, since the economic incentive to adapt specific project features to supply and demand is partially not present. The lack of adequate price signals affect security of supply if investor do not built new power plants to meet electricity demand [18].

Merit-order effect On a related note, the increase of RES-E in the market has a downward effect on electricity prices and creates volatile prices, which is referred to as merit-order effect [23]. Since intermittent RES-E has low to zero marginal costs, average price decrease. However, the production of intermittent sources can change on an hourly basis, which result in a temporarily shortage and creates peak prices. This leads to short-term fluctuations in the price. Both effects deter new investments, or make current power plants unprofitable, which could lead to more shortages.

1.2.2. Problem statement

According to the previous descriptions, the issue at hand is that:

National RES-E polices induce cost inefficiencies, have unclear welfare effects and distort markets among Member States in the EU.

Harmonization of RES-E policies is a mean that is able to deal with the aforementioned problem by aligning the decentralized support schemes among the EU and can contribute to the achievement of the internal electricity market of the EU. There has been a tremendous focus on the cost inefficiencies of decentralized policies. It was shown by [17] using static theoretical analysis with equilibrium models that the costs for RES-E were reduced by harmonization. [24] used the Green-X model to simulate the electricity market and the support policies. They generated market equilibriums by deriving endogenously changing supply and demand curves and concluded significant cost reductions. [25] found a cost reduction as well for harmonized policies by using the REBUS model, which is an Excel spreadsheet calculation tool which computes the effects of an international burden sharing tool. In addition a consultation by [26] pointed out that system costs i.e. generation costs and subsidy costs will reduce under harmonized policies compared to non-harmonized policies. Harmonization creates a level-playing field, meaning that investors face similar market conditions. This leads to innovation and more investments due to increased competition between companies. Increased competition results in lower prices and improvement quality in products and services [19]. In this case it should lead to lower electricity prices, increased security of supply and sustainable energy (improved quality).

Although significant cost reductions and more competitions could take place, there are doubts whether harmonization is be positive. If differences in technologies and regions are not taken into account it can affect the effectiveness and efficiency. This is referred as the absence of context specificity [19].

Another argument against harmonization is that it can lead to the absence of policy competition, which is corroborated during the consultation of [26]; the removal of national control over RES-E support schemes was a main concern because of more investor uncertainty and the associated increasing costs for achieving European RES-E targets. Also neglecting national costs and benefits, i.e. welfare, could defer public acceptance and lead to opposition to policy harmonization [26].

1.3. Objective and Research questions

The aim of this work is to asses the effects for interconnected Member States, that follow a harmonized RES-E tender policy approach, under different conditions and policy design configurations:

1. The primary objective is to investigate the effects on welfare, costs and electricity market performance for the MS involved
2. The secondary objective aims to find which policy conditions and configurations are most beneficial from an EU and Member State perspective

The scope is limited to a two-country analysis, loosely based on the characteristics of The Netherlands and Germany, mainly under soft harmonization. The soft degree implies that the two countries have the same RES-E support policy, but the freedom to choose how to implement the design variables of the policy and to determine their RES-E targets ambitions. Also one scenario will look into full harmonization.

Furthermore, given the recent Energy and Environmental State Aid guidelines, a competitive bidding process is used as RES-E support policy, which allocates fixed income subsidies to investors to stimulate renewable investments. This RES-E policy is a tendering mechanism. The analysis is done by modelling and simulating electricity markets using agent-based modelling within EMLab-Generation, which is a model developed by the faculty Technology, Policy and Management of the Technical University Delft. Together with the problem statement, this culminates into the main research question and its sub questions:

What are effects of RES-E tender support policies on the electricity markets of an interconnected two-country situation in the long run under harmonization?

This leads into the following sub research questions;

1. What are the effects of a renewable energy tender?
2. What are the effects of soft harmonized tender policies in perfectly integrated electricity markets?
3. What are the effects of tender policies with dramatic differences in RES-E target fulfilment ambitions in perfectly integrated electricity markets
4. What are the effects of a technological-specific tender design under soft harmonized conditions?
5. What are the effects of tenders with the same design and targets between two countries i.e. full harmonization?

The first sub question looks into the working of a tender on the electricity market as a competitive bidding process suggested by the most recent Energy and Environmental State aid guide lines [18]. It is thus expected that a tender creates subsidies and increases the share of RES-E over time.

The second and third sub question are addressing the discussion of [22],[21] and [20] to investigate the interactions between harmonized RES-E policies, the available interconnector capacity, and the level of RES-E targets. It is expected that high interconnector capacity converge prices between the two countries. The MS with a high level of RES-E is expected to 'export' the lower prices to the country with higher electricity prices [27]

The fourth investigations follows the suggestion of [19] to include context-specificities, which translates to technology-specificity for this work. A uniform price, resulting from technology-neutral tenders, lead to too much subsidy spent for technologies that have relative low costs and thus results in high profits for producers. The technology-specific tender is able to distinguish between the costs of different technologies and thus limits the producer profits and the cost of tender subsidies. This is illustrated in 6.2.

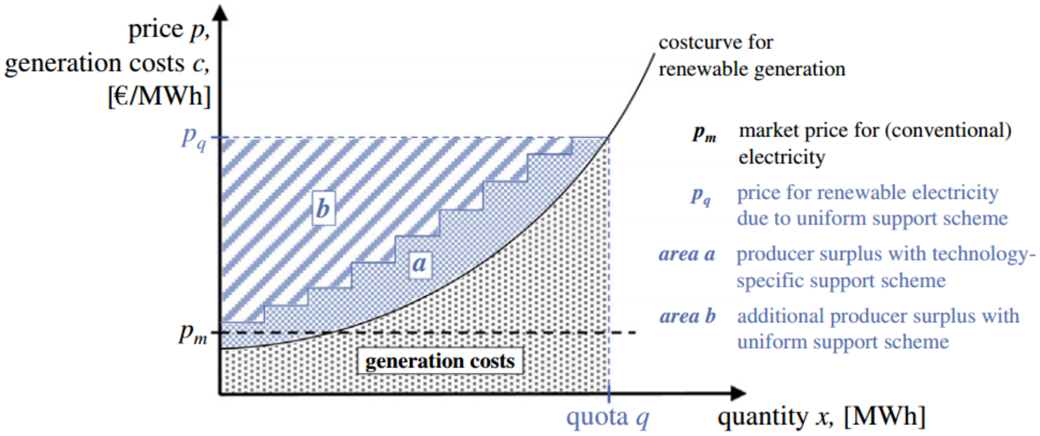


Figure 1.4: Technology-neutral or specific [4]

The final sub question looks into the most extreme version of harmonization: full. The aspiration of the EU to create one single market for electricity is addressed in this scenario [12]. However, due to model limitations, explained later, this scenario approximates full harmonization by equalizing the RES-E targets and implementing the exact same tender design in both countries. It mainly tests the statement of the consultation of [26], which pointed out that system costs i.e. generation costs and subsidy costs will reduce under harmonized policies compared to less harmonized policies.

1.4. Methodology

This section points out the research questions are going to be assessed. Simulations will be carried out using agent-based modelling within EMLab-Generation, a long-term electricity market investment model developed by the faculty Technology, Policy and Management of the Technical University Delft [28]. It is a novel approach compared to previous work on RES-E policy harmonization [17], [24], [25], [19], which used equilibrium or optimization models. The research framework and modelling choice will be justified in more details the next two subsections.

1.4.1. Research framework

The work looks at liberalized electricity markets whereby generation, transmission and distribution are unbundled and are viewed as socio-technical systems. At one hand there is the physical electricity infrastructures and power generating technologies, and in the other the social system that consist of many agents like producers, consumers, policy makers and regulators. It evolves over time due to numerous interactions in the sytems [29]. The three EU Energy Legislation Packages [30], [31], [32] aims establish a well-integrated internal energy market to achieve affordable, clean and secure energy [13]. Generation is privatized and agents can invest in power plants and sell their produced electricity. An overview of the electricity system of the Netherlands is shown in figure 1.5 as example. The focus is on the generation side: the generation companies bid into the spot market to sell electricity and invest in new power plants if there is a profitable investment opportunity.

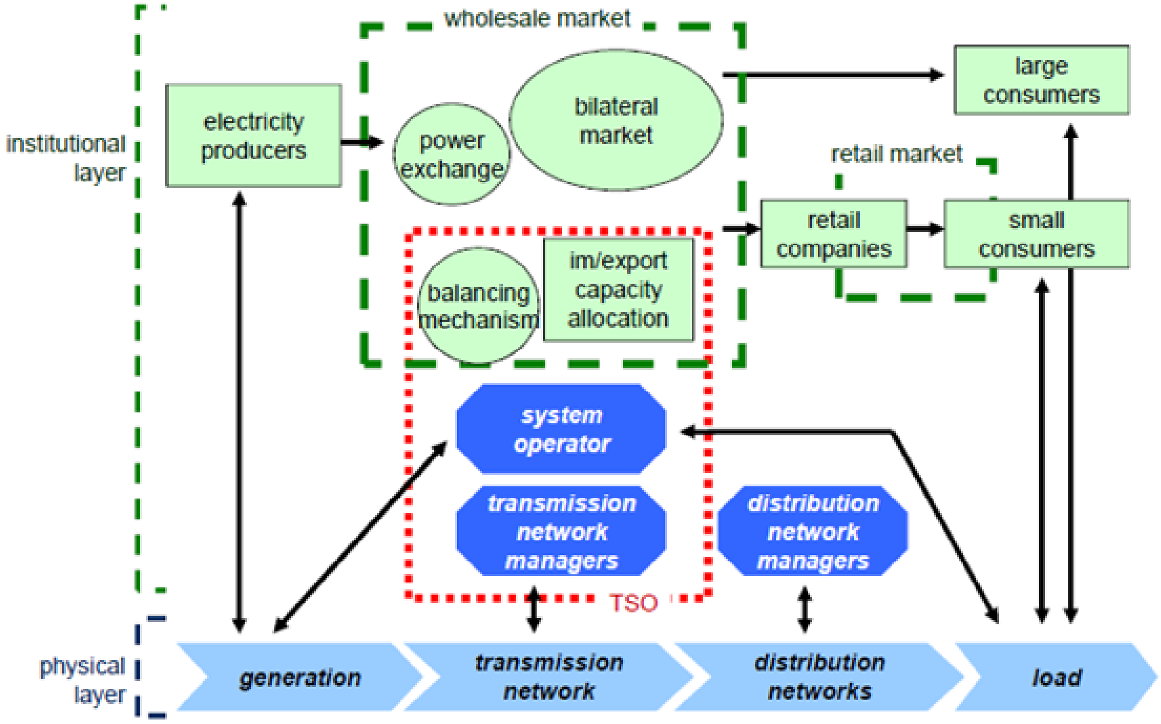


Figure 1.5: Overview liberalized electricity market system [5]

The theoretical framework is based on neoclassical economics. The assumptions of this paradigm are that agents have rational expectations, maximize utility or profits, and act independently on basis of perfect information [33]. However, an electricity market is categorized by imperfect information, uncertainty in expectations and continuous changing states [34]. For investment decisions energy producers have to predict future electricity prices, fuel costs and demand. Hence, they face the risk of price volatilities and thus uncertainty. Their perspective might not be perfect on the information they have of competition and future variables. Moreover, the electricity market is in transition due to renewable energy and climate policies. This creates high uncertainty in the expectations of the producers. It is thus assumed that investors will act rational based on the available but limited information. The consequence is that their behaviour might not be optimal, i.e. they do not maximize their profits in the market because they do not have perfect information. They are bounded by their rationality [35]. The assumption of perfect information is thus relaxed. In the power sector, investment decisions in generation capacity will have long-term effects since power plants take years to build and have a lifetime that often exceed twenty years. New investment decisions will thus depend on the status of the current installed power plant technologies i.e. the future system depends on the state of the previous system. This is referred to as path dependency and it is assumed that electricity market are characterized by this. The (unknown) future values of variables like prices and demand influences the path of how the system develops, and thus many system outcomes are possible. Assuming that many possible future scenarios of the power sector could arise, this needs to be taken into account as well when simulating electricity markets as will be expressed in the next subsection.

1.4.2. Modelling electricity markets, Renewable energy and RES-E policies

To represent the working principles of a system, a model can be used to simulate reality. Testing policies in the real electricity market is complex and costly and therefore a simulation is an alternative that can be used to observe the dynamic states of the system over time.

Modelling choice Computational General Equilibrium Models (CGE) models are based on neoclassical economics. Using CGE has as benefit that results are relative easy to validate and analyse. In an electricity market with continuously changing states, imperfect information, and uncertainty in expectations [34], the assumptions of CGE are likely too stringent to take the characteristics of an electricity market into account. This mathematical construct assumes further that an equilibrium exists and neglects the heterogeneity among the actors in a system [36].

However, an alternative modelling option is available and could be more suitable for electricity market simulations: System Dynamics (SD). This is a common tool to model dynamics and non-linearities. Non-linear means that a small change of the system can have a large impact on the, while a large change could have negligible effects. A drawback of SD is that the user needs to know in advance, or assume how the whole system behaves. This is difficult due to uncertainty in electricity markets and thus one does not know how the system will behave.

The option used in this work is Agent Based Modelling (ABM), which can deal well with complex systems because it can take uncertainty and path dependency into account. The advantage compared to SD is that the behaviour of the system does not need to be known in advance. However, there are three main drawbacks of ABM. Firstly, agent-based models are difficult and time consuming to develop. Secondly, it is difficult to validate and verify the model. Third, results are emerging from the interactions in the system. This creates a challenge for interpreting the results since patterns are observed, which needs to be related to initial conditions or other individual parameters throughout the simulation. The point is that small deviation and statistical noise can spur results. Nevertheless, ABM is the preferred choice of modelling since it is suitable to capture the complex interactions of investment behaviour in electricity markets, which is justified in more detail in the next paragraph.

Agent-based Modelling This bottom-up modelling technique entails the possibility to define autonomous agents with their own characteristics that can interact with each other, based on pre-defined rules [37]. The pre-defined rules forms a complete set of possible behaviour options the agent can perform. It is possible to let them predict future values and react to inputs and changes in an pre-established initial environment where they operate. Moreover, modellers can follow each agent by each step, which gives the opportunity to get insight in dynamic patterns, path ways and effects over time that emerge from the interactions with other agents and the environment [38]. Furthermore, ABM is suitable to study out-of-the-equilibrium economics and path dependencies [39]. These characteristics fit the description of a complex electricity market, briefly discussed in the previous paragraph, quite well. To verify whether electricity market can be viewed as a complex system and is suitable for an agent-based approach it should fulfil the following requirements mentioned by [29]:

1. The problem is of a distributed nature; each actor is autonomous to some extent.
    - Energy Producers are autonomous decision makers
2. The agents (subsystems) operate in a highly dynamic environment
    - Decisions are based on expectations of prices, demand, technological developments, policies and competition and are made under uncertainty and an evolving power power market.
3. The interaction in the subsystem is characterized by flexibility: it can result from a reactive or pro-active attitude, from a propensity to co-operate or to compete.
    - Competition among energy producers in the spot market.

The electricity market fits the requirements of [29] to be viewed as complex socio-technical system. ABM is chosen to investigate the research question since it can take uncertainty, path dependency and autonomous agents into account and is thus suitable to explore the dynamics in an evolving power market.

1.5. Thesis structure

This chapter presented the problems, objectives, research questions and methodology of this thesis. The next chapter conceptualizes the tender based on the theory. Chapter 3 will present EMLab in more detail and chapter 4 continues with the implementation of the formal model of the tender into EMLab. In chapter 5 the experiment design, which entails initial conditions and the model runs, is presented followed by the verification in chapter 6. In chapter 7 an analysis of the results is presented. In the final chapters the conclusion of the research and a reflection of the work is given.

2

Sealed-bid uniform-price tender

This chapter serves as theoretical blueprint for the tender that will be conceptualized for EMLab in chapter 5. The theory of a tender as renewable energy support scheme is presented along with its main design characteristics.

2.1. Tendering: a competitive bidding process

The current Energy and Environmental State Aide guidelines (EEAG) suggest that RES-E should be sold in the market and not bought by the government at fixed prices from 2016 onwards. However, the producers are still allowed to receive aid in the form of a premium on top of the electricity market price. The EEAG strongly recommends Member States (MS) to use a form of a competitive bidding process to stimulate renewable energy starting from 2017. The main justification for this is to limit distortions of competition, increase cost efficiency and with that, increase market integration. Feed-in-tariffs have made renewable energy less affected by market price signals. When renewable technologies mature and reach a substantial share of the market, they should react to market signals, and the subsidy amounts provided by governments should decrease accordingly to decreasing production costs of RES-E. Thus, the current new EEAG aims to integrate renewable energy technologies in the internal electricity market. Further view points of the EEAG are that competitive processes should be open to each MS to reduce market fragmentation and to allow MS to add their production in another Member State to their own RES-E target. Additionally, the support scheme duration should be set at 10 years. It defines a competitive bidding process as follows:

"A non-discriminatory bidding process that provides for the participation of a sufficient number of bidders and where the subsidy is granted on the basis of either the initial bid submitted by the bidder or a clearing price. The quota related to the bidding process is a binding constraint leading to a situation where not all bidders can receive aid" [18].

The competitive bidding process in this work is interpreted as a *tender*, which is also referred to as a reversed auction. The next section conveys the theory of these auctions.

2.2. Basic auction concepts and types

In a normal auction, the highest bidder wins and obtains a contract or object, whereas in a reversed auction the lowest bidder wins the object. Multiple winning bidders could occur as we will see later on. A tender is classified as a reversed auction and is quantity-based support mechanism. It consist of three main processes when the procurer (i.e. auctioneer) is auctioning a certain object [1]:

1. Bidding: bids are calculated by participants and submitted to the procurer.
2. Clearing: bids will be compared to each other and ordered to determine winner(s) and allocate contracts or objects when a predetermined target, set by the auctioneer, is reached.
3. Pricing: determines at which price and when the winners receive objects or contracts.

There a different methods to go through these main processes. Three common practices are described. The first one is the *First-price Sealed-bid*. The submitted bids are sealed such that other bidders cannot know the bids of other participants and thus do not have the information to change their bids accordingly. These auctions are often used for a single object or when a product needs to be allocated to a single entity. The auctioneer will select one winner based on the highest bid price. Another type is the *Pay-as-bid auction*: when multiple units of the same object or product needs to be allocated this mechanism can be used. There can be more winners. The auctioneer collect the bids by increasing price until the supply equals the quantity to be procured. All the bidders below the clearing price receive the object for the price they bid. Each winner receives thus a different financial offer. This auction is prone to strategic bidding since it pays off to try to bid below the competitors to make sure the bidder wins the auction. This can be perilous for the bidder himself though, because when a bidder bids under his cost price, he ends up with a loss. The *Uniform-price auction*, a third type, which is similar to the pay-as-bid auction, but the winning bidders receive all the same price, which is the tender clearing price. In this case it expected that investor bid their true price (i.e. cost) since the risk of losing does not depend on the next bid but only on the marginal bid. This reduces the effect of strategic bidding [1]. In table 2.1 a summary of the aforementioned auctions types is given including their (dis)advantages and most common applications.

Table 2.1: Key auction designs adapted from [1]

Auction Design	**Items**	**Advantages**	**Disadvantages**
First-price sealed-bid (single product)	Concession of power plants and transmission assets	Simplicity, easy to implement, handles weak competition	No price discovery
Pay-as-bid auction (multiple products)	Power purchase agreement, mid and long-term energy contracts	Simplicity, easy to implement, handles weak competition	No price discovery
Uniform price auction (multiple units of same product)	CO 2 emission allowances, Spot market, energy and capacity contracts	Simplicity, easy to implement, handles weak competition, viewed as fair, attracts small bidders	No price discovery, Possibly high political cost

2.3. Tenders as RES-E policy

A tender can be considered as a mix between a feed-in-tariff and a tradable green certificate system. The former because of its (fixed) guaranteed payments that will be received by the winners of the tender, which can reduce investor risk. The latter because of the competition between investors [40], [41]. The advantages of a tender as RES-E policy is that it provides a fixed reliable income to investors, while maintaining a competitive element. Moreover, the regulators knows at the beginning of the period the total quantity procures with an accompanied subsidy price thus the total costs of the support. Furthermore, cost trends over time are reflected in the bids and the true level of support needed is transparent. A tender can also be useful to promote a homogeneous distribution of technologies if it is made technology-specific [24]. Disadvantages are contributed to high transaction costs due to complex and bureaucratic procedures for the bidders. These transaction costs are passed through to the bid price and thus increases the cost of support. Secondly, if the participation rate is low, it removes the competition effect and real costs are less reflected [42].

2.3.1. Tender design

The set of design variables that can be used to design a tender are obtained from [42] and [17] and are the following:

- Auction type: different main types are shown in table 2.1
- Quota: amount procurement per period
- Support type: investment based or generation based, bids and target stated in capacity (MW) or production (MWh)
- Support period: the duration of the support
- Cap on policy costs: the total budget the government is willing to spent on the policy per year

and/or per bidder
- Size of project bids: the size of projects that can participate in the tender per bidder, which stimulates small scale projects to participate.
- Technology-specific support: instead of tendering the full continuum of technologies, the regulator can choose to tender only specific technologies or tender each technology separately to stimulate all technologies instead of only the low cost ones
- Size-specific support: distinguishing the size of installations to promote small scale installations (for decentralized generation)
- Location-specific support: different support levels are provided for plants deployed in places with greater costs. This avoids highly concentrated deployment of RES-E in a few locations.
- Penalties: a penalty for non-compliance

The following design choices are made:

Auction type The thesis will implement a sealed-bid uniform-price tender i.e. a discriminator tender. This fits since multiple units of the same product, energy contracts, needs to be allocated by a sole buyer, the government, and several bidders, the investors. The pay-as-bid is not chosen because the model being used is in not capable of dealing with market power or strategic bidding.

Quota The total quota, amount of energy procured, will be based on the NREAP targets [43],[44] relative to the total electricity demand. This is set by the government and announced one year in advance like the SDE+ of the Netherlands.

Support type A generation-based auction is implemented. This is because the RES-E targets will be set in terms of yearly demand(MWh). Investors receive a fixed income per year for a certain support period. This is a yearly aid calculated by multiplying the tender clearing price (Eur/MWh) by the bid amount (MWh) of the winning bidder, which is similar to a fixed feed-in-tariff.

Support period [42] and [45] review RES-E auctions and find durations ranging from 5 -7, 8 (NFFO1 in England) 10, 15, 20 (wind, biomass), 25 (solar), 30 (hydro). The authors suggests that there should be long-term contracts of 10-20 years depending on the technology, because long durations will result in lower bid prices. The EU State Aid guidelines subscribe a support duration of 10 years, so that will be used initially as main parameter.

Technology-specificity RES-E technologies have different marginal costs and therefore they need to receive different support levels, which is close but higher than the respective marginal costs. But if a support level is significantly higher than the marginal costs, this can induce large producer's surpluses and may lead to low cost-effectiveness [19]. Also [42] state that no technology-specific tenders can result in low effectiveness and high policy costs. Furthermore, no technology-specific support can discourage technological diversity, since, the cheaper, mature technologies are actually promoted only. On the other hand, too many technology-specific bands may lead to a lack of sufficient and qualified bidders, which reduces the effect of competition. However competition among investors in the tender will not be considered in the model. The main point is that investments in RES-E can work out differently when technology-specific bands are taken into account.

Size of project bids Investors can bid multiple plants. The size of the sum of the bid is equal to maximum possible installation capacity of power plants in the power grid node and to 50% of the cash amount the investor currently has. The capacity is translated to generation by multiplying each plant by its expected running hours.

Cap on policy costs A budget can function as cap on the costs of the tender subsidies. Currently, the Dutch government announced the SDE+ arrangement for 2016, where they are willing to spend 8 billion Euros on subsidies [46]. For Germany the latest figure on subsidies was 25 billion Euros from 2008-2012 [47]. These numbers are used to compare the expenses on tender subsidies per year, to estimate whether outcomes of the model is within this range. A formal cap is not modelled.

Other design variables The remaining main design variables, size-specific support, location-specific support and penalties are not taken into account due to the scope of this research.

2.4. Burden sharing

Burden sharing is outside the scope of the tender design, but a relevant question is who is paying the subsidies that are provided by the tender? A MS can use the public budget, which is paid by tax payers or a levy, linked to consumption and included in the final energy price, paid by consumers, to finance policies. The EU clearly prefers RES-E support finance via a levy. The situation in The Netherlands is currently the use of a levy, with a distribution of the financial burden that aims for 50% households and 50% businesses. Germany distributes its costs to electricity consumers via the EEG levy [48].

2.5. Conclusion

This chapter presented the tender design that is used as blueprint after presenting the EMLab model first in the next chapter.

3

The electricity market model

In this chapter the electricity market model, called EMLab-Generation, is described. It will discuss the main aspects of the model that are relevant in this work. A detailed report about the model can be found in the EMLab-generation report [28].

3.1. EMLab generation

EMLab Generation an investment model that is able to analyse long-term effects over multiple decades of energy policies on electricity markets using an Agent Based approach. Steps, or ticks, are per year and it can cover two geographical areas, which are often countries. There are also referred to as zones. The main agents are power companies who invest in generation capacity and sell their electricity in the spot market of their zone. Zones can be interconnected. The model uses a market coupling algorithm for the allocation of interconnector capacity. This mechanism is explained in more detail in 3.1 of this chapter. The overview of the model with its main decisions and interactions is given in figure 3.1 at the end of the chapter. CO2 trading is one of the model features of EMLab but is not considered in this work.

Agents In practice the rationality of agents in decision making is bounded by limited available information, the complexity of the problem, available time and the cognitive limitation of their minds. This is referred to as *bounded rationality* coined by [35]. In the model the power generating companies i.e. investors or energy producers are the main agents who are profit maximizing agents. However, they have limited forecasting power, and are thus bounded by their rationality, which is the main assumption of the model. This is an useful assumption since the effectiveness and efficiency of policies can be tested under non-optimal behaviour of the agents, which is closer to reality than optimization models. The number of the agents is determined at the beginning of a simulation together with the size and types of power plants in their portfolio. Agents make the following strategic and operational decisions: invest in new power plants when they are attractive to them, sell electricity in the spot market and buy fuel in the commodity markets. They do not exhibit strategic behaviour like capacity withholding or strategical bidding.

The energy consumer is another agent who represents solely the total demand of all consumers of a country. The demand is predetermined in the scenario and data files. However, the growth demand trend is based on random sample as explained later onwards in the subsection 6.3 of chapter 6.

Technologies The producers decide can invest in several power plants technologies, which is depicted in table 3.1.

Table 3.1: Technologies in EMLab

Technology
Coal Pulverised Super Critical (PSC), with optional biomass co-firing, and with and without CCS textbackslash
Integrated Gasification Combined Cycle (IGCC), with and without CCS
Gas Open Cycle Gas Turbine (OCGT), with and without CCS
Combined Cycle Gas Turbine (CCGT), with and without CCS
Lignite
Nuclear power
Wind onshore
Wind offshore
Photovoltaic Cells
Biomass
Biogas

Market clearing algorithm The agents sell their power similar as on a power exchange. A load duration curve consisting of 20 segments is used. Each segment has a demand level, and a clearing price and clearing volume will be determined by the supply of the generators. The supply function is created by putting the generator bids in the merit order. The bids are determined by the marginal costs, which reflects the fuel costs of the type of generation. Wind and solar do not have fuel input and therefore their marginal costs are zero. The algorithm clears the market for both zones. In figure 3.2 at the end of the chapter, the full market clearing algorithm is shown.

Market coupling If there are price differences price differences arise between two nodal zones, a trade incentive arise. For example, country A has a high price and country B a low price, then country A will start importing electricity from the neighbouring country with lower prices. This will reduce the price in country A, and increase the price in country B until the interconnector is fully used i.e. congested. Less production will take place in country A to meet demand since it is imported from country B. The reduction of the price and generation in country A implies that the producers earn less profits and that consumer expenditures lower. For country B, the price and the generation goes up and producers earn more than before while consumers will pay a higher price. If the interconnection is very large, it is expected not be congested and prices equalize between the two zones [49].

Investment algorithm As mentioned, the agents invest in new power plants by calculating the Net Present Value (NPV) of power plants. They base this on predictions of future prices and demand. They select the power plants that will likely have the highest returns to invest in. Figure 3.3 presents this algorithm at the end of the chapter.

Nodes Since EMLab has no limit for the amount of investments in renewable energy and intermittent production profiles of RES-E, there is need to implement this. So called nodes are added in a zone in the model to achieve capacity limits and the heterogeneity. Each zone can have multiple nodes. A node is characterized by a capacity limit and hourly data. Investors can built power plants up to a pre-determined node limit i.e. the maximum capacity of the node. The advantage of these nodes can be used to differentiate between regions in the zone itself in terms of production capacity and the realizable potential. It can thus reflects differences in RES-E output. The nodes represents thus different regions within an zone. It is important to note that no flow between these nodes occur within a zone. The usefulness of these nodes is that they represent the node load factor for intermittent sources. By supplying data in terms of availability of intermittent renewable technologies for each hour for a year, the model is able to translate this into load factors. However, EMLab is characterized by 20 segments instead of 8760, and this hourly production needs to be translated to the load duration curve and its 20 segments. This algorithm was created by the model creator and is described on page 22 of the work of [50].

In this thesis three nodes per zone are used. One main node per zone takes care of the load duration curve and the interconnection (like if it was one zone) with the other main node of the neighbouring zone. There is no market clearing in the other nodes. The node load factors that are calculated are averaged such that the model sees this is as one node load factor per segment for the main node. The nodes are thus merely used to create different investment opportunities for the energy producers.

One of the data inputs for the model are thus different full load hours per node, other data input are capacity node limits. The input for this was obtained from the database of the Green-X model. The mid-term potentials up to 2020 are given for various RES-E technologies like biogas, biomass, onshore wind, offshore wind, and photovoltaics [51]. Different series of full load hours have been derived for the three intermittent RES-E sources as explained in appendix B. After obtaining a series of full load hours per intermittent RES-E technology, these hours were scaled up or down according to the potential of the country there are applied to. The implication is that the hourly production data is correlated and thus that the renewables in different regions are available at the same time but for different levels of production. The node limits are based on the same static cost curves of [51], which are also derived in appendix B. The costs of RES-E over time are modelled via learning curves and are obtainable on github via `https://github.com/rjjdejeu/emlab-generation/blob/feature/TenderRob10/emlab-generation/src/main/resources/data/learningCurves.csv`

Renewable energy policies The EMLab Generation model has currently only a proxy for RES-E policy, called the target investor, which is an agent in EMLab that has absolute RES-E volume targets and invests in RES-E. He essentially fills up that what the other investors do not invest in RES-E. Implementing a tender policy result in benefits in comparison to the target investor. The benefit of the tender is that it deals with each investor individually, which make predictions for their tender bids and are thus prone to uncertainty i.e. the might not bid optimally since they do not know the future. The tender is also beneficial since it can be upgraded to test different tender designs, like including technology-specificity, to test the difference in policies. Moreover, the regulator in the tender needs to set the RES-E target right, which he does based on developments in consumption and generation from renewable energy in the market. The regulator is thus also prone to uncertainty: he might set the targets wrong or targets are not met. Whereas in the case of the target investor, the targets are always met, which can gives no insight in RES-E target dynamics. These examples, which are dealt with in more detail in the next chapter, shows the possible improvements regarding the target investor to reflect reality and test policies under uncertainty.

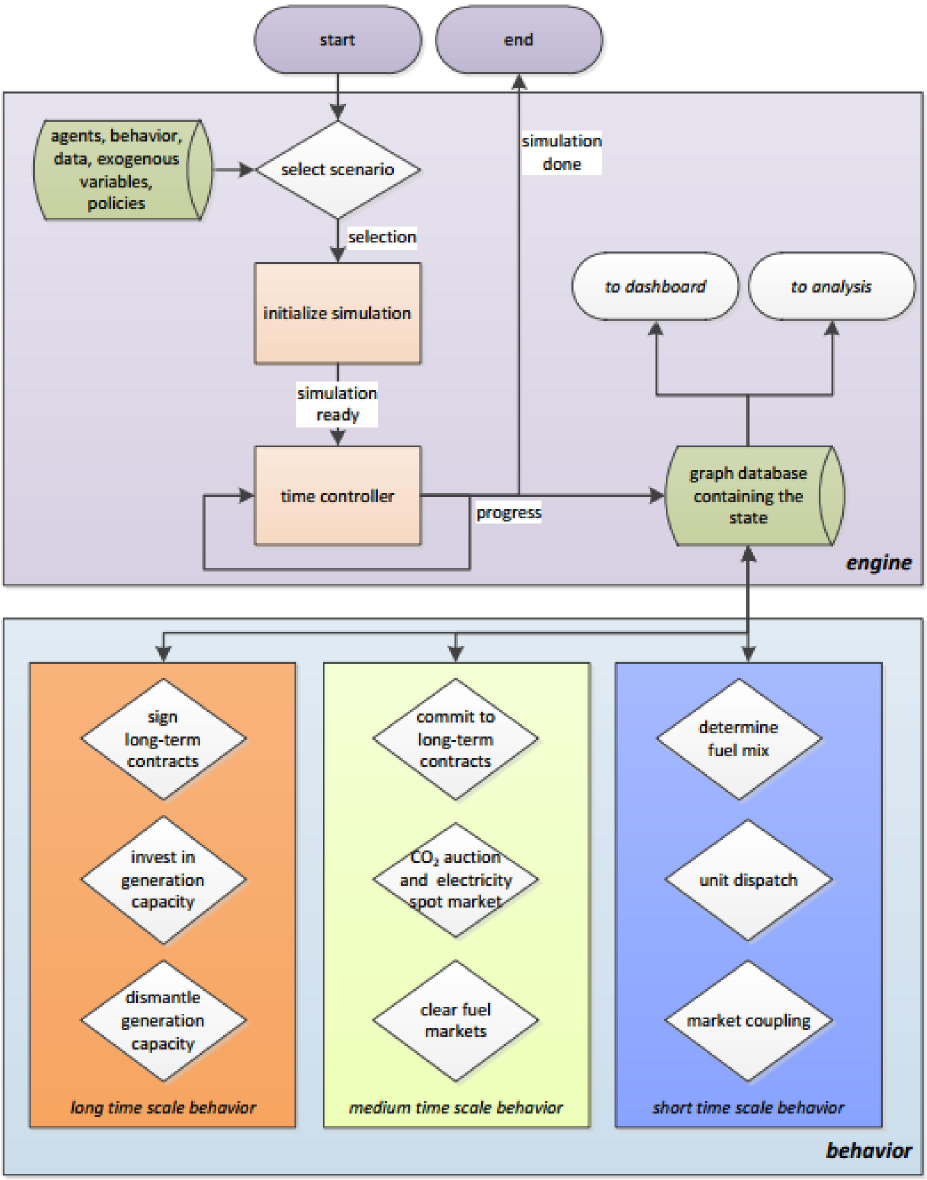


Figure 3.1: Overview of EMLab Generation model

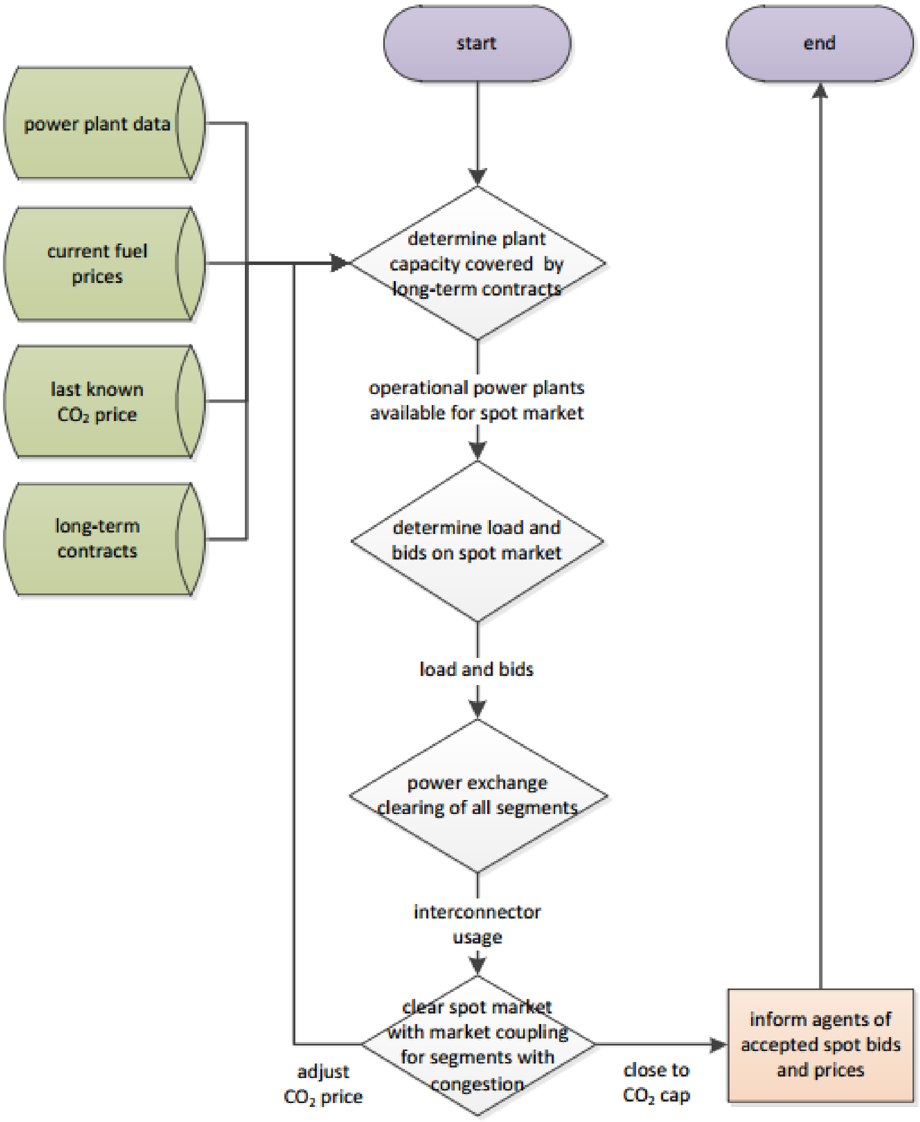


Figure 3.2: Market clearing algorithm

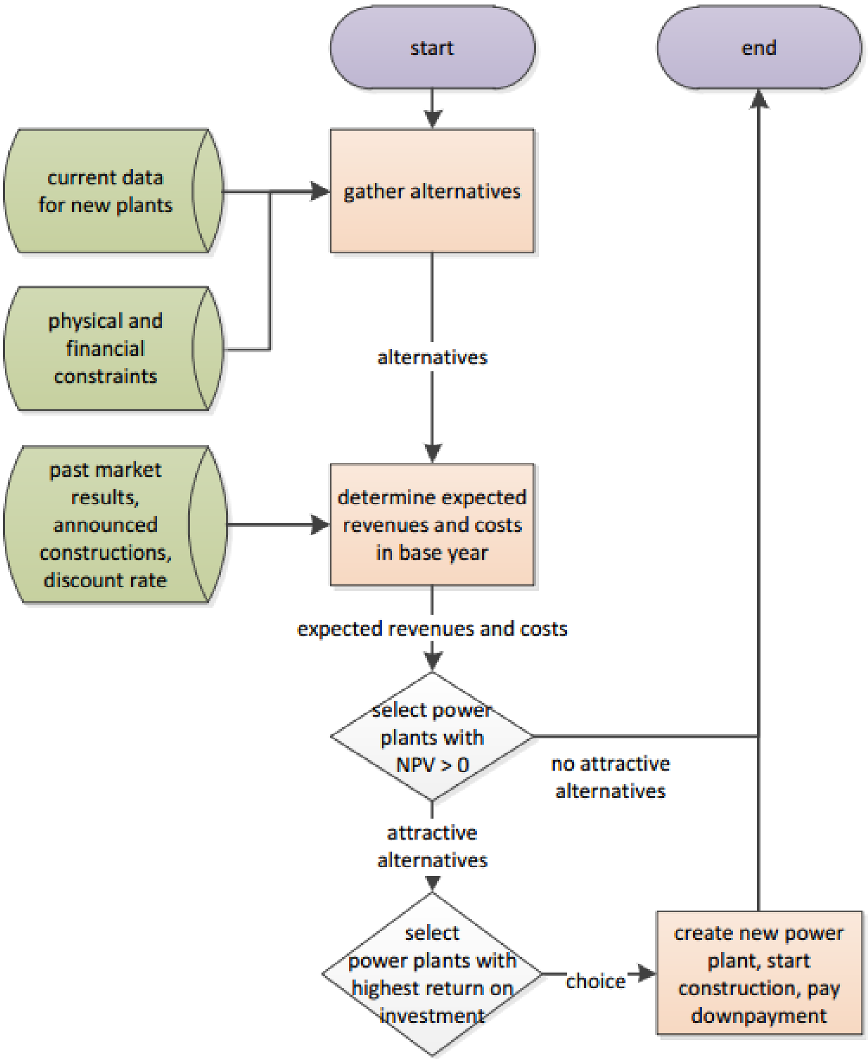


Figure 3.3: Investment algorithm

3.2. Conclusion

This chapter presented the the model used in this work. The main addition to this model is the tender, which is conceptualized in the next chapter. Also existing potential cost curve have been used to derive regional renewable energy productions and its accompanying potential capacity limits. Since different nodes represents different generation patterns, different investment opportunities for the energy producers arise where they can install RES-E power plants up to the capacity node limits.

4

The formal model

Based on the tender design of chapter 2 and the model description of EMLab in chapter 3, the tender is formalized. To clearly present the working of the model, a narrative is used. The complete code is obtainable via github at `https://github.com/rjjdejeu/emlab-generation/tree/feature/TenderRob10`.

4.1. Model formalization and narrative

The structure of EMLab can be decomposed in four main parts:

1. Domain classes: are used to define objects and the properties of these objects. These classes can inherit, or *extend*, properties of other classes.
2. Role class: executes the behaviour of a certain object
3. Repository classes: act as a graph database that contains functions, called queries, to deal with the interaction between objects and classes and obtain input values. The relationships between the objects are constructed via the graph database Neo4j.
4. Scenario files: used to obtain initial conditions and parameters prior to the simulation. The scenario files can be connected with data files like time series data.

Before start reading the following section, some notions need to be stated. In Java a less convenient writing style is used to program the model. For reading purposes a 'readable' writing style is used in the following sections. Appendix C contains a glossary of the variable names used here in the text and the ones used in Java. Classes, domains and variables are recognized by the *italic* font. When the variable *year* is encountered, this can also be read as *tick*, which is a step in the simulation, as stated in chapter 3. The terms *energy producer* and *investors* are used interchangeably. And finally, for the sake of overview, readability and understanding, the processes are summarized and presented in steps.

4.1.1. Domain classes

Four new domain classes are introduced within the domain *domain.policy.renewablesupport*. Their meaning and purpose are explained in the subsequent paragraphs.

1. *Renewable tender support scheme*
2. *Renewable target for tender*
3. *Tender bid*
4. *Tender clearing point*

Renewable tender support scheme This domain class has the function of containing the support scheme design properties for each specific support scheme, which are:

- *tender future start time*: defines how many years in advance the tender is announced and thereby selecting the NREAP target for the corresponding year that needs to be met.
- *support scheme duration*: a pre-determined period in years that states how long the subsidy will be paid out yearly to the winners of a tender.
- *eligible power generating technologies*: determines the technologies for which the investors can receive subsidy. This property allows to create technology-specific tender.
- *scheme*: is the name of the renewable tender support scheme so the model is able to indicate which specific support scheme is considered at certain moments in the simulation.
- *cash*: cash sums the total subsidy that is spent by a specific support scheme. This domain class extends the class *decarbonization agent* and can therefore use the property *cash*.

Renewable target for tender The purpose of this domain is to provide the RES-E target for the corresponding *tender future start time*. Is has the properties:

- *renewable target factor*: it reads the time series file that contains the yearly RES-E target factor, which is the predetermined value based on NREAP targets in a certain year.

Tender bid This class extends the class *Bid*. Therefore, *Tender Bid* has the following properties that will be used to specify and store the information of the tender bids that are submitted by the investors. One bid is associated with one power plant, which will only be build when the bid is accepted.

- energy producer: the name of the investor that submits the bid
- power plant: the name of the power plant
- technology: the technology of power plant
- bid amount: the expected generation of the power plant in MWh per year
- bid price: the expected price in Euro per MWh needed needed to compensate for the negative profit
- country: the country that the power plant will be built in
- node: the specific location within a country that the power plant will be built in
- start year: the year when the power plant is constructed and the subsidy starts to pay out. It is defined as the current year plus the actual lead time of the project. The lead time includes permit and construction time
- end year: the year in which the subsidy ends and is equal tot he start year plus the support duration period
- current year: stores the year in which the bid is made
- status: contains information whether the bid is submitted to the tender or not. Its status changes after the tender procedure into failed, accepted or partially accepted
- scheme: to which renewable tender support scheme the bid belongs
- downpayment: the cash needed for the downpayment of the plant

Tender clearing point Similar to the domain *Tender bid*, this class extends another domain class called *Clearing point*. A clearing point is actually a snapshot of the end results after a tender has been (un)cleared. These results are the following properties:

- clearing amount: the total generation value in MWh that has been accepted in the tender
- clearing price: the final price in Euro per MWh that will be received by the winning bids of investors
- current year: stores the current year, so it can be compared with the bids from the same year that needs to be paid out.
- scheme: the name of the renewable tender support scheme

Other domain classes The *Regulator* and *Energy producer* are already existing agents, and play a central role in the tender algorithm. The relevant properties of these two domain classes are presented below:

- *Regulator*: each country has a regulator that defines the *renewable energy target* in terms of yearly demand in MWh.
- *Energy producer*: the investing agents of the model that have properties that affect their decision making, the ones relevant for the tender model are stated below:
  - *future investment time horizon*: the number of years that the investor looks into the future to make his NPV calculation for a potential power plant.
  - *number of years looking back*: an investor makes prediction for the future by looking back several years at past variables like fuel prices and uses a linear trend regression to predict future values i.e. he extrapolates a historical trend for predictions.
  - *cash fraction available for downpayment*: The fraction tells how much of the current cash of the investor he is willing to spend on downpayments. The downpayment is the payment that needs to be paid upfront to start creating a power plant. This is independent of the tender subsidy.

4.1.2. Role classes

These classes distinguish themselves by executing behaviour, they are the driving force of the model. Five roles are defined that model the tender. A sixth role, the *Tender main role* is merely used to make sure the five roles are integrated with the rest of the model and executed in the chronological order as depicted in the next item list:

1. Calculation of the renewable energy target
2. Computation and submitting of tender bids
3. Filter tender bids for which there is enough cashflow for downpayments
4. Clearing the tender
5. Constructing power plants for winning tender bids
6. Pay out successful tender bids

The main sequence of these roles are given in a flow diagram on the next page. The legend of the symbols is given in 4.1

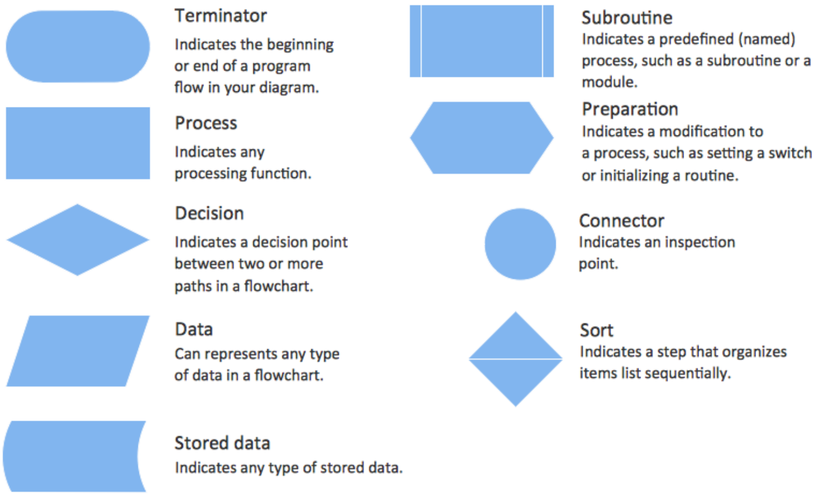


Figure 4.1: Flowchart design elements, symbols, shapes, stencils and icons adapted from Conceptdraw [6]

The following paragraphs explains the roles and the assumptions made. At the end of the discussion of a role, the overview of the role is given by a flow diagram. Table 4.1 gives an overview of the variables used in the equations of the roles.

Table 4.1: Variables used in equations of the submit tender bid role

variable	Unit/Content	Description
g_{demand}		Demand growth factor
s		Segment
$BaseLoad_s$	MW	Segment load
p		Power plant
c_{fuel}	Euro	Fuel cost (Marginal cost)
t_0	years	Current year
t_b	years	Building time in years
t_D	years	Life time
t_{ref}	years	Reference year in the future
$t_{support}$	years	Support scheme duration
I	Euro	Investment costs
$WACC$		Weighted average cost of capital
l_s	hours	Segment length in hours
FLH	hours	Full load hours
CF_s		Capacity factor for segment
$\kappa_{nominal}$	MW	Nominal capacity
$\kappa_{available}$	MW	Available capacity
$\widehat{CF}$	Euro	Estimated cash flow
$\hat{X}$	Euro	Estimated cash flow needed

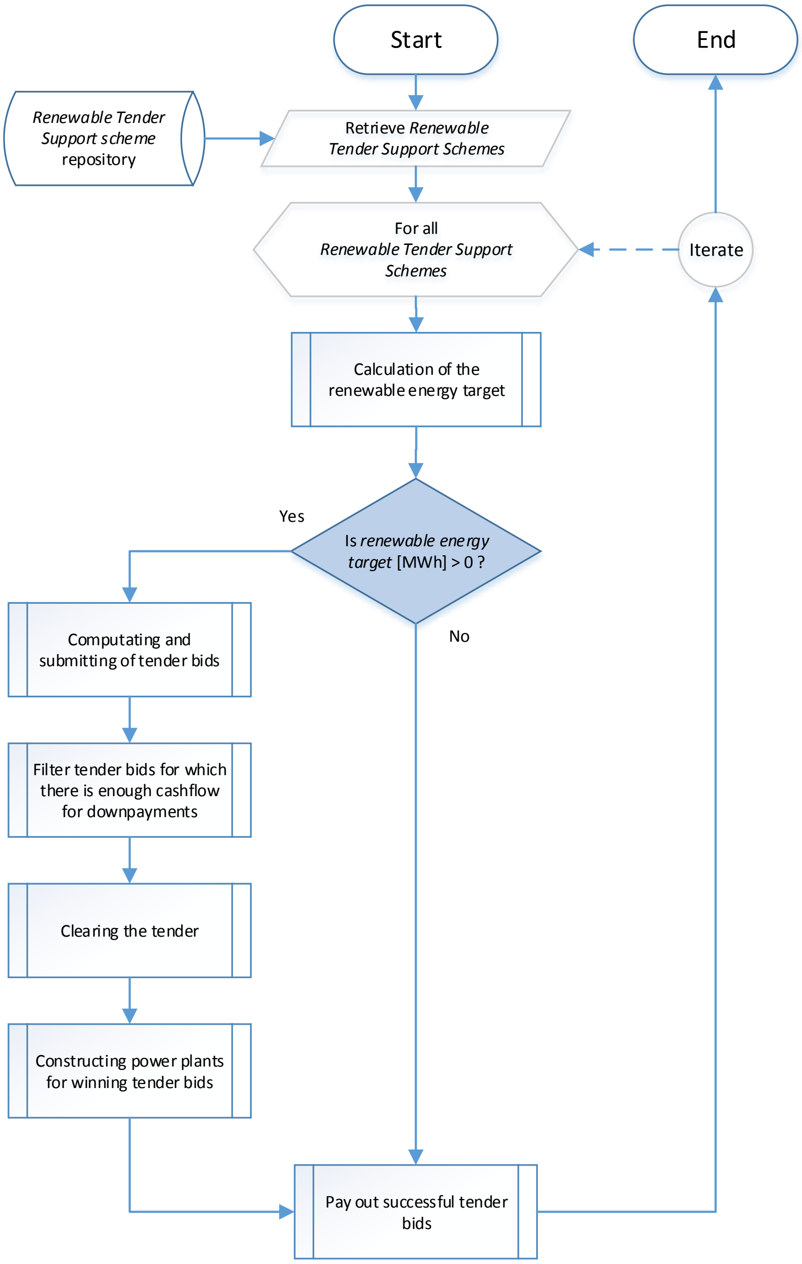


Figure 4.2: Flow diagram of the main sequence of the roles

Calculation of the renewable energy target The aim of this role is to calculate for each *country* a renewable energy target in terms of demand that needs to be met in the future, which is the current time plus *tender future start time*.

1. The *expected consumption*: is calculated via a geometric trend regression, the demand growth factor g_{demand} is obtained for the *tender future start time*. This factor multiplies the base load $BaseLoad_s$ of each segment s of the load duration curve to get the expected capacity. Subsequently this capacity per segment is multiplied by the corresponding segment length in hours l_s to obtain the expected consumption per segment. The sum of this gives the *expected consumption*:

$$\text{expected consumption} = \sum_{s=1}^{20} BaseLoad_s \cdot g_{demand} \cdot l_s \tag{4.1}$$

2. *gross renewable energy target*: is computed by multiplying the *renewable energy target factor* at *tender future start time* with the *expected consumption*:

$$\text{gross renewable energy target} = \text{renewable energy target factor} \cdot \text{expected consumption} \tag{4.2}$$

3. *expected renewable generation*: the expected available capacity for each plant of the eligible renewable technologies for each segment is determined and multiplied by the segment length in hours:

$$\text{expected generation per plant} = \sum_{s=1}^{20} \kappa_{available} \cdot l_s \tag{4.3}$$

   Summing all these power plants for a single technology gives the *expected generation per technology*:

$$\text{expected generation per technology} = \sum_{\text{p}}^{\text{all power plants}} \text{expected generation per plant} \tag{4.4}$$

   And summing now up over all technologies of the expected generation per technology gives the total *expected renewable generation*:

$$\text{expected renewable generation} = \sum_{technology}^{\text{all eligible technologies}} \text{expected generation per technology} \tag{4.5}$$

4. The *renewable energy target* is now obtained by deducting the *expected renewable generation* from *gross renewable energy target* and stored to be used later for the *tender quota*:

$$\text{renewable energy target} = \text{gross renewable energy target} - \text{expected renewable generation} \tag{4.6}$$

   The target is set to zero when the *expected renewable generation* is higher than the *gross renewable energy target* since sufficient generation is apparently expected.

The flow diagram of this process is illustrated on the next page.

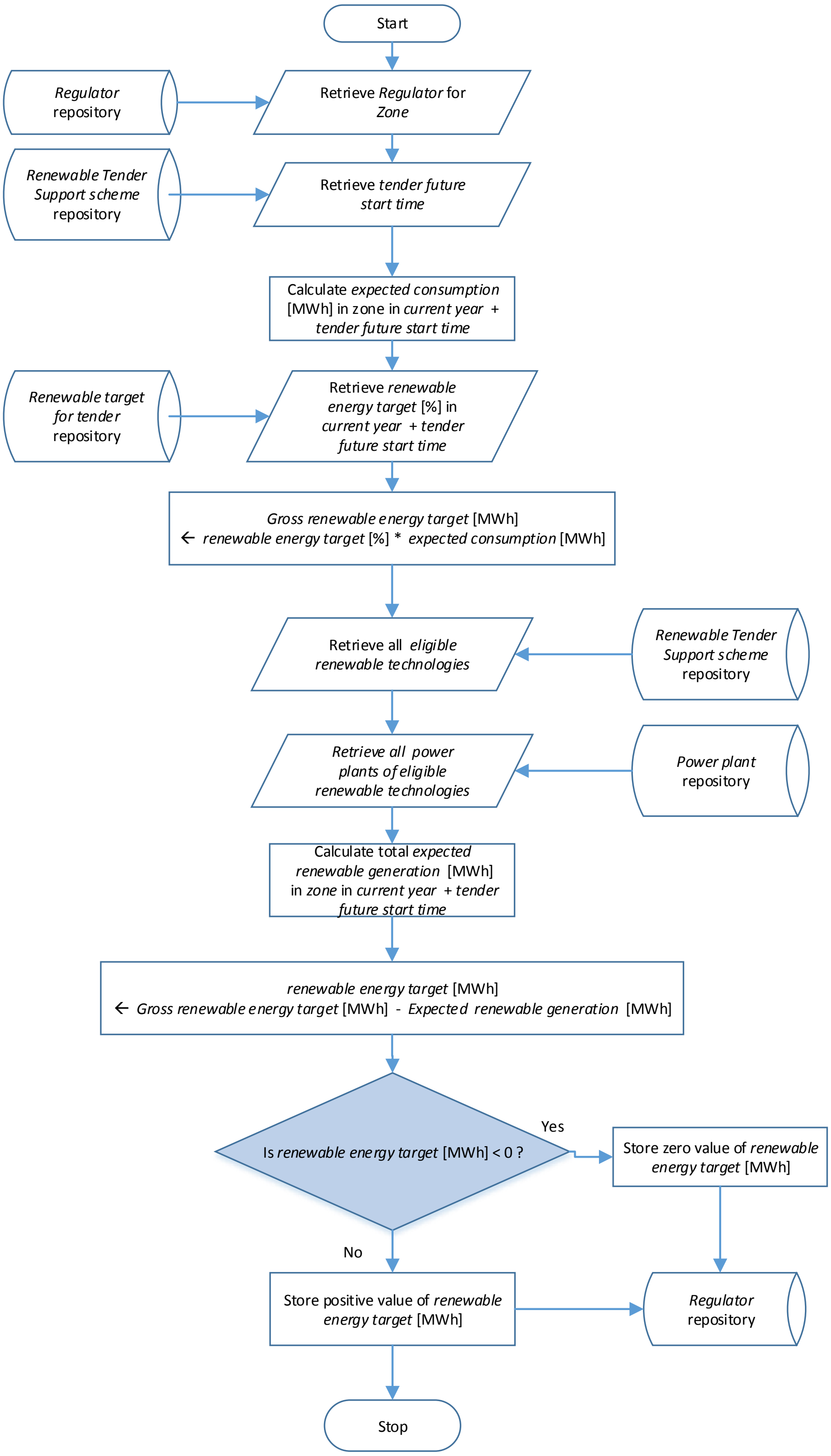


Figure 4.3: Flow diagram of Calculation of the renewable energy target Role

Computation and submitting of tender bids The function of this role is specifying and storing bids made by the energy producers that contain the information mentioned in 4.1.1. This procedure follows the investment algorithm from chapter 3 with the central modification: energy producers select not profitable RES-E projects instead of profitable projects. The procedure of this role is explained below.

1. At the start the energy producer looks at his *future investment time horizon*, which lies t years ahead of the current year, and is defined as the reference year t_{ref}. For this year, the energy producer determines the expected demand, expected fuel prices and expected electricity prices. This information is stored and used later in the algorithm.

2. the energy producer considers each eligible *technology* in each of the three installations nodes. For the intermittent RES-E the investor takes the full load hours of the nodes into account to calculate while for the non-intermittent sources he will pick a random node since those are not depending on the generation potential of the node. From the next step onward, the energy producer will repeat the forthcoming sequence for each eligible *technology* and node to determine the bids he will submit to the tender.

3. To calculate the *bid amount*, renewable energy plants are considered for each of the three installation nodes within the countries.

   Gross number of plants: an investor that considers to invest in a certain node for a certain *technology* aims to bid the total capacity of that node. He computes how many multiples of the same power plant technology fits in that node. The capacity of each power plant is a fixed predetermined value:

$$\text{Gross number of power plants} = \frac{\text{power plant capacity}}{\text{total capacity of node}} \tag{4.7}$$

   Subsequently, a *downpayment* for the total associated number of plants is considered. This is the initial upfront portion of the total investment cost. If the *cash* of the investor is not sufficient for this payment, the investor will bid only the fraction of power plants that correspond with the available cash for downpayments he has:

$$\text{Fraction of available cash} = \frac{\text{available cash for downpayment}}{\text{Cash needed downpayments all power plants}} \tag{4.8}$$

   The available cash for downpayment is influenced by the predetermined *percentage of cash available for downpayments*, which is is 50%. The percentage is an assumption made by the creators of the model and gives the total amount of *cash* that an investor can spend on downpayments:

$$\text{available cash for downpayment} = \text{Percentage of cash available for downpayment} \cdot \text{Cash flow available} \tag{4.9}$$

   The *fraction of available cash* of equation 4.8 is multiplied by the total number of power plants to arrive at the actual number of plants the investor can and will bid for:

$$\text{Actual number of power plants} = \text{Fraction of cash available for downpayment} \cdot \text{Number of power plants} \tag{4.10}$$

   From here onward, each plant is considered as a separate tender bid. For each non-intermittent renewable power plant the total expected generation is calculated by taking the sum of the expected generation in each segment of the load duration curve:

$$\text{Expected generation non-intermittent} = \sum_{s=1}^{20} l_s \cdot \kappa_{available} \tag{4.11}$$

   and for intermittent plants by:

$$\text{Expected generation intermittent} = \sum_{s=1}^{20} \cdot l_s \cdot \kappa_{nominal} \cdot CF_s \tag{4.12}$$

The variable CF_s is the capacity factor and is defined as as the fraction of actual energy output over maximum potential energy output per segment:

$$CF_s = \frac{FLH_s \cdot \kappa_{nominal}}{8760 \cdot \kappa_{nominal}} \tag{4.13}$$

This total expected generation is the *bid amount*.

4. Subsequently, the *bid price* is calculated for the plant. If the plant is expected to be in the merit order, the expected gross profit is obtained by multiplying the difference between expected electricity price per segment p_s and the marginal costs c_{fuel}. The relation for non-intermittent power plants is given by:

$$\text{Expected gross profit non-intermittent} = \sum_{s=1}^{20} (p_s - c_{p,fuel}) \cdot l_s \cdot \kappa_{available} \tag{4.14}$$

and for intermittent plants by:

$$\text{Expected gross profit intermittent} = \sum_{s=1}^{20} (p_s - c_{p,fuel}) \cdot l_s \cdot \kappa_{nominal} \cdot CF_s \tag{4.15}$$

Then the operating profit is calculated by subtracting the fixed O& M costs of the current year:

$$\text{Operating profit} = \text{Expected gross profit} - \text{Fixed O\&M Costs} \tag{4.16}$$

Subsequently the total investment cash outflow I are spread linearly over the building time t_b. The actual investment costs are pre-determined for each type of plant. The future cash inflows $\widehat{CF}(t_{ref})$ are determined by the operating profit over the life time t_D of the power plant. $\widehat{CF}(t_{ref})$ is also linear over time and is a function of the reference year t_{ref} mentioned in the beginning of the paragraph. The weighted average cost of capital (WACC) is the discount rate. The Net Present Value method is used to determine the *project value* in the current year:

$$\text{Project value} = \sum_{t=0}^{t_b} \frac{\frac{I}{t_b+1}}{(1+WACC)^t} + \sum_{t=0+t_b}^{t_b+t_D} \frac{\widehat{CF}(t_{ref})}{(1+WACC)^t} \tag{4.17}$$

If the project value is negative, the energy producer will consider this as a project that needs subsidy. The *cash* amount he needs is $\widehat{X}(t_{ref})$ and is also linear over time and is a function of the reference year t_{ref}. The *support scheme duration* determines the yearly payments the investor needs to cover the negative project value:

$$\text{Project value} = \sum_{t=t_b+1}^{t_b+t_{support}} \frac{\widehat{X}(t_{ref})}{(1+WACC)^t} \tag{4.18}$$

Solving the equation for $\widehat{X}(t_{ref})$ and taking the absolute value of the (negative) project value gives:

$$\widehat{X}(t_{ref}) = \frac{|\text{project value}|}{\sum_{t=t_b+1}^{t_b+t_{support}} \frac{1}{(1+WACC)^t}} \tag{4.19}$$

Subsequently, $\widehat{X}(t_{ref})$ is divided by the expected generation to arrive at the *bid price* in Euro per MWh:

$$\text{Bid price} = \frac{\widehat{X}(t_{ref})}{expectedgeneration} \tag{4.20}$$

5. Each bid is stored and contains the specific information about the bid amount, bid price, energy producer, power plant, country, node, technology, start and end year of the bid, its status, to which national support scheme it belongs and how much cash is needed for downpayment.

This process is summarized on the next page.

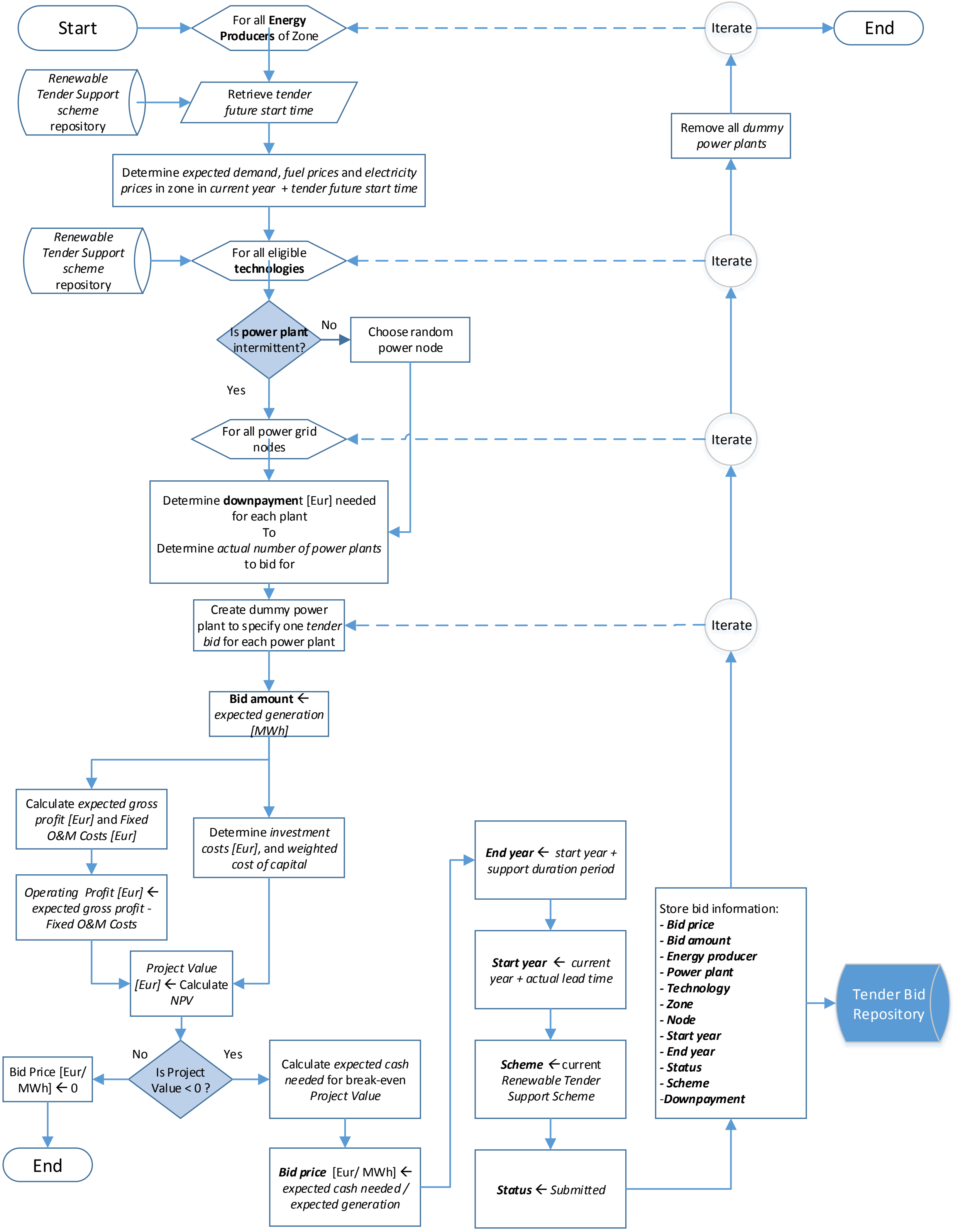


Figure 4.4: Computation and submitting of tender bids

Filter tender bids for which there is enough cashflow for downpayments This role is needed since in the previous role, the agent creates as many bids per technology as his available cash for downpayment will let him. However, this means that that for each technology he will deplete his cash flow. If more than one technology is involved, which is always the case in the model, the agent will deplete his cash flow multiple times, which should not be allowed. This role has as purpose to filter all the bids for all technologies that are allowed to be submitted i.e. up to his available cash for downpayment. The following sequence makes the exact working more clear:

1. The *tender bids* are sorted ascending by *bid price* for each energy producer.
2. The sum of *cash available for downpayments* is calculated
3. The *cashflow needed for the downpayment* for each bid is determined
4. The *tender bids* are submitted as long the *sum of cash available for downpayments* is not reached, starting with th lowest *bid price*
5. When the *cashflow needed for the downpayment* is larger than the *sum of cash available for downpayments*, the current and subsequent bids are not submitted.

This process can be viewed 4.5 The next role will process the submitted *tender bids* further during the clearing of the tender.

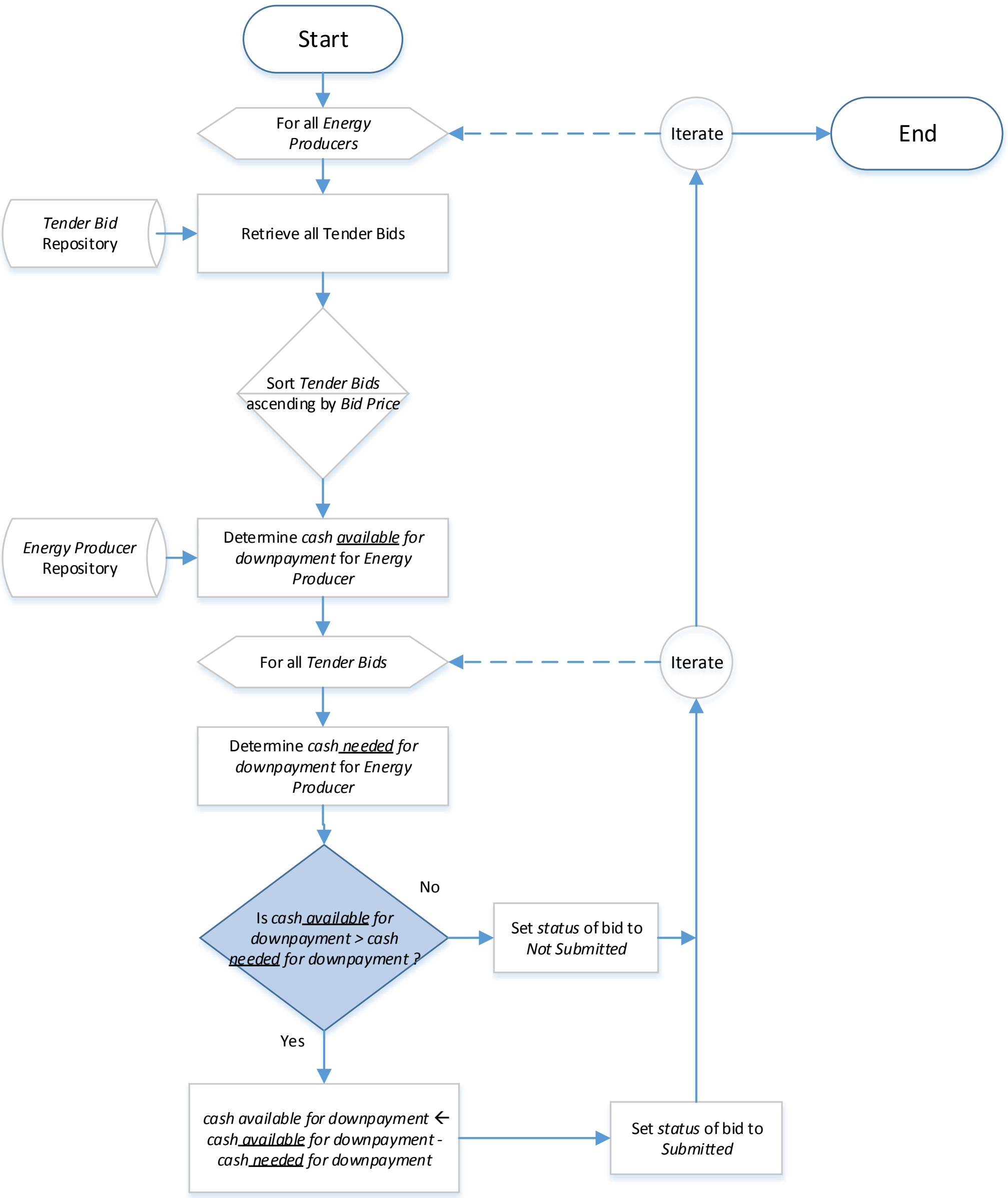


Figure 4.5: Flowdiagram: Filter tender bids for which there is enough cashflow for downpayments

Clearing the tender The goal of this role is to collect the bids in ascending order of the *bid price* until the *tender quota* is met and selects the winners of the bid round.

1. The *tender quota* is equal to the the earlier stored property *renewable energy target*, and serves as maximum clearing volume.
2. For each *scheme* the bids are sorted ascending by price and filtered by *country* and the *current year*.
3. The tender is cleared when the cumulative bid amount from the *tender bids* reaches the *tender quota*. The *bid price* of the last accepted bid determines the *clearing price*, which serves as the accepted tender subsidy in Euro per MWh.
4. The accepted bids are stored containing the specific information mentioned in paragraph 4.1.1. This information needs to be accessed in the next role to create the power plants of the bids that won the tender.
5. A tender clearing point is created that contains the clearing price, volume, current year and scheme it belongs to for paying out the subsidies in the next role.

The flow chart of this process is given on the next page.

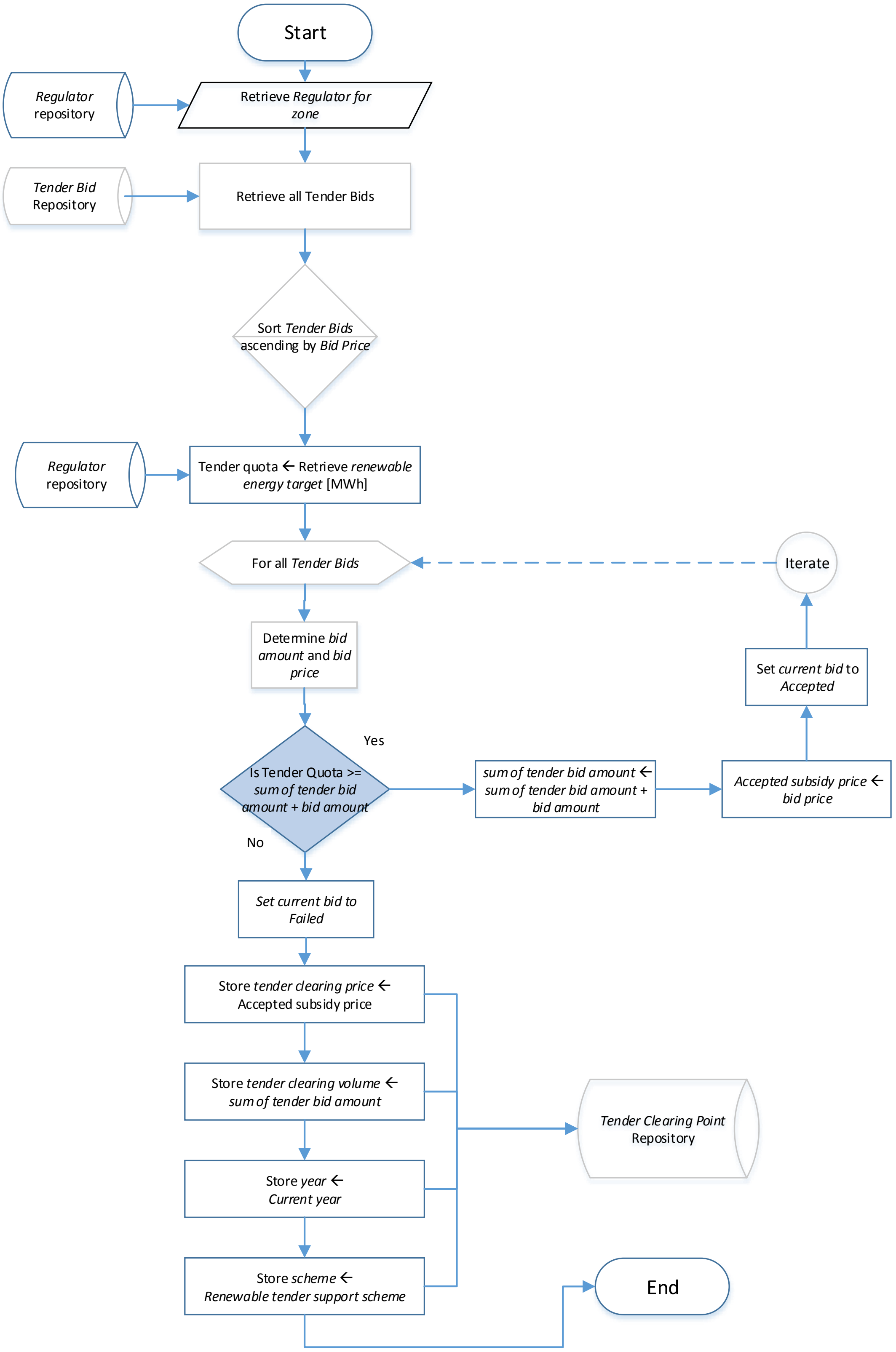


Figure 4.6: Clearing the tender Role

Constructing power plants for winning tender bids The power plants are created of the tender bids that were accepted.

1. All accepted bids are collected for the *current year* and filtered by *scheme*.
2. A *plant* is created in the corresponding *node* and attributed to the respective energy producer of the bid.
3. The power plants become operational after the actual lead time and permit time have passed.

A flow diagram is given in on the next page.

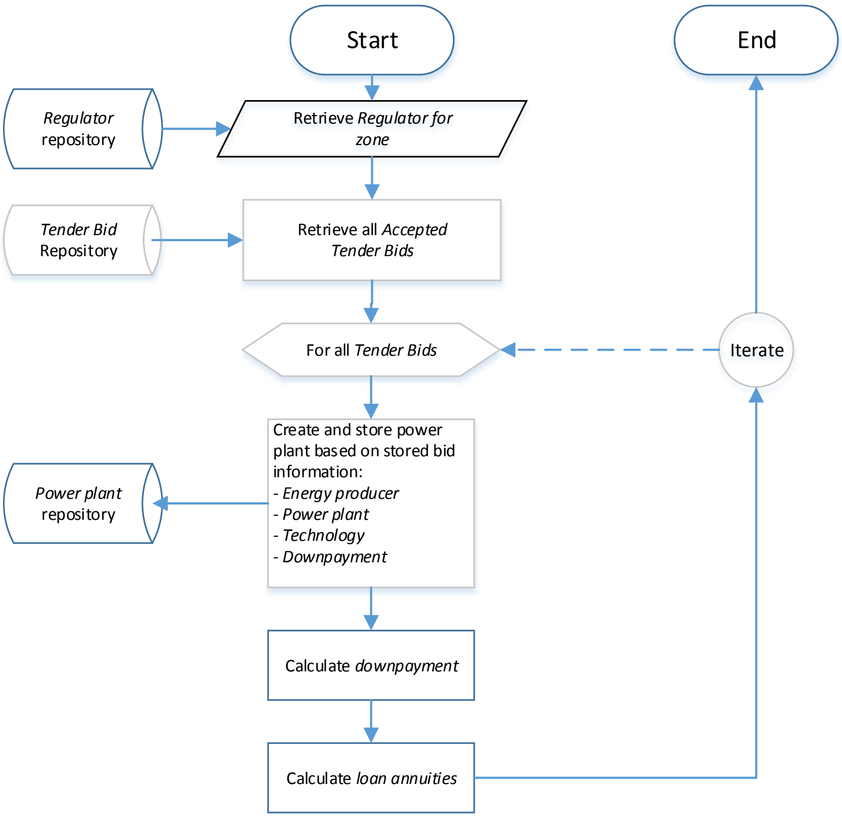


Figure 4.7: Flowdiagram: Constructing power plants for winning tender bids Role

Pay out successful tender bids This role ensures that the winning bids receive their yearly subsidy until the duration of the support ends.

1. All tender bids that have been accepted and active in the *current year* are collected. Active, in the sense that the *support scheme duration* for that bid has not finished yet. The bids contain information about to which investor a payment should take place and for what *bid amount*.
2. Subsequently, the *tender clearing point* of the year that corresponds with the year the bid was accepted is accessed. It contains the *clearing price* that is multiplied with the *bid amount*, resulting in the subsidy being paid out. This process is done for each accepted bid

. The flow diagram is shown on the next pages.

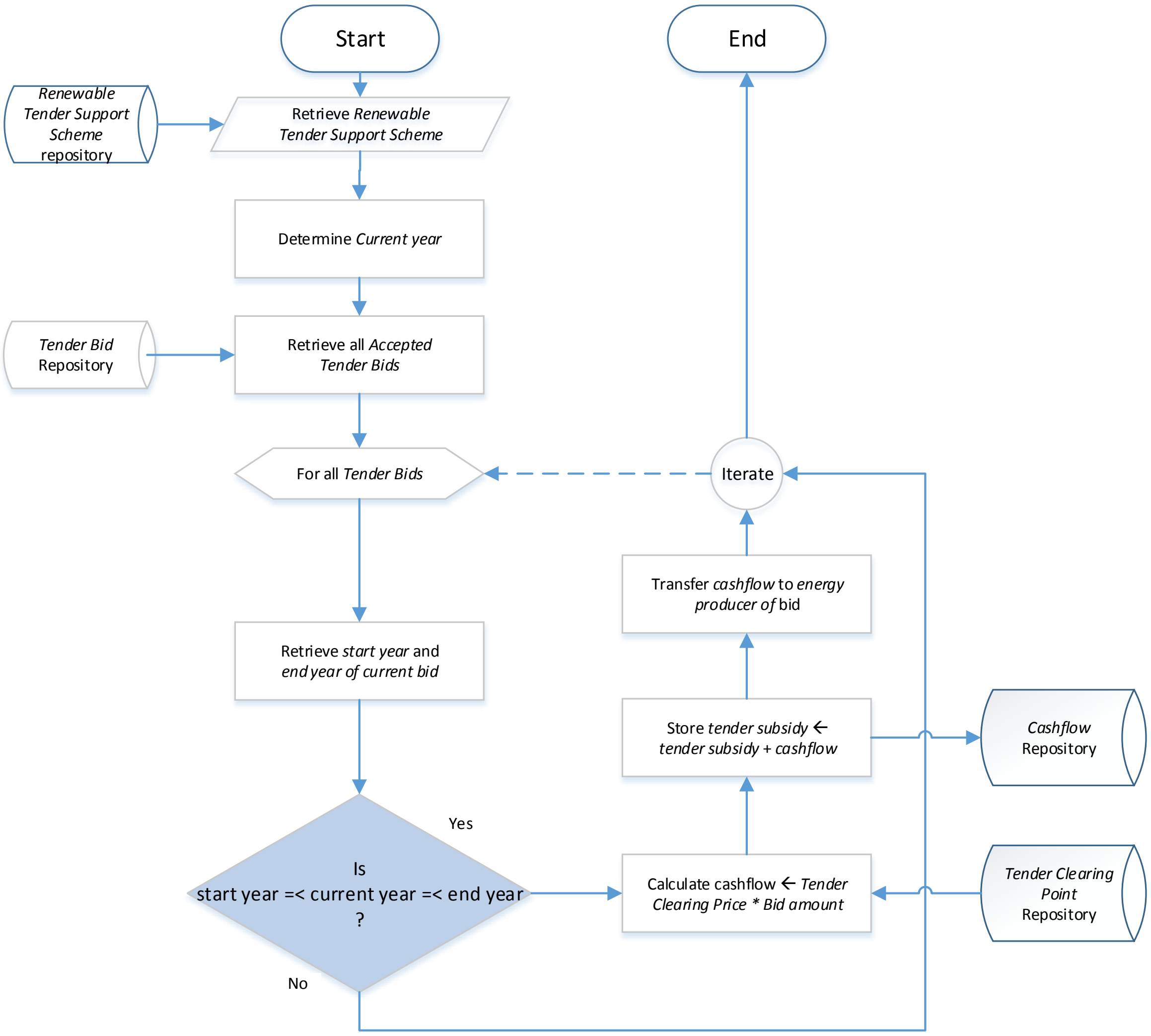


Figure 4.8: Flowdiagram: Pay out successful tender bids Role

4.1.3. Technology-specificity

After finishing the model, it was observed that it could not deal well with technology-specificity. More precisely, it was only able to select one technology as specific while the model needs to be able to select all the available renewable technologies for one of the research questions. An adjustment was made to the original tender in which it can deal now with multiple tenders per country. The structure and working principle is equal to aforementioned narrative. The source code of the adjusted version of the model can be found here `https://github.com/rjjdejeu/emlab-generation/tree/feature/TenderTechnologySpecificity`. Since the logic is similar, the specific adjustments for the technology specific flow diagrams can be found in appendix D.

4.2. EMLab integration

The tender algorithm is placed before the actual investment algorithm but after the electricity spot market clearing. This sequence ensures that the energy producers consider an investment in renewable technologies first before they potentially use their available *cash* on conventional power plants for that year. It also makes sure that in the next tick, both the power plants of the actual investment role and of the tender are being bid into the spot market.

4.3. Conclusion

This section explained the properties and the procedure of the tender algorithm. The tender role is implemented in EMLab before the actual investment role to ensure that investors consider renewable technologies first.

5

Verification

Verification makes sure the implementation of the model is correct and without errors, and it is therefore concerned with the question whether the model was correctly built or not. Validation, on the other hand, answers the question of the model being the right choice, which relates to the accuracy of the model compared to reality and its results being in line with the research questions [29]. Country A refers to The Netherlands, the relative small country. Country B refers to Germany, the larger country which is characterized by its higher demand as stated in the subsection 6.3.

5.1. Verification

Verification in the EMLab model is time-consuming and difficult. A full run of 40 ticks for two countries and three nodes each, could take up to 3-4 hours. The difficulty is due to the complete model, which is complex and very large compared to the added tender module. It is hard to get an understanding of each part of the model within the scope of time. This complexity might have had unexplainable effects on the tender role, since it is hard to trace errors without having a perfect understanding of the model itself. Besides the model itself, one needs to have sufficient understanding in how to perform model runs, to set up scenarios, define query properties, repositories, use R, the statistical software and LaTeX.

The verification is done by tracking the behaviour of agents and comparing the outcomes of variables with expected values. The expected values are obtained via loggers, which log data and results in a separate file that can be read and stored. The advantage of loggers is that information originating from the beginning of the simulation is relatively quickly obtained. However, logger are less advantageous to look into later parts of the simulation, since it takes time for a run to finish. The output of a run can also be obtained via queries, which prints a well structured data output file for further data processing after the simulation has been finished.

Tracking the behaviour of agents This part follows one agent through the processes of bidding, filtering the bids based on available cash flow for downpayment, clearing and the subsequent procedures of building a power plant and receiving a subsidy. The following points were verified as working:

- The agent creates bids in based on not profitable projects i.e. a negative NPV
- The agent submits the lowest cost bids in [Euro per MWh] until his available cashflow for downpayments [Euro] is strapped. Bids are indeed not submitted when there is not enough cashflow for the downpayments anymore
- The sum of the bid amount in [MWh] of each bid is equal to clearing volume in [MWh]
- When the tender is cleared, the the clearing volume [MWh] corresponds to the tender quota [MWh]
- When the tender is partially cleared, the clearing volume [MWh] corresponds to the sum of each accepted bid [MWh]

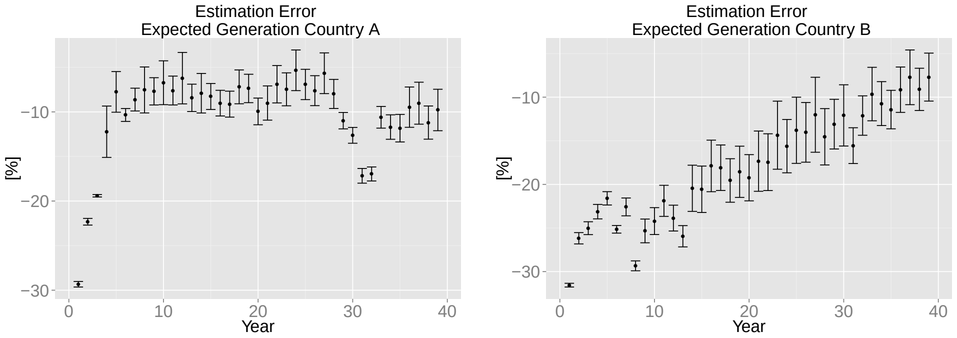
- The clearing price [Euro per MWh] corresponds to the last accepted bid price [Euro per MWh]
- Power plants are created based on the information of the accepted bids
- It is observed that the energy producers receives payments for the number of years that is equal to the support duration of the tender

Expectations in generation and consumption by regulator Initially, the model design was based on the regulator looking five years into the future, meaning that the tender is announced five years ahead. The expected generation predicted by the regulator was significantly different from the actual generation. The regulator underestimated the RES-E target and therefore renewable energy was not stimulated sufficiently via the tender. Setting the announcement of the tender to one year ahead did not improve the results. It turned out that the regulator was using the total generation of both countries together for each country. This lead especially to high deviations in the Netherlands (Country A) because it is the smaller country.

After incorporating the power plant in the pipeline, the expected generation was improved and closer to the actual generation but still had deviations up to 43% for country A and 23% for country B. It also has an extreme outlier of over 700% for the Netherlands in the final year of the simulation.

After further debugging it appeared that only the expected generation from existing power plants was calculated and the renewable power plants that were under construction were not included. After adjusting this the expected generation was predicted with less, but remaining deviations.

This led to the decision to run a sensitivity analysis for different years ahead of forecasting to see if the initial choice of five years and the years in between are influencing the outcomes of the tender significantly. The justification of the experiment is to see to what extend uncertainty at the level of regulators plays a role in determining the renewable energy targets since the determination of expected generation affects the net renewable energy target.



(a) Expected generation 1 Year ahead - Country A

(b) Expected generation 1 Year ahead - Country B

The expected consumption for the year ahead should be reasonably close to the actual consumption, which is the case for both countries with a minimum deviation of -3.17% and maximum deviation of 2.88% as can be viewed in appendix E.

No tendering with zero RES-E targets In this test, the pre-determined RES-E targets are set to zero for both countries. In this extreme case, the following three actions should be observed:

1. no tender biddings be made
    - It was observed that tender bids are made, although the target is zero. To make sure no biddings are done, an extra logical statement was added that skips the bidding if the RES-E target is zero. After this correction, it was observed that no tender bids are prepared and submitted, because the bidding role is simply skipped.
2. no bids are accepted in the tender
    - It was observed that there are no accepted bids.

3. no tender is cleared i.e. no tender clearing volumes or prices exist

    - There were no clearing volumes and prices obtained.

It can be concluded that the tender is operational only when a RES-E target is present.

Eligible RES-E technology This option is used to simulate technology-specificity. For country A only wind was eligible, and for country B only photovoltaic. It is verified via loggers that only the eligible RES-E, instead of all, were used in the bid by the agents. Thus the technology-specificity option is verified as working correctly. However, the model permitted only one technology to be specified and not the full range of renewable technologies. A slightly adjusted model was created that could deal with technology-specificity for all technologies instead.

No initial shortages In the initial phase of the model verification, the simulation created large capacity shortages, resulting in very high electricity prices in a number of segments and thus created incentives for power producers to invest in many power plants at the beginning of the simulation. Therefore a capacity margin was introduced. The margin adds a certain fraction of the current installed capacity to the installed capacity to overcome initial shortages. It is verified that the segment prices were lower than the Value of Lost Load [52], implying no shortages.

Lowest cost nodes are used first Three nodes are attributed per country, which have as function to represent different cost potentials for renewables due to site-specific conditions like the weather. The full load hours were constructed in such a way that the lowest cost potentials for wind offshore, wind onshore, and photovoltaics are in the first node of the countries, the medium potential in the second one, and the mostly costly in the third node. Each country has thus three nodes in total as depicted in table 5.1.

Table 5.1: Cost potential distribution for three nodes in Country A and in B

node	Country A	Country B
1	low cost potentials	low cost potentials
2	medium cost potentials	medium cost potentials
3	high cost potentials	high cost potentials

The point is that the first nodes are expected to be filled first with the intermittent technologies, before the second and third. This is expected due to the lower cost i.e. more full load hours in the first node. It is observed that the intermittent plants are build in the first node first, then the second node and the other node three as last for country B but not often for country A. This is due to the lower RES-E targets of the Netherlands and that technologies are dismantled after their lifetime, and thus creating new availability in the low cost nodes. For Germany the RES-E targets are ambitions and more costly nodes are earlier achieved. This has been observed in .csv output tables called FinancialReports and can be requested by the author.

Supply ratios between 1 and 2 A value of supply ratio lower than 1 indicates shortages. If the ratio is higher than 2, it indicates that there is relative more capacity in the market than actually needed. Ideally a supply ratio of 1 would indicate that the capacity is installed perfectly with no undersupply and oversupply, but ratios between 1 and 2 are accepted in the model. A graphical representation of obtained ratios from 120 runs is shown in the next figure.

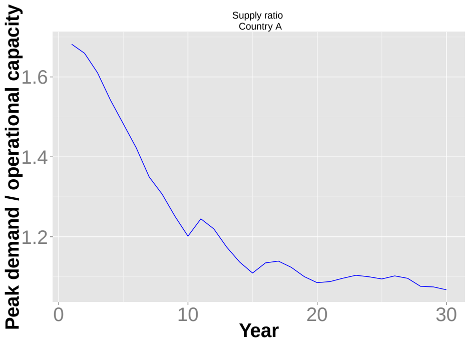


Figure 5.2: Supply ratios - Country A

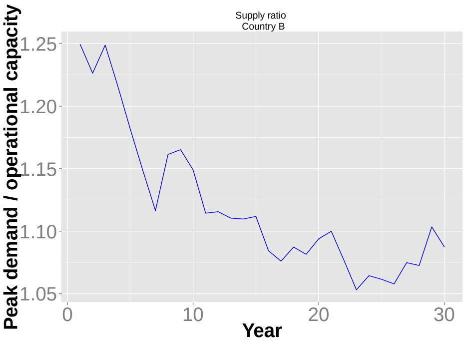


Figure 5.3: Supply ratios - Country B

It can be stated that the supply ratio is mostly between 1 and 2 indicating that the model does not create significant oversupply or under-supply most of the time and runs.

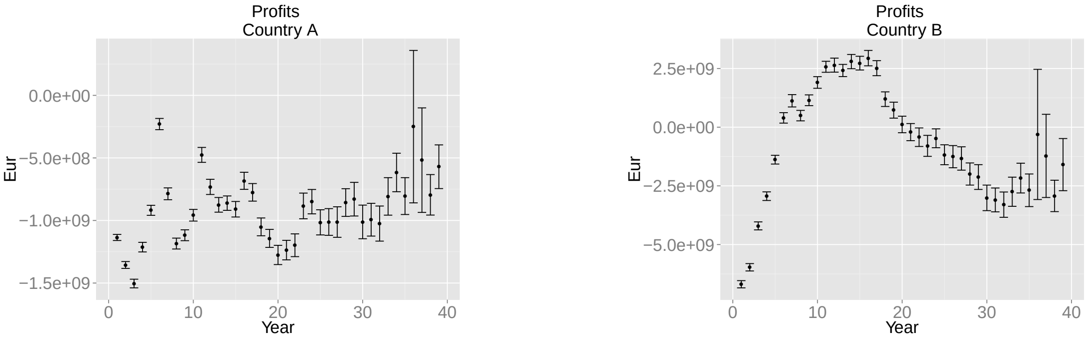
Expected renewable power plants The power plants created by private investment and the tender should equal the total added power plants. Initially this was not the case. An overshoot of power plants was observed in the model. This error was caused by power plants being were stored during the submit bid role that was not supposed to be happen. The power plants created in this role were merely used as blueprint to create tender bids. After adjusting the code, these power plants were deleted before becoming active and the overshoot was corrected. A second error was observed in which an undershoot of power plants was observed. Due to a storing error, only a small fraction of the power plants were created in the model. After this bug had been corrected the correct number of power plants were observed and it could be concluded that the creation of power plants is verified as working correctly.

Aggregate profit is zero In a perfect market, one expects marginal costs equal to marginal profits [53] If this is not occurring, one can conclude that there are imperfections in the market. The mean aggregate profits over 120 runs have been observed to be negative. Non-zero profits are explained by the forecasting uncertainty in demand and price developments on which the model is based, which reflects the non-optimal investment behaviour.

However, according to the model creators, the profits should be on average zero, which then indicates that the model is well calibrated and debugged. However, in the simulations of this work this is not the case. After observing these negative profits, the following improvements have been made that should negate the negative profits:

- A redundant downpayment algorithm was removed that lowered the profits of the investor. This downpayment was necessary since it belonged to the dummy power plant creation and was thus not attributed to real power plants.
- In the Technology-Specificity feature the partial clearing was removed, which caused investors receiving less subsidy than required. This is due to that a power plant in the partial clearing is built for full nominal capacity while the investor receives only the fixed subsidy over the remaining generation up to the clearing point in the tender clearing.
- The introduction of the filter bid role that was not built initially, which makes sure that investors do not submit more bids than they their available cash for downpayment that is necessary to built power plants from the winning bids.
- Partial tender clearing was removed for the Technology-Specificity feature, but not for the original feature due to time constraints. It occurred that bids were partially cleared, and that the bidder only received subsidy for the partial generation of that bid while a power plant was created for full nominal capacity (and thus higher generation) instead of the corresponding partial capacity. The point is that the investor only receives a subsidy for the partial generation while he operates a plant with higher generation output.

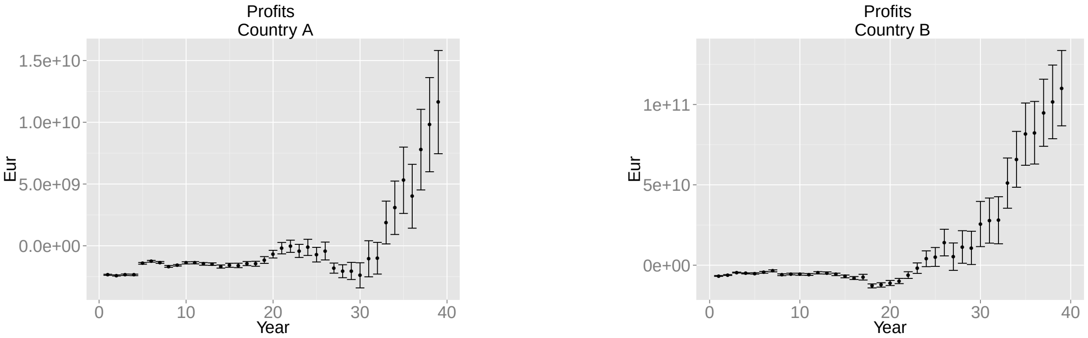
However, after running the simulation with and without a tender and in the new feature Technology-Specificity, the negative profits are still present and it cannot be stated that they are on average zero. These three tests are depicted in figures 5.4, 5.5 and 5.6.



(a) Profits country A

(b) Profits country B

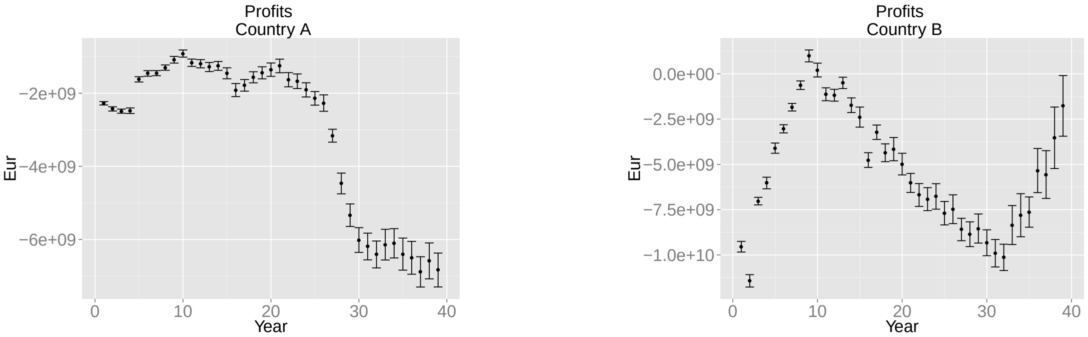
Figure 5.4: Aggregate profits without Tender module



(a) Profits country A

(b) Profits country B

Figure 5.5: Aggregate profits with Tender module (Base Case scenario)



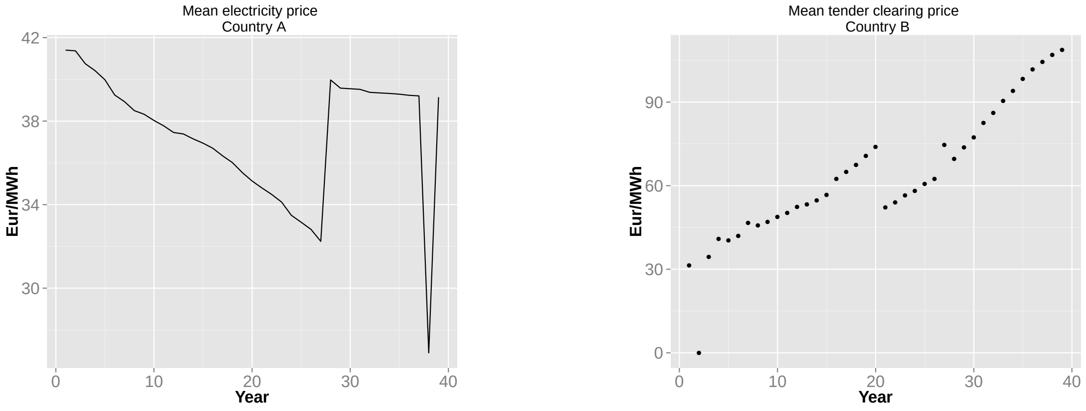
(a) Profits country A

(b) Profits country B

Figure 5.6: Aggregate profits with Tender module (Technology-Specificity scenario in one country

Due to the projects time constraint it has been decided to continue working with this anomaly in the model. One should take into account that the interpretations and results analysis of absolute profit values do not give a clear insights. Therefore only the change of profits will be considered as valid to work with. A recommendation for future work on this error is to check whether investors that own conventional power plants, do not bid in the tender for renewable power plants that might compete with their own assets in the merit order.

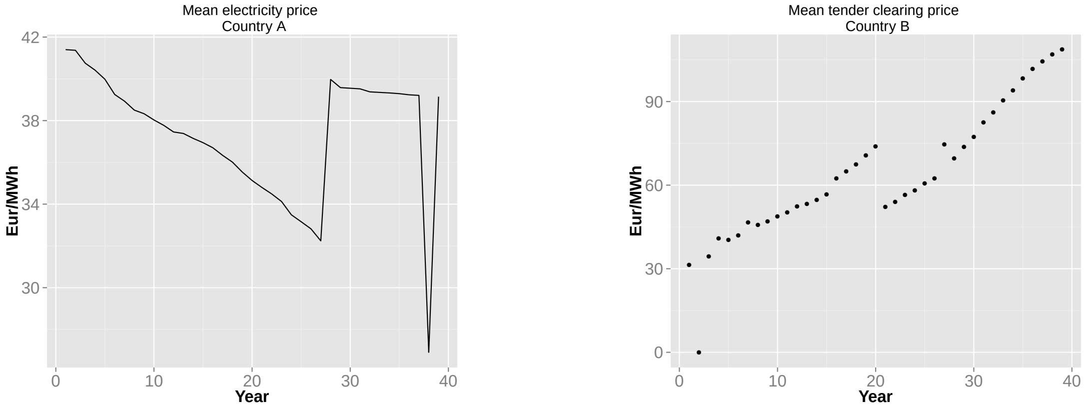
Tender clearing prices extreme case A tender clearing price should reflect the amount in Euro per MWh that is needed for a technology, on top of the average electricity market price to be profitable. The levelised costs of electricity (LCOE) of wind onshore in 2012 was reported to range between 60 - 110 Euro per MWh [47]. The sum of the electricity market price and the tender clearing price should be in that range to reflect correct tender clearing prices. A scenario was created with only OCGT and wind onshore technologies. A fixed gas price and a 100% coverage of OCGT plants were given as initial condition. This made sure that the electricity price was not influenced by the gas price, and the system started without any wind plant built yet. The OCGT plants were set to a lifetime of 100 years to make sure that no OCGT plants were dismantled, which could have led to shortage prices and affect the tender clearing price verification process. The results are shown in figure 5.7 and 5.8 and the inverse relation between the tender clearing price and the electricity price in 5.1. The sudden increase after 25 years is the dismantling of the wind plants that met their life time.



(a) Tender clearing price

(b) Electricity price

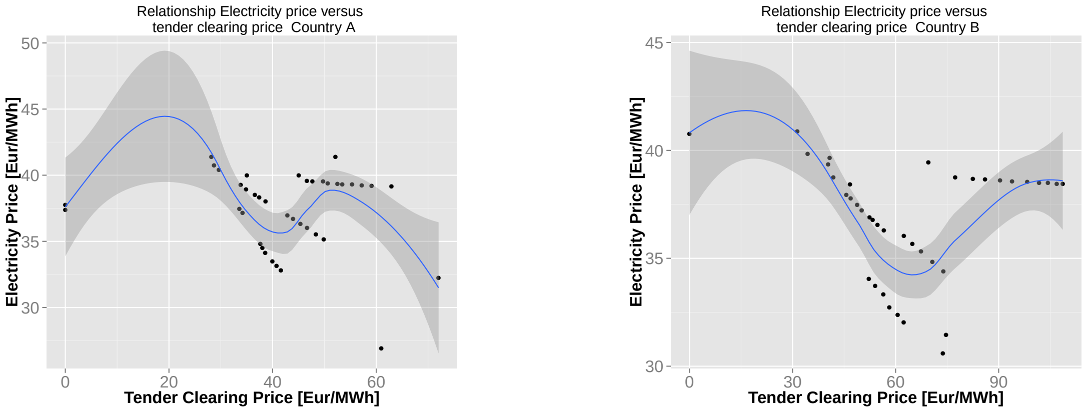
Figure 5.7: Country A



(a) Tender clearing price

(b) Electricity Price

Figure 5.8: Country B



(a) Country A

(b) Country B

Figure 5.9: Scatter plot and non-linear regression of Electricity and Tender clearing prices

For both, country A and B, the sum of the electricity price and tender clearing price is in the range of 60 - 110 Euro per MWh, implying that the tender reflects an extra amount needed to be profitable in the electricity market. Figure thus show that in isolation (only OCGT and Wind), fixed conditions (zero demand growth and fixed gas price) and no shortages, a declining electricity price is followed by an increasing tender clearing price.

Upwarding electricity market price trend artefact: shortage-effect One would expect an inverse relation between the electricity spot market price and the amount of RES-E since the intermittent technologies have zero marginal costs. However, during the tender scenarios, it was observed that the electricity market price increases over time even though more RES-E investment were made. Further investigation pointed out shortages in the market after 20-25 years of running the simulation. Figure 5.10 illustrates this.

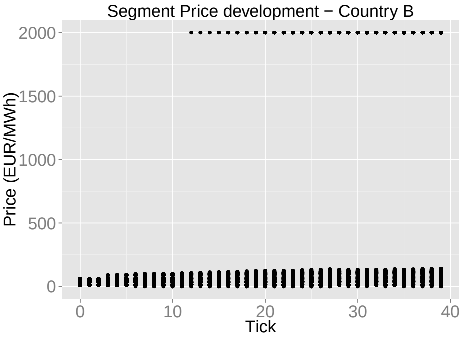


Figure 5.10: Shortages

Of the 96000 segment clearing prices, a total of 2171 outages were observed i.e. the segment clearing price was equal to 2000 Eur/MWh (the VOLL level in the model), which is the cap on the electricity price. Most of the outages were observed in the first four segments, 610, 448, 332 and 248 times respectively. This explains the increasing trend in the electricity price, but it does not tell why it is happening.

After all HPC results were processed and the available time to run more simulations was depleted, it was pointed out that this anomaly was caused by a part of the standard investment algorithm outside the tender environment. The high variable RES-E creates shortages in the higher segments and thus creating peak prices. Investors should respond to these peak prices by installing (conventional) technologies since there is a shortage in the market.

However, the standard investment algorithm does not allow for an investment to occur in any technology if the capacity (in MW) in the pipeline exceeds the 20% of the load that is expected at the future time point. In combination with the increasing investments in RES-E, which need a relative higher amount of capacity to meet their generation potential, there is a high capacity in MW (>20%) of technologies constantly in the pipeline.

The point is thus that investors will not build enough flexible capacity (CCGT, Coal) in time to respond to the scarcity prices and the shortages will remain since also RES-E keeps increasing. In the thesis, this effect will be referred to as the shortage-effect.

A single run was performed to confirm this effect by removing the aforementioned statement in the algorithm. The shortages were reduced and the electricity price did not exhibit the up-warding trend as before anymore.

Another (unexpected) outcome is the change in the height and behaviour of the tender clearing prices as shown in figure 5.11 when compared to the previous outcomes in figure 5.8.

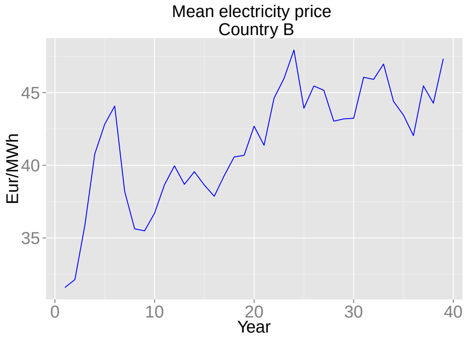
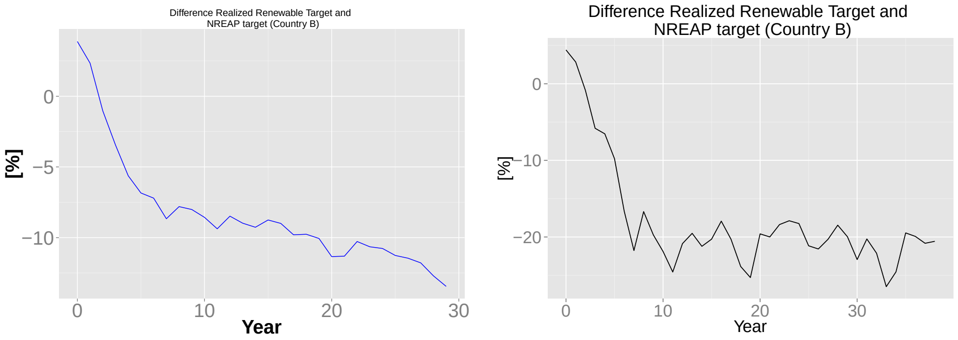


Figure 5.11: Tender clearing prices after correction

Since there are no severe shortages any more, the tender target is unmet at a constant difference instead of a changing increasing difference. This is important since an increasing unmet target implies that less investments are made over time to meet the target. In the meantime the target is growing, which gives high clearing prices the chance to occur as shown earlier in figure 5.8.



(a) Tender fulfilment previous model version (b) Tender fulfilment improved model version

Figure 5.12: Difference in fulfilment trend

The impacts of using the previous state of the model is pointed out in the next paragraphs and needs to be taken into account when analyzing the results.

Impact on tender clearing prices This artifact has an impact on the tender clearing prices since the bid price depends on the future expected electricity prices. Since two other factors, the available full load hours and the renewable energy target, also influence the tender clearing price it is not straightforward to report to what extent the up-warding electricity price trend influences the tender clearing prices.

Impact on cross-border price effects Another impact is when a high RES-E differences between countries is present. The occurrence of the high priced country will affect its neighbouring country by ’exporting’ the high prices via the interconnector. Consequently, this severe cross-border effect could on its turn also affect investment decisions in the neighbouring country.

Impact on aggregate values Table 5.2 shows the aggregate monetary base case indicators for country B of the used model versus those of the improved model version. Producer profits, producer cash, cost of outages, revenues, subsidies, loan costs and downpayment costs are deviating in the improved version.

Table 5.2: Used model output versus improved model output

Indicator in [Billions Euro]	Used model version	Improved model version
Consumer expenditures	777.9	613.8
Producer profits	14.6	-9.4
Producer cash	378.3	246.5
Cost of outages	5.3	4.89E-005
Revenues	62.8	36.3
Generation costs	64.5	49.4
Tender subsidy costs	16.4	3.7
Fixed costs O&M	10.6	8.8
Loan costs	30.1	19.0
Commodity costs	13.7	16.1
Downpayment costs	10.2	5.6

To reduce the bias in the analysis due to skewed results originating from the shortage-effect, it has been decided that the analysed period is set to 30 years instead of 40 years. This is justified because the significant impact of the shortage-effect starts taking place after 30 years. The shortage-effect has been reduced and does not significantly affect the model results anymore.

5.2. Validation

The method of validation to asses the structure of the model has been done by the existing tender theory and its recommendations for specifically for RES-E tenders. The model conceptualization has been discussed during the multiple states with the supervisors of the project. And the design of the tender model has been based on the recommendations and findings of scientists like [42] and the EU State aid guidelines as presented in the conceptualization.

5.3. Conclusion

The tender module has been verified and is reporting as working correctly. However, in combination with the rest of the model the so-called shortage-effect was discovered near the end of the project. The impacts on the results have been discussed and will be taken into account during the analysis. Changing the analysis horizon from 40 to 30 years significantly reduced the biased outcomes.

6

Experiment design

The first section of this chapter describes the scenarios that are used to investigate the research questions. Next, a sensitivity analysis is carried out, which looks into the forecasting power of the regulator for determining the tender quota. It continues by discussing the setup of the model and its initial conditions. The chapter ends with a description and justification of the indicators that interpret the results. Again, country A refers to The Netherlands, and country B refers to Germany. Country B is the large country compared to country A. Large, meaning that country B has a substantial higher demand than country A.

6.1. Experiments

Four experiments are conducted to evaluate and answer the research question. The experiments are based on the sub research questions, where the first three look into the effects of a tender, infinite interconnector capacity and technology-specificity. These three experiments are variations of a soft harmonized policy situation. The fourth experiment involves full harmonization. The four experiments are summarized in table 6.1.

Table 6.1: Experiment scenarios

Experiment	Technology specificity	Interconnector Capacity	RES- E targets
1	No	3950 MW	NREAP
2	No	9 PW	NREAP
3	Technology-specific tender (B)	3950 MW	NREAP
4	No	3950 MW	Both NL NREAP targets

6.1.1. Experiment 1 - Effect of the tender

This experiment compares a two-country situation with and without a tender. This exercise is used to get insight in the effects of a tender under harmonization. The countries share an interconnector with a transmission capacity of 3950MW and set their RES-E targets according to the individual NREAPs. Country A has relative lower targets than country B. The outcomes of the scenario with the tender is used as reference case i.e. Base Case for the other experiments.

The main effect to be expected is that RES-E shares are significant higher for both countries, the highest for country B since they have more ambitious targets than country A. Table 6.2 summarizes the scenarios. The specific RES-E targets for country A and B are obtained in table 6.8. The standard target differences between the countries are visualized in figure 6.1

Table 6.2: Scenarios for the comparison of the effects on the system with and without tender

	No tender	**Base case**
RES-E Targets	n/a	NREAP targets
Technology-specificity	n/a	No
Interconnector capacity	3950 MW	3950 MW

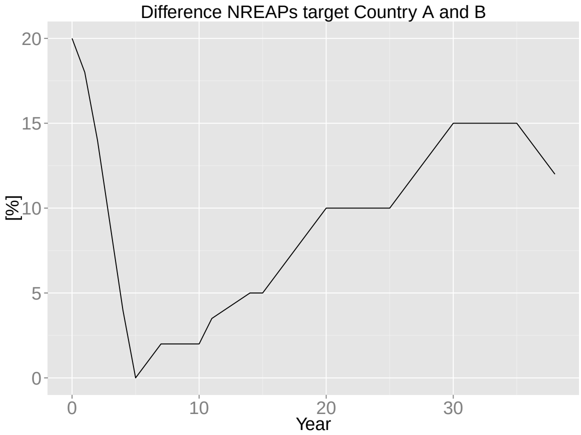


Figure 6.1: Standard Difference RES-E Target ambitions: Country B - Country A

6.1.2. Experiment 2 - Infinite Interconnector

This scenario compares the Base Case with a scenario with infinite interconnector capacity. *Infinite* is translated to the large number $9 \cdot 10^9$ MW or 9 PW. Microeconomic theory argues that there are gains from trade and that the exchange between countries is almost always mutual beneficial, but the effects of the welfare gain of a nation is ambiguous [54]. In this case the trade object is electricity, which is limited by the interconnector capacity in the Base Case, but unlimited for the scenario Infinite Interconnector.

When a price difference arises between two nodal zones, a trade incentive arises as well. For example, country A has a high price and country B a low price, then country A will start importing electricity from the neighbouring country with lower prices. This will reduce the price in country A, and increase the price in country B until the interconnector is fully used i.e. congested. Less production will take place in country A to meet demand since it is imported from country B. The reduction of the price and generation in country A implies that the producers earn less profits and that consumer expenditures lower. For country B, the price and the generation goes up and producers earn more than before while consumers will pay a higher price. If the interconnection is very large, it is expected not to be congested and prices will equalize between the two zones [49].

It is expected that with high interconnector capacity prices converge between the two countries. The MS with a high level of RES-E is expected to ’export’ the lower prices to the country with higher electricity prices. To calculate welfare effects, the congestion rents should also be taken into account but are not analysed. However, this work restricts itself to use the theory of cross-border trade to describe the price effects as cross-border effects on the welfare development of consumers and producers.

The specific expected observation is: lower average electricity prices and higher tender clearing prices for country A due to country B. In the country with relatively high RES-E targets the increase in intermittent RES-E technologies, which have close to zero marginal costs, is expected to have a downward effect on the electricity market clearing prices. These lower prices of country B are ’exported’ via the interconnector, as illustrated in one of the previous paragraphs, to country A. The lower electricity prices suppose to affect the tender clearing prices in country A, which makes it more costly for country A to subsidize RES-E.

A sub experiment is carried out to observe under the same interconnector circumstances to assess the effect of substantially increasing the difference in RES-E target ambitions between the two countries. This scenario is referred to as Infinite Interconnector PT. Where PT stands for paced target, meaning that the targets of country B are increasing with a significantly higher pace than country A. The targets are given in table 6.8, where country A uses the 'slow' target. The expected effect is an amplification of the main experiment: lower average electricity prices are observed for country A due to country B.

Table 6.3 summarizes the scenarios of this experiment.

Table 6.3: Limited and infinite interconnector scenarios for experiment 2

	Base case	**Infinite Interconnector**	**Infinite Interconnector PT**
RES-E Targets	NREAP	NREAP	Country A: Slow Country B: NREAP
Technology-specificity	No	No	No
Interconnector capacity	3950 MW	9 PW	9 PW

6.1.3. Experiment 3 - Technology-specificity

Experiment three compares the Base Case with a scenario where country B implements technology-specificity. This is scenario Tech-Spec 1, 1 indicates that only one country applies technology-specificity. It is expected that a uniform price, resulting from technology-neutral tenders, leads to more subsidy spending than with technology-specific tenders. Since each technology is cleared in a separate tender, the profits for producers are also expected to be lower. However, technology-specific tenders can result in higher generation costs since the more costly technologies are also promoted.

Figure 6.2 illustrates these expectations. In a technology-neutral tender, producers receive area *a* and *b* due to the uniform pricing: low-cost technology bids are profiting the higher-cost technology bids, whereas in a technology-specific tender, only area *b* is awarded to the producers. The difference between *a* and *b* represents the reduction in subsidy costs i.e. a lower burden for the government and/or society.

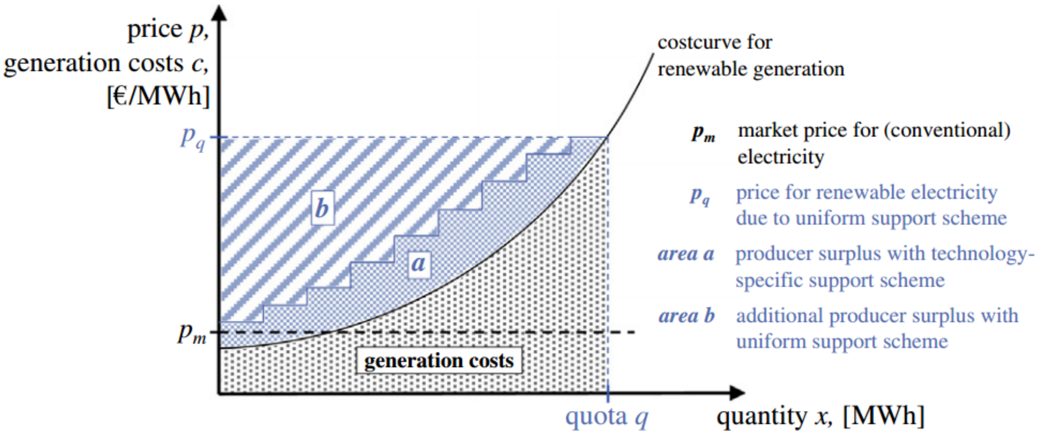


Figure 6.2: Earnings and subsidies from a technology-neutral and technology-specific tender [4]

Table 6.4 summarizes the scenarios for experiment 3 and table 6.9 gives an overview of the specific technology targets used in country B.

Table 6.4: Technology-specificity scenarios for experiment 3

	Base case	**Tech-Spec 1**
RES-E Targets	NREAP	NREAP
Technology-specificity	No	Country B
Interconnector capacity	3950 MW	3950 MW

6.1.4. Experiment 4 - Different RES-E target ambitions

The fourth experiment looks into the effects when a country has the same tender design and countries have the same RES-E targets, which approximates the case of full harmonization. The tender design is the same as in the Base Case but the targets of country A are used for both countries. This approximates the shared target that is needed to comply with full harmonization. A limitation of this experiment is that investors cannot bid in the other country.

6.2. Sensitivity analysis

A sensitivity analysis is carried out for country A and B where the future start time, announced by the regulator is varied. In the previous experiment a future start time of one is used. This means that the regulator announces the new tender quota one year in advance and clears the tender the next year. For the calculation of the tender quota, the regulator takes the expected consumption and generation from renewables into account. In the verification phase it was pointed out the generation occurring in the future time point is prone to erroneous forecasts of the regulator.

The logical consequence of overstating (understating) renewable generation is setting the quotas for the tender too low (high) than necessary. This implies that the regulator does not meet its RES-E targets derived from the NREAP, or is over fulfilling them leading to higher yearly subsidy costs than necessary.

The Base Case, experiment scenario 1 in table 6.2, is used for this analysis. It is expected that the regulator takes less generation into account when he looks further into the future since he cannot foresee which plants will be built in the years ahead and this will affect the calculation of expected generation in the market. The measure of prediction accuracy for the expected generation is calculated by formula 6.1 and an example over time is given in figure 6.3. The corresponding scenarios for this analysis are summarized in table 6.5.

$$\text{Estimation error} = \frac{\text{Actual renewable generation - Expected renewable generation}}{\text{Actual renewable generation}} \tag{6.1}$$

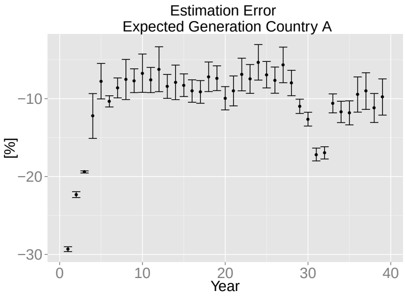


Figure 6.3: Deviation from expected generation 1 year ahead - Country A

Table 6.5: Sensitivity analysis on future operating start time of the tender

Sensitivity scenario	Future operating start time tender
1	1 year ahead
2	2 years ahead
3	3 years ahead
4	4 years ahead
5	5 years ahead

6.3. Experiment setup

This section presents the experimental setup that is used for the aforementioned experiments and sensitivity analysis. It entails the data input, initial conditions and trends used in the simulation.

Model runs Each scenario is run 120 times. 120 runs provide a statistical valid number of observations [29] and this is within reasonable computation time. Multiple scenario runs are necessary since one single run could be merely an outlier due to the randomness in the model, which originates from:

- Stochastic demand growth and fuel price trends;
- Randomized iteration of agent to account for the first-mover advantage
- Random age of initial power plants via a uniform distribution which is taken from the interval zero to the technical lifetime.
- Random ownership of the power plants

Agent characteristics The energy producers in the scenarios are homogeneous, implying that they have the same characteristics. In country A and B the investors look seven years ahead for considering investments and look back five years for the forecasting purposes. All producers have the same equity and loan interest rate of respectively 12% and 9%, the debt ratio for investments is fixed to 7% and the cash that is available for downpayments is set to 50% of the current cash balance of each investor per year. The only difference is that investors of country A start with a cash level of 3 billion Euros, and in country B with 80 Billion Euros since the market and demand is larger in country B, which means they have more power plants to maintain or invest in.

Trends in demand and fuel prices 120 different random trends in demand and fuel prices were created and used as a fixed random seed [29]. This results in 120 different trends used for each scenario. An example of the 120 different paths of demand is depicted in the following two figures.

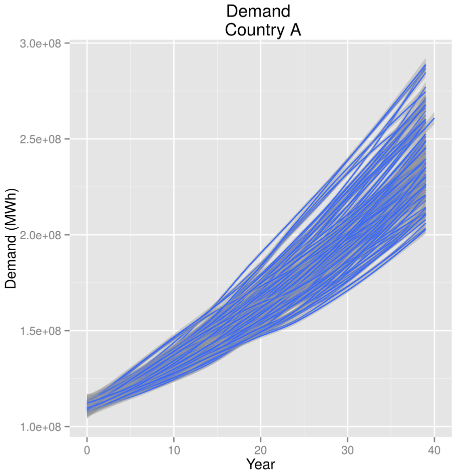


Figure 6.4: Country A

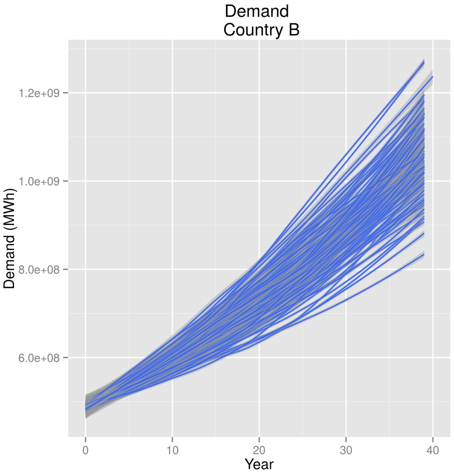


Figure 6.5: Country B

The initial demand values are taken ENTSO-E data of the year 2010 for both countries. Hourly demand values are used as pointed out in the appendix B. The demand growth is 1.5%, which is based on a mean reverting probability distribution. The value of lost load is set to 2000 Euro per MWh, taken from literature [52],[55],[56],[57],[58],[59]. Fuel prices for gas and coal [60] and biomass [61] are based on future price scenarios.

Nodes To take heterogeneity over RES-E output in a region into account, the three nodes per country are used. Data for full load hours and capacity limits are based on the mid-term potentials of the work of the beyond2020 group via the green-X toolbox [51]. The different full load hours for the three intermittent RES-E technologies per country are presented in table 6.6 and the capacity node limits are shown in table 6.7. Recall chapter 3 for a demonstration of deriving the full load hours and capacity limits. Note that although full load hours for photovoltaics in node 1 of country A (The Netherlands) is quite high, the node capacity limit is relative low. In table 6.6 the weighted average of the full load hours with the corresponding capacity node limit is shown.

Table 6.6: Full load hours per year per country

	Country A				Country B			
Technology	**node 1**	**node 2**	**node 3**	**average**	**node 1**	**node 2**	**node 3**	**average**
Photovoltaics	1641.9	1064.4	673.6	981.0	1904.9	1369.7	864.3	1865.6
Wind Onshore	2662.3	2035.4	1549.7	2219.9	2568.4	2383.4	1922.2	1476.1
Wind Offshore	3053.2	2505.8	2237.5	2594.6	2887.9	2600.1	2294.4	3083.8

Table 6.7: Node limits in MW

	Country A			Country B		
Technology	**node 1**	**node 2**	**node 3**	**node 1**	**node 2**	**node 3**
Photovoltaics	375.7	8072.0	2996.8	2538.0	26864.3	9987.4
Wind Onshore	1494.9	1948.0	450.6	15228.5	4557.8	6184.6
Wind Offshore	2925.9	7151.0	1979.3	6912.7	10465.9	12906.7
Biomass	7006.3	0	0	9272.7	0	0
Biogas	721.7	0	0	1842.9	0	0

Renewable targets Directive 2009/28/EC defines the contribution of each member state to reach the RES-E targets relative to primary energy consumption [43]. The EU aims at a greenhouse gas emission (GHG) reduction of 20% in 2020 [7] and 80% in 2050 [8]. This is translated into national renewable action plans, which are Member State specific plans that describe how to achieve the targets [44]. In the Netherlands, for 2020, the expected share renewables in the electricity sector is 37.0% in relation to gross electricity production. There is no mention of targets towards 2050. So to arrive at targets for the Netherlands, it is assumed that Germany's 'Energiewende' [62] is more ambitious and thus willing to set relatively higher targets than the Netherlands. Table 6.8 summarizes the targets. Since the tender has a yearly quota, the yearly RES-E targets are interpolated. The row 'Country A slow' will be used in the second experiment (Infinite Interconnector PT) where country A has low RES-E ambitions. Figures 6.6 and 6.7 show the complete path of country A and B with RES-E targets accordingly to the NREAP.

Table 6.8: NREAP targets The Netherlands and Germany

RES-E target factor	2016	2020	2030	2040	2050	2055
Country A [%]	13	37	45	55	60	70
Country B [%]	31	35	50	65	80	80
Country A slow [%]	10.5	13	17.5	22	28	30

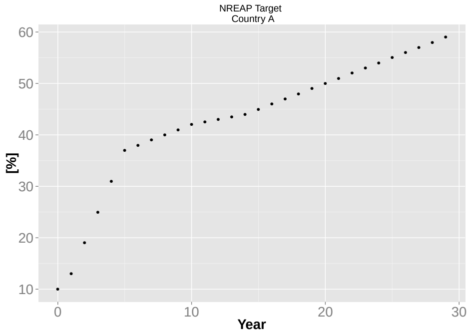


Figure 6.6: RES-E target factor path - Country A

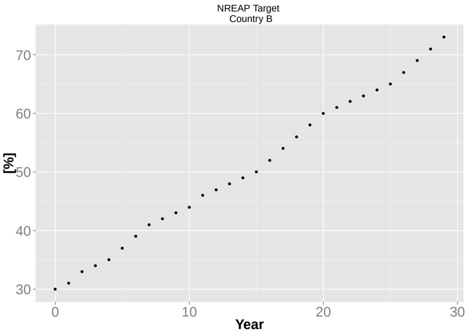


Figure 6.7: RES-E target factor path - Country B

Country B has the following technology-specific targets in figure 6.9, which are based on the relative energy potential of each technology. The full range of targets is obtained via github: `https://`

`github.com/rjjdejeu/emlab-generation/blob/feature/TenderRob10/emlab-generation/src/main/resources/data/policyGoalNREAP_NL_DE_2050.csv`

Table 6.9: Snapshot of technology-specific targets - Country B

		Country B				
realtime	**tick**	**Wind**	**Wind Offshore**	**PV**	**Biomass**	**Biogas**
2015	0	7.0%	10.0%	6.3%	5.7%	1.1%
2020	5	8.6%	12.3%	7.8%	7.0%	1.3%
2025	10	10.2%	14.6%	9.3%	8.3%	1.6%
2030	15	11.6%	16.6%	10.6%	9.4%	1.8%
2035	20	14.0%	19.9%	12.7%	11.3%	2.1%
2040	25	15.1%	21.6%	13.7%	12.3%	2.3%
2045	30	17.5%	24.9%	15.8%	14.2%	2.7%
2050	35	18.6%	26.5%	16.9%	15.1%	2.8%
2053	38	18.6%	26.5%	16.9%	15.1%	2.8%

Initial capacity mix The capacity fraction of power plant technologies are needed as initial input for he simulation. The current capacity mix of The Netherlands and Germany are used within the simulation. Data of [63] is interpolated for 2015, which is the starting year of the simulation. Table 6.10 and 6.11 presents the initial mixes.

Table 6.10: Initial capacity portfolios The Netherlands

Technology	Fraction
Coal PSC	24%
CCGT	42.5%
OCGT	17.2%
Biomass	1.6%
Nuclear	1.9%
Wind onshore	8.4%
Wind offshore	11%
Photovoltaics	3.3%
Biogas	0%

Table 6.11: Initial capacity portfolios Germany

Technology	Fraction
Coal PSC	15.4%
Lignite	12.2%
CCGT	9.1%
OCGT	7.2%
Biomass	5.2%
Nuclear	6.4%
Wind onshore	21.1%
Wind offshore	12%
Photovoltaics	22.2%
Biogas	0%

Other simulation parameters In the simulation country A has four energy producers and country B five. Since the countries are loosely based on the The Netherlands and Germany, it is assumed that the market in Germany is larger than the Netherlands with slightly more big energy companies. The CO2 module and long term contracts option will not be used. This means that there is not CO2 market or carbon tax in the model, which might have altered the results to a certain extent since conventional power plants are more profitable without carbon policy.

6.4. Indicators

The purpose of key performance indicators is to give insight in the effects on costs, welfare, the performance of the electricity market and the tender. If possible, the indicators are presented on the country specific and overall level. The latter is the summed result of the two countries. The electricity market and tender performance is related to the aforementioned goals of EU energy policy: affordability and competitively priced energy, environmentally sustainable energy, and secure energy for everybody [13], which translates into analysing electricity market prices, renewable energy shares and generation adequacy i.e. supply ratios.

The outcomes of the indicators tells how 'good' a certain configuration of harmonization is. Descriptive statistics is employed to analyse the data. It is important to note that although they are quantitative results, mainly qualitative statements are derived. The *main* indicators are presented in the following paragraphs. Monetary indicators are in the order of billion Euros:

Producer welfare Producer welfare is presented as the profits of the producer. Since the problems with negative profits explained in the verification chapter in paragraph 5.1 are a severe problem of the model to derive a valid statement in terms of producer welfare. In practice negative profits deter producers from entering the market. So we will look at the relative change in producer profits, at the profits that are the least negative.

Producer cash Producer cash is basically the cash balance of the investors. Cash balances need to be sufficient for producers to make payments and do transactions. Therefore the cash balances are measured to indicate the financial health of a producer. High cash balances implies that money is being accumulated and indicates economic inefficiencies. The opposite is true for very low cash balances: producers do not have sufficient cash to make new investments. However, it is ambiguous what high or low cash balances are. Therefore the change in cash balances is used to compare scenarios.

Consumer welfare Consumer welfare is measured in the change of consumers expenditures in the electricity spot market between scenarios. Standard economic analysis measure consumer welfare by calculating the differences in willingness to pay and the actual price paid. The computation of the willingness to pay is hard to measure in the model and therefore the welfare of consumers is approximated by the change in expenditures of consumers. A positive change in consumer expenditures represents a decrease in consumer welfare since they pay more for electricity and vice versa.

Cost of outages This represents the costs of outages, created due to shortages in the market. It calculated as:

$$\text{Cost of outages} = (\text{Total demand - Energy Served}) \cdot \text{VOLL} \tag{6.2}$$

Generations costs The generation costs per country are calculated by taking the sum of all costs incurred by producers, which entails their fixed O& M, loan, commodity and downpayment costs. Fixed O& M costs comprises of the yearly costs that need to be paid to keep the power plant running e.g. paying employees. The loan costs are the yearly annuities to pay of the debt that has been taken to invest in a power plant. The commodity costs are paid for the fuel intake of power plants like coal, biomass, uranium or natural gas. The downpayments are the payments that needs to be done immediately at the investment of a power plant, which is a part of the total amount serving as initial upfront and are evenly distributed over the construction time of the power plant. The rest of the power plant is financed by debt, hence the loans.

Tender subsidy costs The spent tender subsidies are used in the analysis to observe how much a government spend on renewable subsidies.

Electricity market performance The median 'weighted average electricity spot market price', is calculated by taken the weighted average over each of the 20 segments of the load duration curve. Consequently, the median value is taken from the 120 model runs.

The volatility of the electricity price is measured by taken the standard deviation of the average electricity spot market price. It is important to have low volatilities because this means stable prices and thus the forecasting is less uncertain i.e. reduced risk.

A proxy for the market integration is given by the difference in the average electricity prices of the two countries. The closer the difference is to zero, the better the markets are integrated. A high interconnector capacity can establish zero price difference between the two countries.

Supply ratio To observe shortages, or over capacities, the supply ratio is used. This is defined as the installed available operational capacity (MW) per zone over peak demand (MW) per zone. A value of supply ratio lower than 1 indicates capacity shortages. If the ratio is higher than 2, it indicates that there is relative more capacity in the market than actual needed:

$$\text{Supply ratio} = \frac{\text{Available operational capacity}}{\text{Peak Demand}} \tag{6.3}$$

Other sub-indicators are used to aid the analysis:

Tender performance: target fulfilment The goal of the tender policy is to stimulate renewable energy sources. This indicator has the objective to compare actual renewable generation of a technology, with the pre-defined RES-E targets. The actual RES-E production is calculated by the ratio of renewable electricity generation over total generation:

$$\text{Fraction technology} = \frac{\text{technology generation in MWh}}{\text{National generation in MWh}} \tag{6.4}$$

The sum of each technology share is the total generation share occurring in a certain year. Subsequently, the RES-E targets are subtracted from the actual production renewable production:

$$\text{Realized RES-E target} = \text{Total renewable generation share} - \text{predetermined RES-E target} \tag{6.5}$$

Ideally, this difference should be zero meaning that RES-E targets are perfectly met. A negative percentage indicates that the renewable target is not met for the current year, and a positive percentage shows that more generation originates from renewables than is required by the regulator. An example is given in figures 6.8 and 6.9.

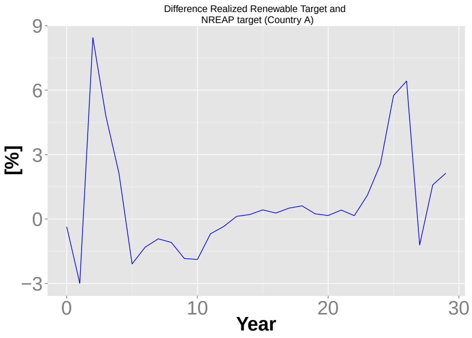


Figure 6.8: Example RES-E target realized - Country A

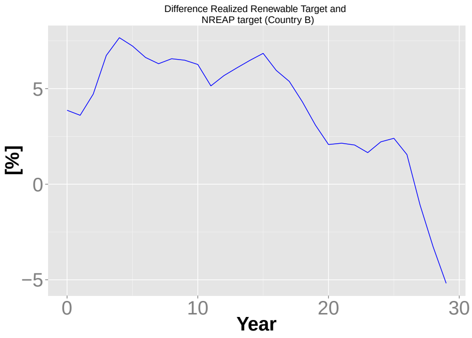


Figure 6.9: Example RES-E target realized - Country B

Tender performance: clearing prices The tender clearing prices reflects the extra price that is needed on top of the weighted average electricity price to make a profitable investment in renewable energy technologies. A high tender clearing price indicates that the returns from the electricity price are insufficient to cover the cost and vice versa.

Generation and capacity shares This work presents generation and capacity in fractions in stacked graphs, which gives a direct insight in the relative contributions of technologies that are installed or those that are generating and thus in the merit order. The shares for generation are calculated as follows:

$$\text{Fraction technology} = \frac{\text{technology generation in MWh}}{\text{National generation in MWh}} \tag{6.6}$$

The capacity shares are are obtained as following:

$$\text{Fraction technology} = \frac{\text{technology capacity in MW}}{\text{Total operational capacity MW}} \tag{6.7}$$

Skewness Descriptive statistic is used to describe the development of the indicators. The mean or median of the 120 runs for each tick calculated, depending on the skewness of the data. The calculation of the mean is a valid method to calculate the average of a dataset, however the mean could be influenced by outliers, which skews the data. An alternative is the median, which gives the middle value based on an ascending sorted data set. In this cases outliers will not affect the median in the same way as it affects the mean. Although the aforementioned shortage-effect [5.1] has been reduced by setting the analysis to 30 years, it still could have an influence on the indicators. The indicators are being tested for skewness in a rather simplistic fashion.

In appendix G the mean and median of the indicators over time are given. When the two graphs are out of sync, it means that the data is skewed and the median should be used. This is a simplification of testing whether the mean follows a normal distribution or not. Normality tests should be employed for higher precision tests, but for the purpose of this research it is sufficient to conclude that median values of some of the indicators should be used in the analysis.

The median is used for the welfare and costs indicators (except for the cost of outages), and the electricity prices. The mean is used for indicators that involve generation variables since the calculation of median capacity or generation share gave total shares that did not add up to one, which is incorrect. So the other variables that involve generation as well like expected generation and target fulfilment are averaged. The cost of outages are truncated to zero by using the median while there are still outages occurring, so the mean is used instead. Also the tender clearing prices will use the mean since it truncated some of the technology-specific clearing prices to zero while there were clearing prices present.

6.5. Conclusion

Three experiments have been presented that look into the effects of the tender, interconnector capacity, technology specificity under soft harmonization and a one experiment that investigates full harmonization. A sensitivity analysis will look at different future starting times of the tender, which serves as purpose to determine the forecasting power of the regulator in terms of expected generation, which can affect the actual RES-E target set.

The experimental setup entailed an extensive overview of the justification of multiple model runs, the input data and the initial capacity mix.

The chapter ended by discussing the main indicators (welfare, costs and electricity market performance) and the sub indicators (tender performance and generation shares). The next chapter executes this experimental design.

7

Results and Discussion

The outcome of the experiments under the four different scenarios are conducted to asses the research questions. The sensitivity analysis experiments are carried out after that. Each experiment consist of three main parts: the observations under the different indicators, the interpretation of the observed phenomena and a conclusion about the experiment. One might also observe graphical design differences since most of the graphs and data are processed in R and a part of it in Excel. Note that the consumer welfare change in the Base Case is relative to the No Tender scenario. The consumer welfare change in the other scenarios are measured relative to the Base Case. The experiments are based on the sub research questions. Experiment 1 looks into the effects of a tender, the second one into infinite interconnector capacity, the third in and technology-specificity. The fourth experiment involves full harmonization. The fifth experiment is the sensitivity analysis. The chapter will continue with a discussion of best policy configuration to implement from an EU and Member State perspective. At the end a short validation is carried out. Recall that country A refers to The Netherlands, and country B to Germany.

7.1. Experiment 1

This experiment compares a two-country situation with and without a tender. The countries share an interconnection of 3950MW and uses their NREAP target in the tender scenario.

7.1.1. Observations

Welfare effects

- On the overall level and for both countries, producer welfare, measured in profits, decreases [7.1]
- An overall increase of consumer welfare is measured, which is stronger in country A (6.45%) than in country B (4.40%) [7.2]
- Producer cash changes by -22% for country B and -4% for country A [7.3]

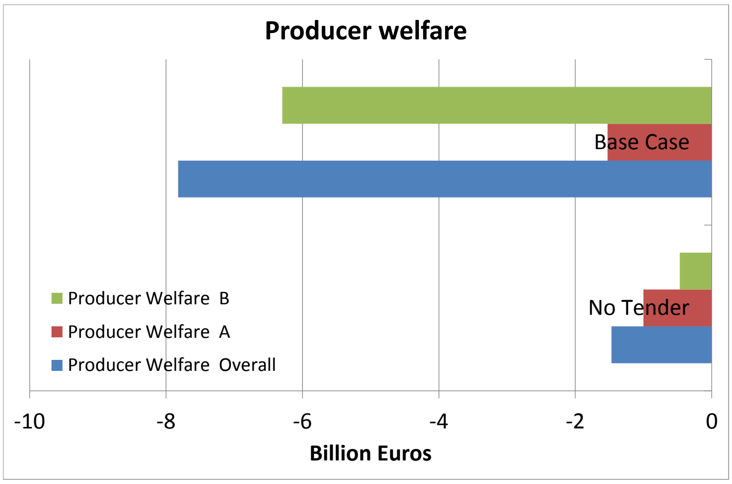


Figure 7.1: Producer profits

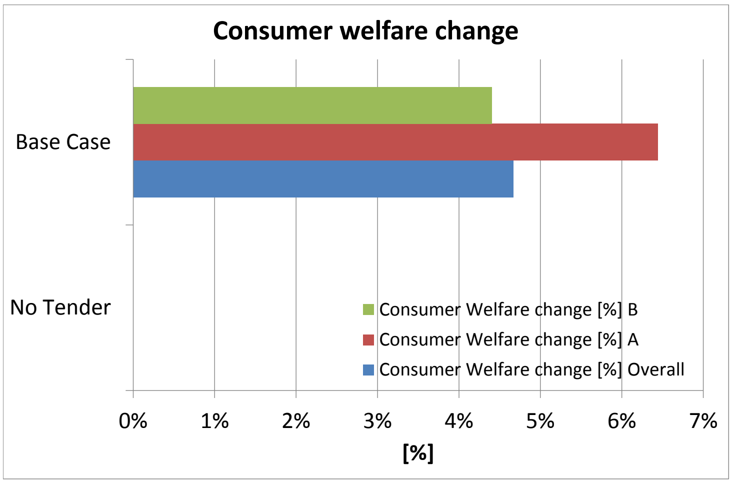


Figure 7.2: Consumer welfare change

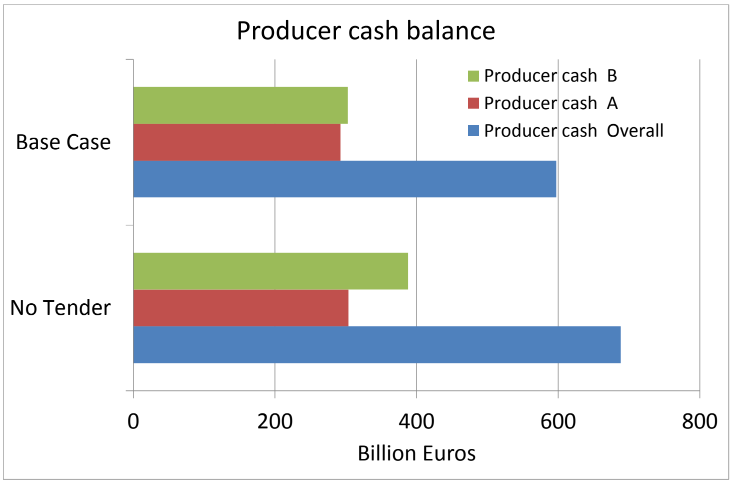


Figure 7.3: Producer cash

Costs

- Generations costs increase on the aggregate level mostly due to the impact of country B by 36% whereas country A contributes by a change of 14% [7.4]
- The change generation costs results for both countries from an increase in loan (i.e. annuities) and downpayment costs, which is partially offset by the decrease in commodity costs [H.4]
- With the tender implemented, the median yearly subsidy costs for country A and B are 0.5 and 3.5 billions euros [7.5]. In figure 7.6 the full development over time is given for the subsidies, and it is observed that the yearly amounts are increasing over time
- Outages were non-existent before the implementation of the tender, but now country B faces outages costs around one billion Euros [7.7]

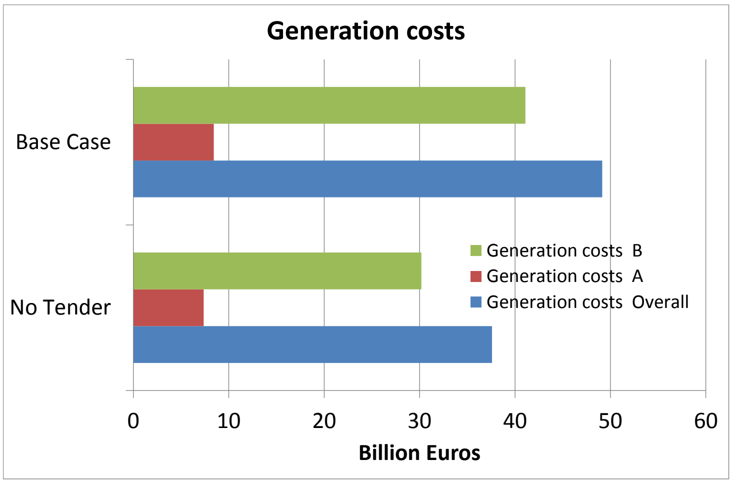


Figure 7.4: Generation costs

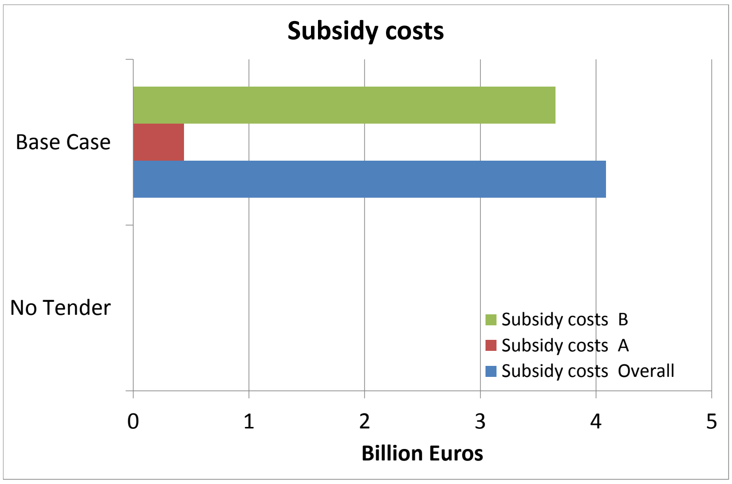
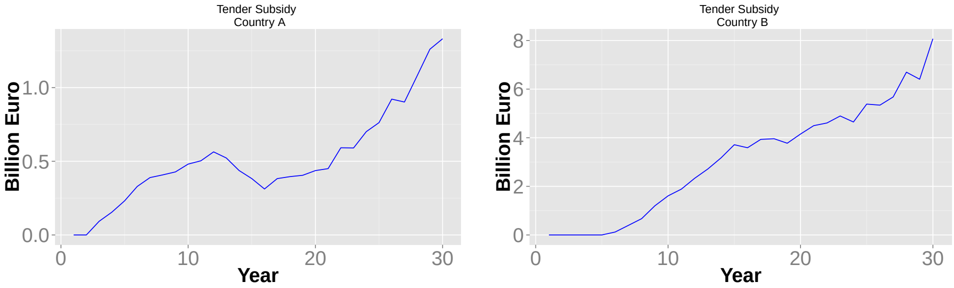


Figure 7.5: Subsidy costs



(a) Country A

(b) Country B

Figure 7.6: Tender subsidy costs development

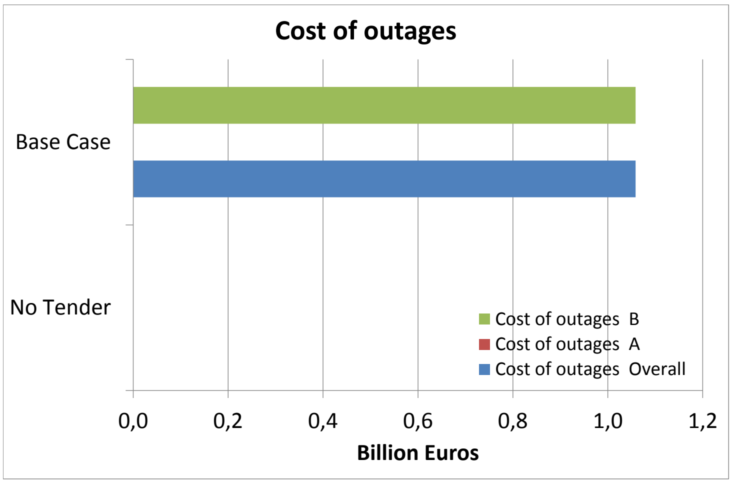
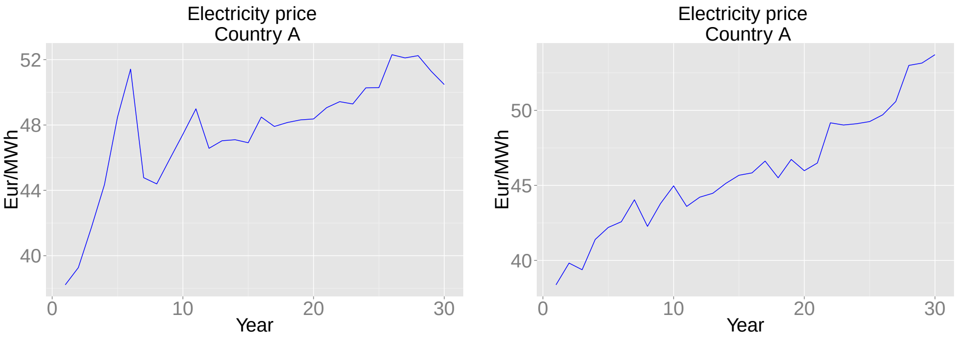


Figure 7.7: Cost of outages

Electricity market performance

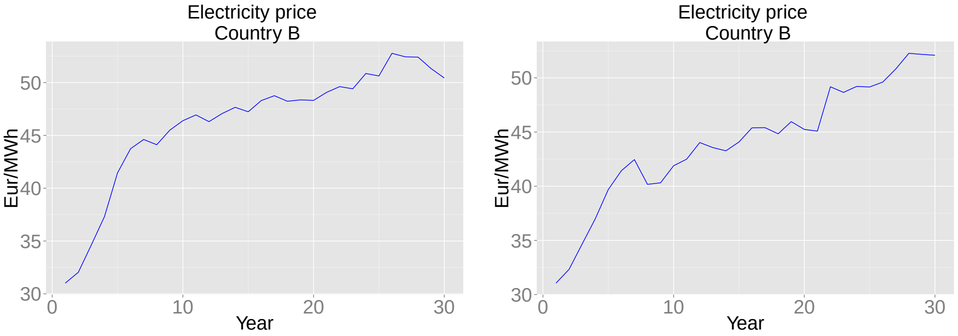
- For both scenarios the median weighted averaged electricity prices increases over time [7.8, 7.9]
- Once a renewable tender is introduced, the electricity prices falls around for both countries around 3 Euro per MWh [H.3]
- The volatility increases by 13.80% for country A and reduces by 2.71% for country B [H.3]
- There is less convergence of the electricity price between the two countries when a tender is implemented [H.1]
- Supply ratios for both countries reach 1.10 compared to 1.20 in the scenario without tender [H.3] but the volatility is higher in the tender scenario [H.2 H.3].



(a) Without Tender

(b) Base case

Figure 7.8: Median weighted average electricity prices - Country A



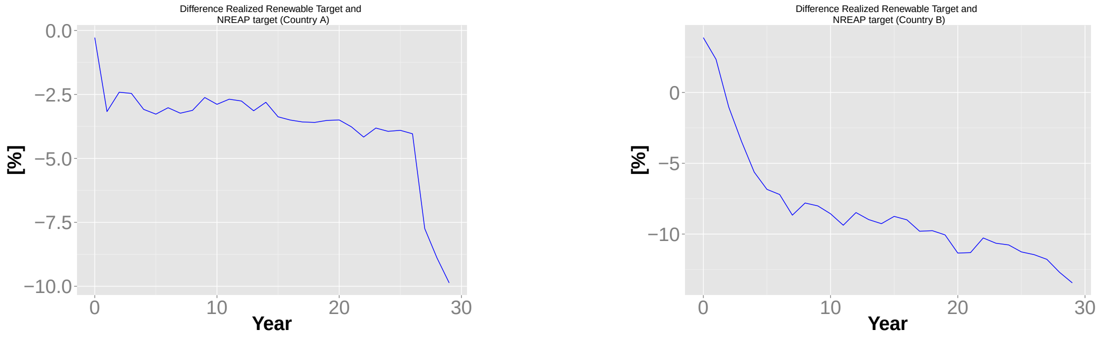
(a) Without Tender

(b) Base case

Figure 7.9: Median weighted average electricity prices - Country B

Tender performance: tender target fulfilment In figure 7.10 the fulfilment of RES-E targets is presented. Negative percentages means that targets are not met, while a positive value means that the targets are met and that more generation from renewables occur than is required by the regulator.

- In country A the targets are not met by 2.5-3.0% in the first 25 years, after that the fulfilment is suddenly more negative and reaches -10.0%
- For country B the targets are mostly not met over time, stable around -7.5 to -10% and gradually declines to -12.5%



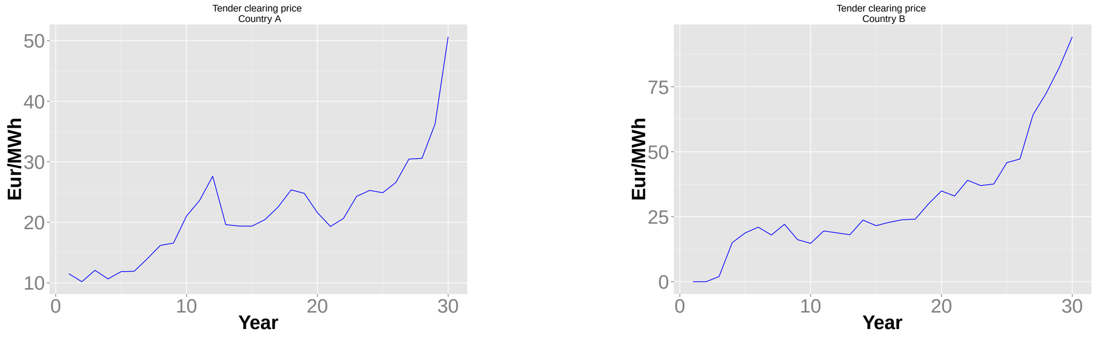
(a) Country A

(b) Country B

Figure 7.10: Tender target fulfilment - Base Case

Tender performance: tender clearing prices

- Tender clearing prices are increasing over time, and after 25 years the increase of clearing prices starts to develop faster [7.11]



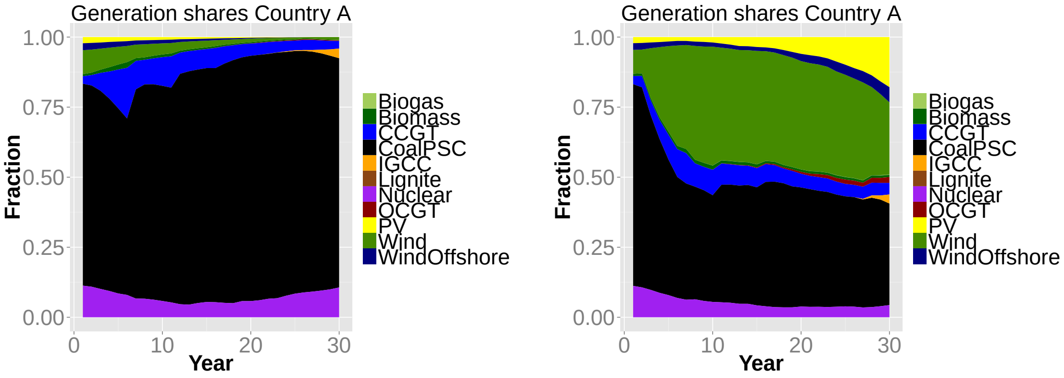
(a) Country A

(b) Country B

Figure 7.11: Tender clearing prices - Base Case

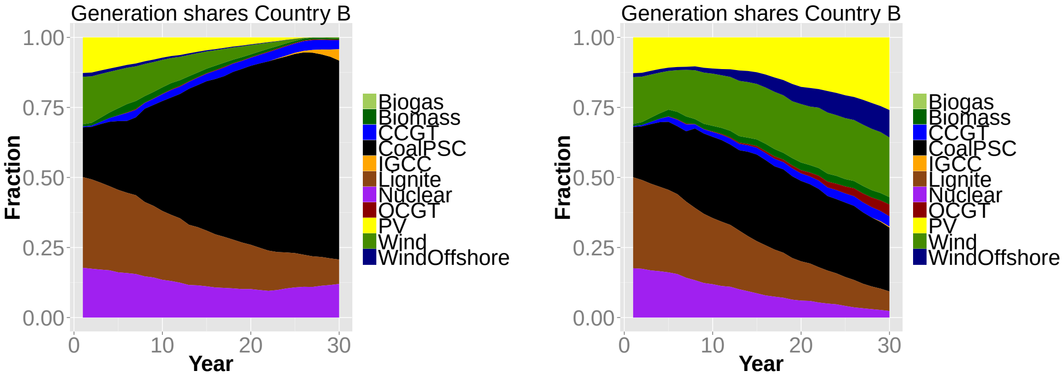
Generation and capacity shares Figures 7.12 and 7.13 show the generation mixes, and figures 7.14 and 7.15 present the relative installed capacity in the market with and without tender.

- In country A the tender creates a transition of generation from mainly coal to mainly wind onshore and photovoltaic [7.12]
- The installed capacity shares of photovoltaic and wind is large compared to its generation shares, while e.g. coal has a low ratio of capacity to generation shares
- A shift to mainly wind onshore and photovoltaic technologies in the merit order is observed for country B
- More generation of OCGT and CCGT is occuring with the tender than without in country B
- The shares of biomass and biogas are very low compared to the intermittent RES-E sources for both countries.



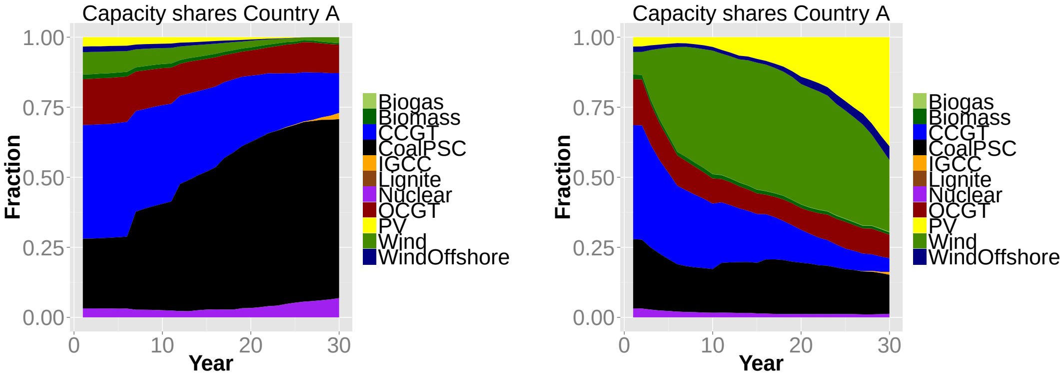
(a) Without Tender (b) Base Case

Figure 7.12: Generation shares - Country A



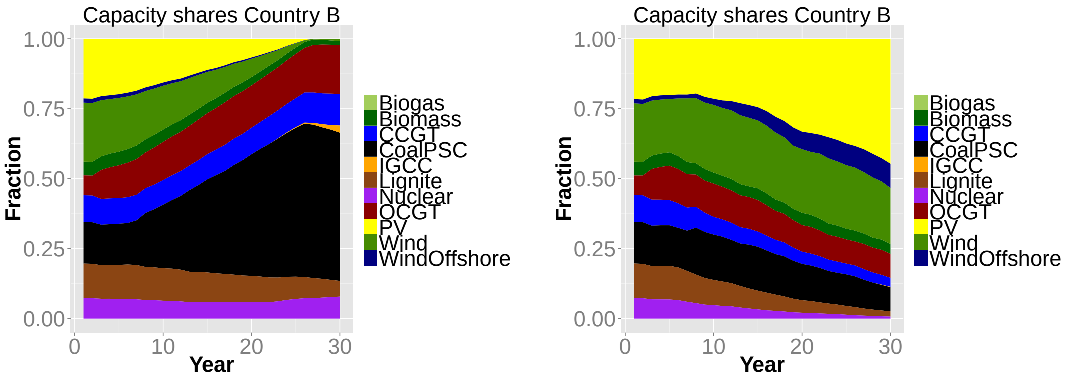
(a) Without Tender (b) Base Case

Figure 7.13: Generation shares - Country B



(a) Base Case No Tender (b) Base Case

Figure 7.14: Capacity shares - Country A



(a) Base Case No Tender (b) Base Case

Figure 7.15: Capacity shares - Country B

7.1.2. Interpretation

The introduction of the tender gives rise to lower consumer expenditures i.e. higher consumer welfare and lower producer welfare in both countries. This is related to the lower electricity price since consumers pay less and producers thus face an increase in their earnings. However, the introduction of subsidy costs offsets the gain in welfare, which is corrobated by [64]. Also the larger penetration of RES-E observed in country B accounts for higher subsidy costs. This is also mentioned by [24], who states that in the case of a tendering scheme the costs for society depends on the actual national RES-E capacity and whether a high total electricity generation from RES-E occurs.

It is expected that with high shares of RES-E the electricity price decreases over time due to zero marginal costs of intermittent RES-E. The cost of outages in country B reveal that high RES-E creates shortages as explained in subsection 5.1 referred to as the infamous shortage-effect. This effect is more severe after 30 years and becomes dominant, which spurs the results. Therefore, only the first 30 years are considered, compared to the initial 40 years.

The decrease in producer cash for country B indicates lower economic efficiency since the cash balances are affected negatively by the tender. Once can expect an increase in cash due to the received tender subsidies, but this is partially offset by the increase in payments for loan and downpayment for the new RES-E plant investment. The effect is lower in country A because of lower RES-E target ambitions and thus less (new) loans and downpayments. This interpretation is corroborated by the total increase in generation cost, which is increases from 31% while for country A the cost increase is 14%.

The observed increasing electricity price in country A is accompanied by a higher relative change in volatility of 14% if the tender is introduced, whereas the volatility decreases by 2.7% in country B. However, country B already had a reasonable share of RES-E initially, and after introducing the tender, the generation and capacity shares are gradually increased, while for country A a sudden boom of RES-E investments takes place, which distorts price stability more and therefore the relative increase in volatility is higher for country A. However, when one observes the absolute values of volatility in the presence of a tender, country B still has a larger value of 5.6 Eur/MWh compared to 4.0 Eur/MWh of country A. This is expected since a higher volatility is related to higher shares of intermittent RES-E due to merit-order effect. The increased volatility is observed for Germany practice as showed by [65]

The increase of renewables is attributed to the regulator who sets RES-E targets and tenders renewable technologies. In despite of the large stimulation of RES-E, the targets are not accomplished in each year for both countries. Since the negative deviation is constant for a great time of the simulation, it means that the regulator keeps on track towards it final goals. Nonetheless, target fulfilment faces a sudden decline in country A after 25 years, which is explained by the dismantling of wind onshore power plants that became operational around the beginning of the simulation with a lifetime of 25 years. This is visible in the declining share of the generation and capacity share plots. In the meantime, the regulators demand for RES-E keeps increasing and target fulfilments falls. Investors are not able to bid for the difference in missing RES-E plants since they are constraint by their cashflow. For country B the downward trend after 20 years is less sudden. Since the country already started with a relative high initial share of RES-E plants, these power plants are more gradually dismantled while new RES-E plants enters the system gradually over time.

The increasing demand of the regulator in the later years for RES-E generation is reflected by the tender clearing prices: it starts to increase more rapidly around year 20 for both countries. Moreover, the bids for intermittent RES-E in the nodes with high full load hours become unavailable when more investment takes places i.e. the capacity node limits are reached. Investors will consider the nodes with less expected generation and thus bid for higher prices. However, the latter effect is partially offset by the dismantling of RES-E power plants in the nodes with high full load hours and lower cost nodes becomes available again. In addition, the learning curves of the RES-E technologies decline over time, which implicates that the more expensive nodes are becoming better accessible since the reduction in investment costs can be offset with a lower return from nodes with less generation. In literature, it is stated that this latter effect is essential to achieve the full potential for RES-E technologies and thus be able to obtain higher shares of RES-E [24].

Finally, the contribution of achieving RES-E targets by biomass and biogas are relatively low since they do not participate in the tender, which is briefly explained in the next sub paragraph. The authors of [64] state that technologies should be stimulated at the same time, instead of basing it on lowest generation costs. In the long run targets are achieved quicker when more technologies are mature

Tender-participation-effect The low generation of biomass and biogas is due to their low participation in the tender and originates from step 5 of the *Computation and submitting of tender bids*-role in the *The formal model* chapter in paragraph 4.1.2. In this step only plants of tender bids that have an expected electricity price per segment larger than the marginal costs are processed in calculating their expected gross profit. The marginal costs of intermittent RES-E sources are zero in the model and thus always first in the merit order. Hence, intermittent sources definitely calculate their expected profit, which is needed to arrive at a competitive *bid price*.

Non-intermittent sources like biomass and biogas may not have marginal costs lower than the electricity price and when they do not fulfil this statement, they will not be in the expected merit order. This logic is directly taken from the original investment algorithm. Since a plant that is not in the merit order has basically no running hours, and thus no expected generation, and thus no information to calculate its expected *expected gross profit*, which is needed to determine a competitive *bid price*. This results in a high bid price and bids from biomass and biogas will be beaten by bids from technologies with lower bid prices. Hence, the results is a low tender participation of the non-intermittent RES-E sources.

However, one can argue that the biomass (or biogas) producer could make an expectation about the subsidy he needs to run certain hours based on merit-order forecasts *if* he will be in the end in the merit order. The forecast is thus prone uncertainty, and subsidies might be given to a plant that does not produce (sufficient) amounts of energy during the support scheme duration. This makes subsidies highly ineffective and costly for this type of renewable generators. Therefore, it was assumed that the regulator will only allow plants to participate in the tender that are expected to have marginal cost lower, or at least equal to expected electricity prices. When this effect with biomass and biogas occurs again, it will be referred to as the tender-participation-effect.

7.1.3. Conclusion experiment 1

This experiment mainly served as introduction to the effects of a renewable tender and to verify the working of the model. Is was found that the stimulation of RES-E by a tender leads to lower electricity prices, which creates higher welfare for consumers, and lower welfare for producers, but exhibit higher volatility. However, the improvement in consumer welfare is offset by subsidy costs, which are transferred to society.

A further fall of the declining trend in electricity prices is offset by increasing shortages over time that results in scarcity prices i.e. the shortage-effect. Furthermore, a rapid development of RES-E creates high generation costs. Next to the objective of de-carbonisation, it is important for the regulator to gradually stimulate RES-E such that no sudden declines of generation occurs, which impedes RES-E targets, creates higher clearing prices and transfers a higher cost to society than needed.

7.2. Experiment 2A

The second experiment looks into the comparison of the Base Case with a scenario where infinite interconnector capacity is present, this scenario is referred to as Infinite Interconnector. An additional experiment 2B, name Infinite Interconnector PT (Paced Target) looks into the effects of infinite interconnector capacity while having large differences in RES-E target ambitions. The results are interpreted separately, but a joint conclusion is given.

7.2.1. Observations 2A

Welfare effects

- Country A and B are facing a reduction in producer welfare of 6% and 7.4% respectively [7.16]
- The consumer welfare is strongly increased in country A (9.46%) while it decreases in country B by 1.36% [7.17]
- Producer cash increases slightly [7.18].

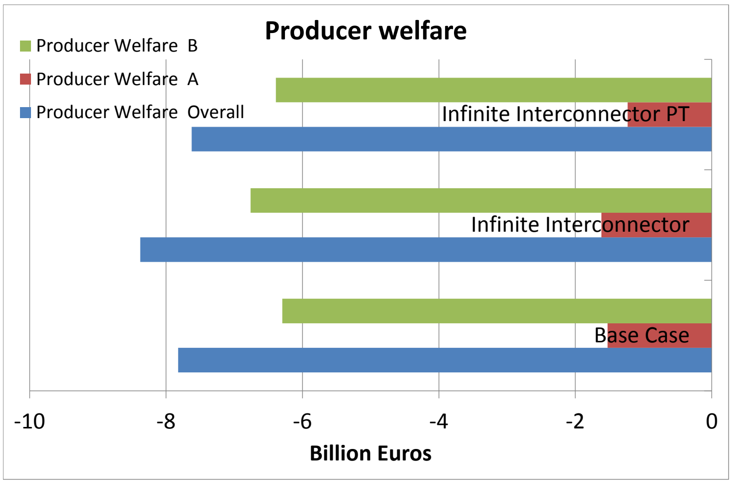


Figure 7.16: Producer profits

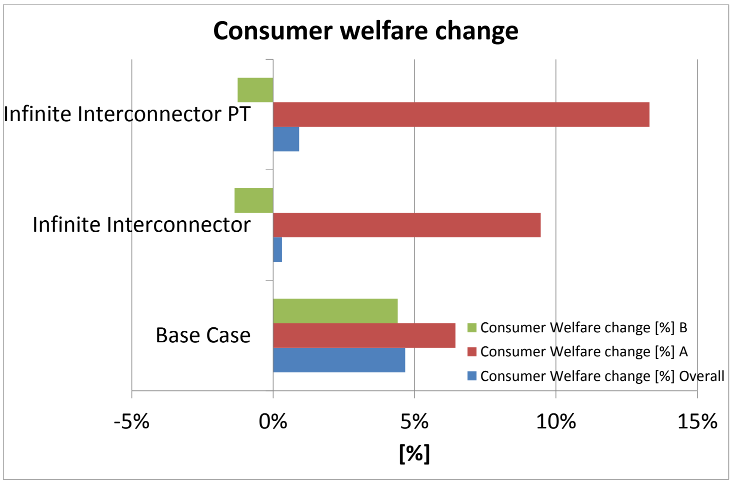


Figure 7.17: Consumer welfare change

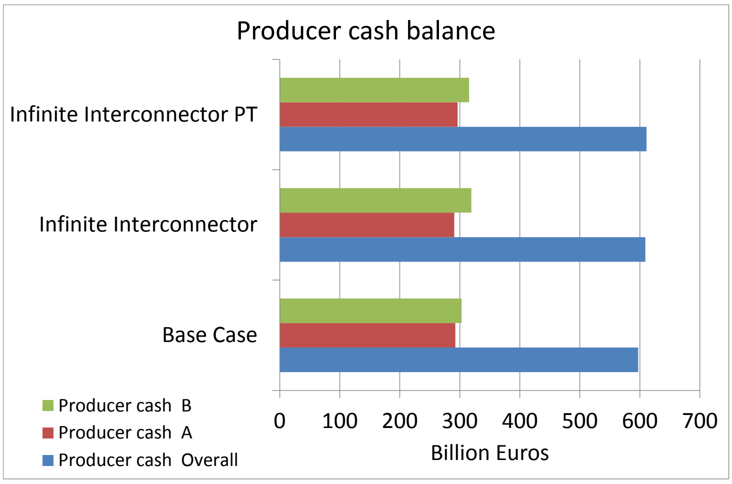


Figure 7.18: Producer cash

Costs

- The level of generations costs have not changed significantly [7.19] and looking at the break down of costs, there has been no change in the relative contribution of each cost type [H.4]
- A change in the subsidy costs are observed: +5.1% in country A and -4.4% in country B, relative to limited interconnection [7.20]
- Outages cost have been reduced for country B to a level of 0.1 compared to the initial 1.0 billion Euros [7.21]

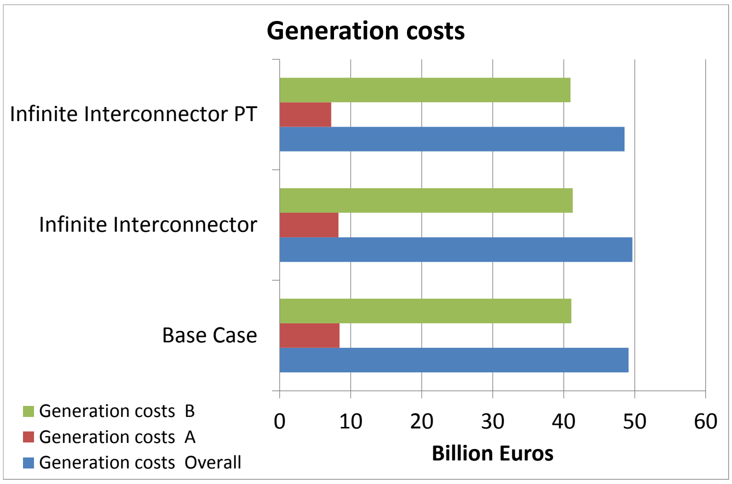


Figure 7.19: Generation costs

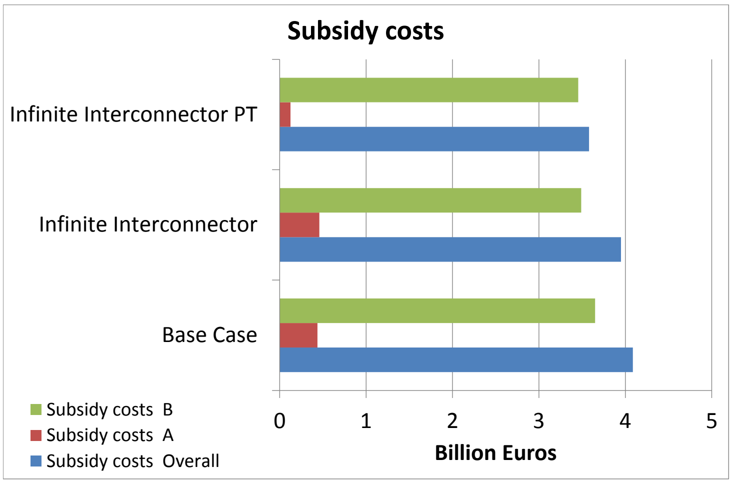


Figure 7.20: Subsidy costs

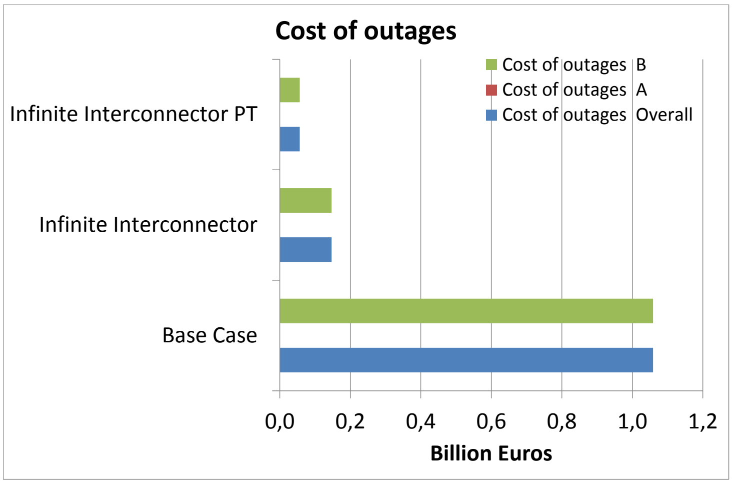
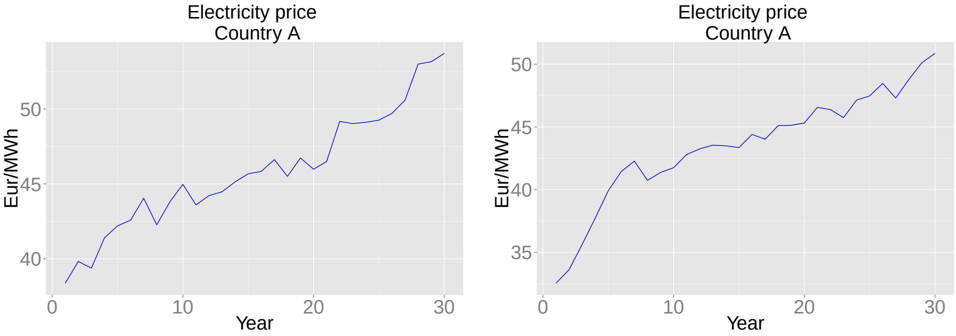


Figure 7.21: Cost of outages

Electricity market performance

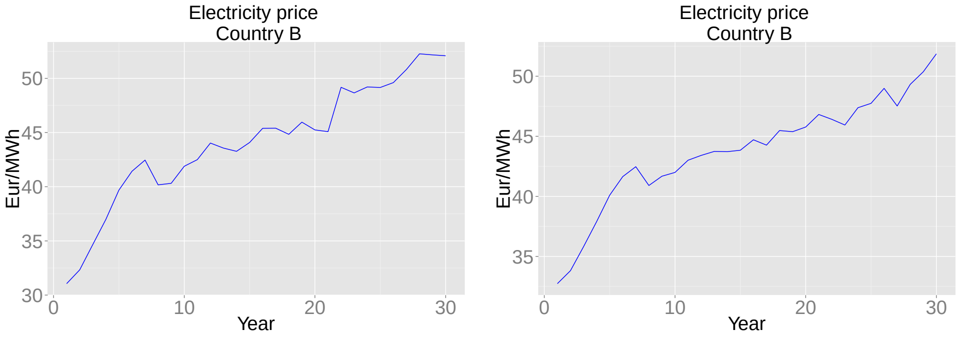
- For both scenarios the median weighted averaged electricity prices increases over time [7.22, 7.23]
- The prices converge under unlimited interconnector capacity [H.4]
- The electricity price falls for country A by 4.0% and for country B by only 0.91% [H.3]
- The volatility increases by 12% for country A and reduces by 18% for country B [H.3]
- Supply ratios are similar and reported in table H.3 and figures H.5, H.6



(a) Base case

(b) Infinite Interconnector

Figure 7.22: Median weighted average electricity prices - Country A



(a) Base case

(b) Infinite Interconnector

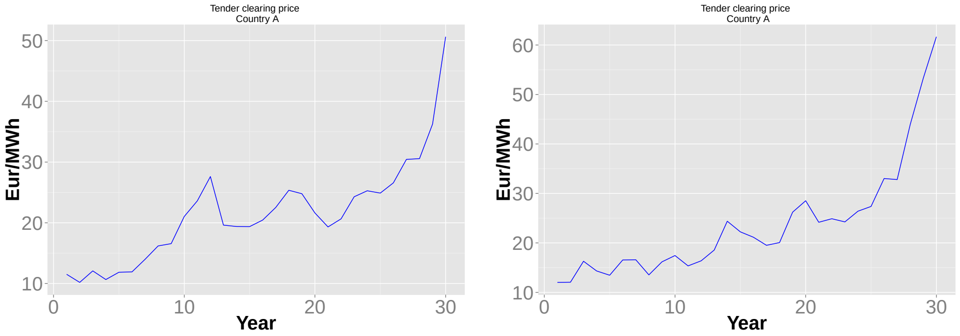
Figure 7.23: Median weighted average electricity prices - Country B

Tender performance: tender target fulfilment

- Target fulfilment dynamics for both scenarios and countries are similar. Only country B has less volatility in its fulfilment under infinite interconnector capacity [H.13, H.14]

Tender performance: tender clearing prices

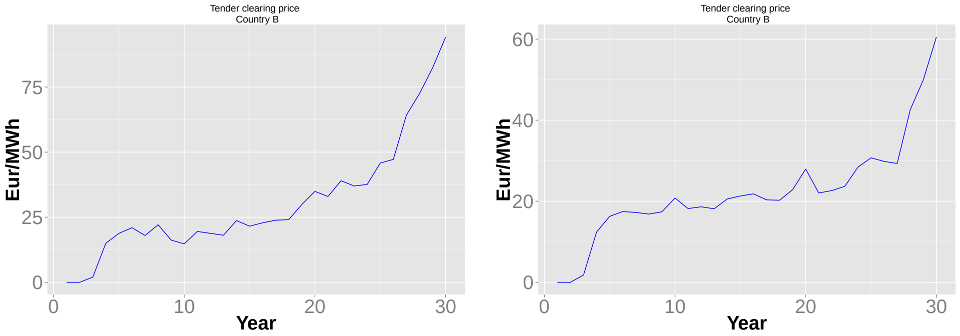
- Tender clearing prices are increasing over time and higher for country A (except at the local peak in year 10) but lower for country B compared to the Base Case [7.24, 7.25]



(a) Base Case

(b) Infinite interconnector capacity

Figure 7.24: Tender clearing prices - Country A



(a) Base Case

(b) Infinite interconnector capacity

Figure 7.25: Tender clearing prices - Country B

Generation and capacity shares The generation and capacity shares are for both countries in both scenarios nearly identical with negligible differences in the mixes [H.7, H.8, H.9, H.10]

7.2.2. Interpretation 2A

The interconnector established price convergence between the countries. The equalization lead to a lower, but more volatile, electricity price in country A and a slightly lower and less volatile price in country B compared to the Base Case. Price convergence arise when the prices were already equal, but this was not the case in the Base Case, or price convergence takes place if there is a price difference between the two countries, as explained by [49] in paragraph 3.1. However, the large interconnector lowers the median price over the simulation since there less outages (reduction in cost of outages) and thus lower scarcity prices that drove up the prices before in country B. The price in A was initially higher, and I assume that it must have been lower in B although this was not observed by comparing the price of scenarios Infinite Interconnector with the Base Case [H.3]. Thus, electricity prices were lowered in country A and increased in country B to reach price convergence.

It can also be stated that electricity price 'volatility-convergence' takes place. The volatility increases by 12% for country A and reduced by 18% for country B. Compared to the Base Case, country B, due to its high RES-E penetration, is exporting its merit-order effect to country A.

Due to the effects of price convergence, the tender clearing prices of country A increase. Investors receive a lower return from the electricity spot market, and thus need to increase their bid price. This explains the increase in subsidy costs (5.1%) in country A. The opposite occurs in the neighbouring country: the tender clearing prices in country B decline, since investors receive a higher return from the market. This interpretation strengths the assumption in the previous paragraph, which stated that country B must have had lower market price initially. Furthermore, the subsidy costs have declined in country B by 4.4%.

It is observed that welfare losses occur among producers both in country A and B, while consumer welfare is increased in A but reduced in B. On the overall level consumer welfare increases slightly. This is in line [22] who states that system-wide welfare always increases when cooperation for RES-E support is introduced if the countries are perfectly interconnected. But he adds that the welfare effects also depend on the level of the RES-E target since the generation costs and consumer welfare. However, no significant change in generation costs was observed compared to a small interconnector.

7.2.3. Observations 2B

The current experiment is repeated with an additional scenario: the effects of infinite interconnector capacity with a high difference in RES-E targets between the countries. In this scenario called, Infinite Interconnector PT (Paced Target) Country A has a very low target compared to the previous scenario and country B has its usual target. It serves merely as verification of the observations made in the previous scenario and it is expected that the results are similar but amplified. The difference in RES-E ambitions is shown in figure 7.26.

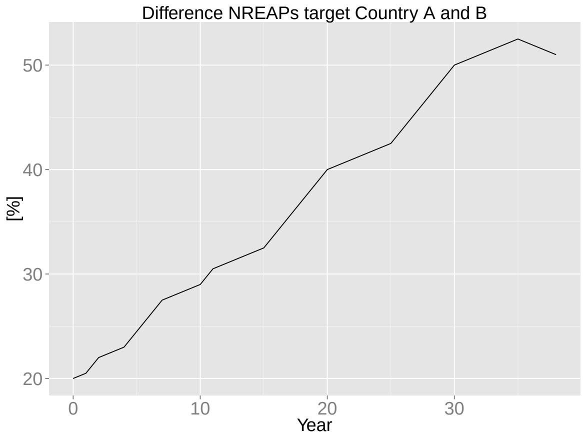


Figure 7.26: High Difference RES-E Target ambitions: Country B - Country A

Main observations

- Producer welfare is increased by 23.2% in country A and 5.5% in country B[7.16]
- Overall consumer welfare improved for A by 13.31% and reduced by 1.3% for country B [7.17]

- Electricity prices change is similar [H.11, H.12]
- Subsidy costs are lowered substantially in country A by 73% [7.20]
- Generation costs have been lowered by 12% in country A [7.19, H.4]
- Outages in country B have been reduced by 60% compared to the Infinite Interconnector scenario [7.21]
- In the generation shares of country A there is a high amount of conventional technologies presents while for country B the generation share trends do not differ considerable as is observed in figures H.17 and H.18
- The tender clearing prices for country A are lower on average [H.15]

7.2.4. Interpretation 2B

It was expected that the results from 2A were amplified, especially an increase of tender subsidy costs in country A was expected. However, the tender subsidies are decreases significantly by 73%. The rationale is that the reduction in RES-E target ambitions for country A offset the cost in tender subsidies because there is simply less RES-E subsidized.

Since country A has relative high shares of conventional technologies, it provides country B with another reduction in the cost of outages. Since the variability of the intermittent RES-E sources are reduced, country A is a more secure 'back-up' for country B. Furthermore, the improvement of consumer welfare in country A is related to the lower electricity price originating from the conventional power plants that are present in country A due to the low RES-E target ambitions. Since the countries are interconnected these lower prices of country A are affecting the prices in country B as well, which explains the decrease of electricity prices in country B.

7.2.5. Conclusion experiment 2

Country B exports its lower prices, originating from high RES-E shares, to country A, which faces a decrease in the electricity price. Subsequently this led to an increase in the tender clearing prices and therefore subsidy costs of country A. Moreover, country B also exports its volatility to country A.

Thus, the country with higher shares of RES-E exports electricity price to its neighbour with lower RES-E targets and also increases its subsidy costs due to higher tender clearing prices. However, this effect is limited that depends on the difference in RES-E targets as was shown in the scenario with significant high differences in RES-E target ambitions: the increased subsidy costs due to country B were largely offset by the reduced policy costs.

7.3. Experiment 3

In the third experiment, the Base Case is compared with the scenario Tech-Spec 1 in which country B implements a technology-specific tender. Country A remains having a technology-neutral tender. Compared to the other experiments in this work, the technology-specificity scenario has ran only 100 times instead of 120 due to time constraints. However, 100 is still the minimum number of runs that is statistically valid [29].

7.3.1. Observations

Welfare effects

- The profits of producers are increased on the overall level, mainly due to an increase in country B of 28% [7.27]
- Consumer welfare degrades for both countries [7.28].
- Producer cash increases by 14% in Country B [7.29].

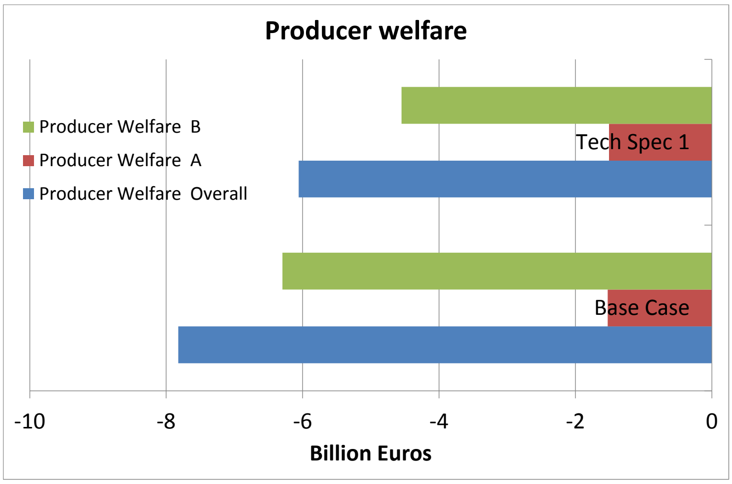


Figure 7.27: Producer profits

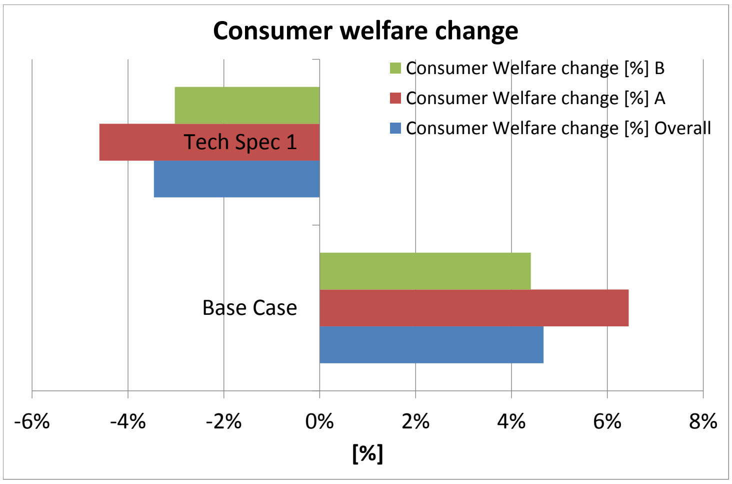


Figure 7.28: Consumer welfare change

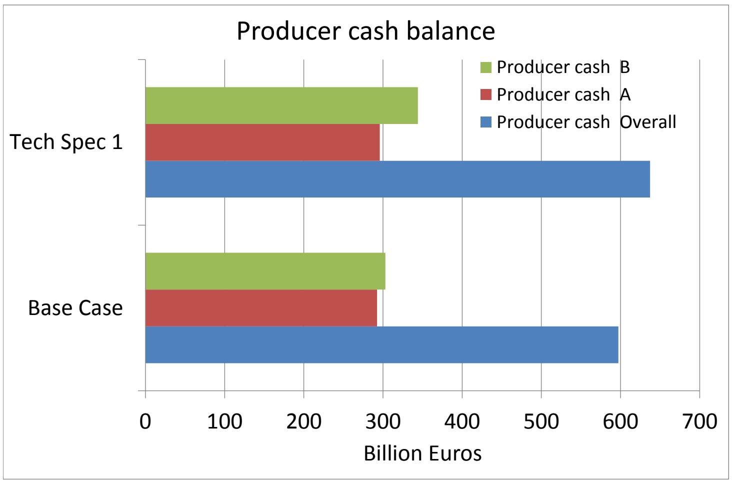


Figure 7.29: Producer cash

Costs

- Generations costs decreases on the aggregate level because of lower loan and downpayment costs in country B [H.4], which is slightly offset by an increase of 3% country A 7.30
- The subsidy costs for country B lower by 24% while it increases for country A by 37% [7.31]
- Outages are very low and close to zero in the Tech-Spec 1 scenario [7.32]

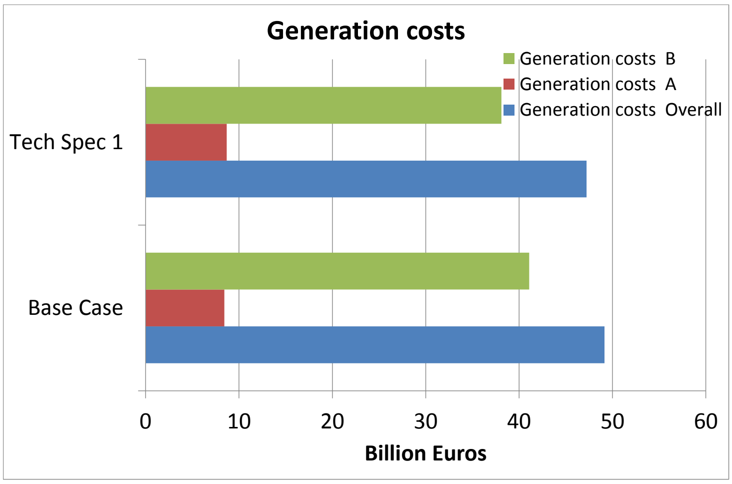


Figure 7.30: Generation costs

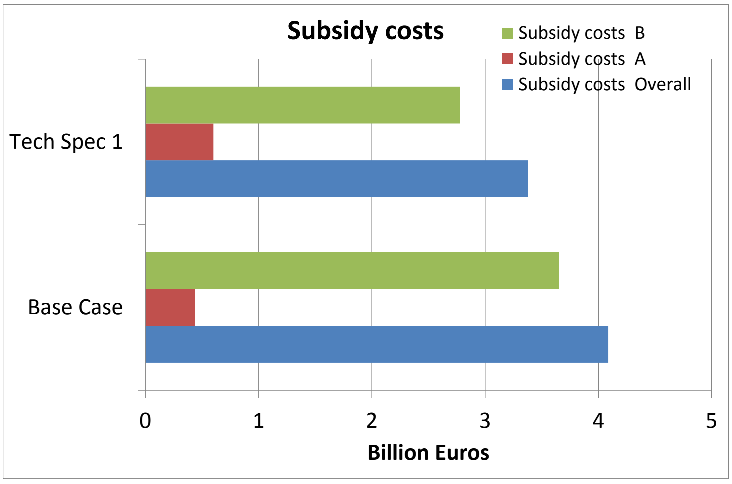


Figure 7.31: Subsidy costs

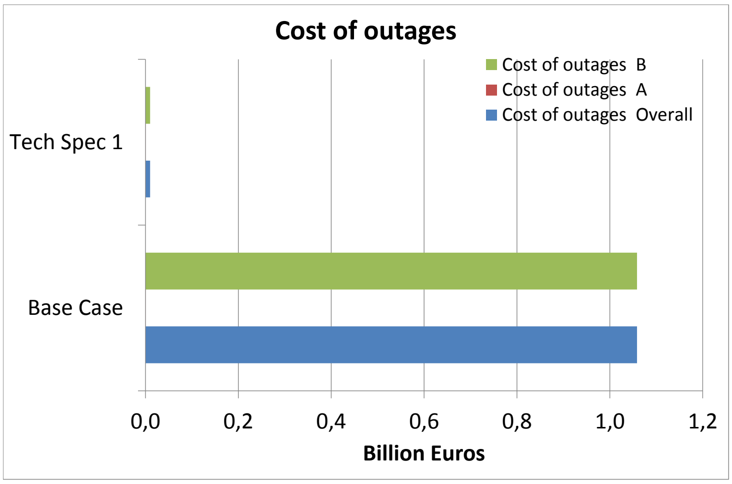


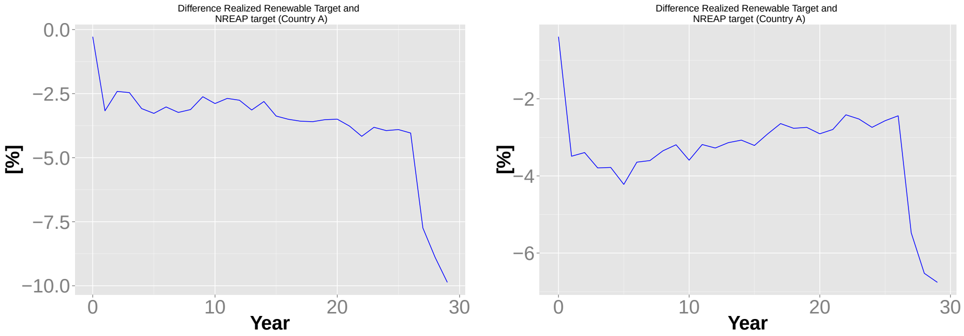
Figure 7.32: Cost of outages

Electricity market performance

- Similar price trends are observed for Tech-Spec 1, but the electricity prices are for both countries higher compared to the Base Case [H.20, H.21]
- Price volatility has been reduced by 8% and 2.7% for country A and B respectively

Tender performance: target fulfilment The tender performance is characterized by the realization of the predetermined NREAP targets and the tender clearing prices. The difference this time is that, for country B, the target fulfilment is presented per technology [7.34]. Observations for country A are presented in figure 7.33.

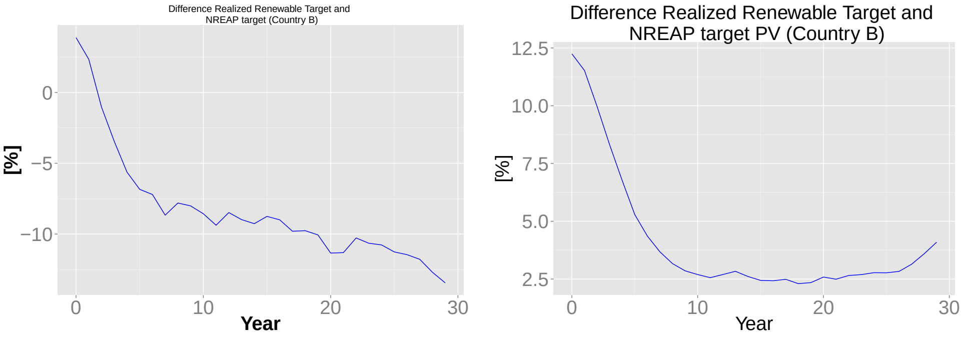
- When the large neighbouring country implements a technology-specific tender the realization over renewable targets exhibit a similar pattern compared to the Base Case for country A: the targets are not met with a difference around 3.0% at the beginning and 6% near the end of the simulation
- Country B meets the targets of PV more than needed at the beginning of the simulation and evolves later with an overshoot between 2.5% and 5.0%
- Wind onshore targets are always met by 16% at the start, but moves later towards an 8% overshoot
- Wind offshore targets are undershot, and volatile at the beginning but stabilizes at -3.5%. It drops around year 25 to an 8% undershoot
- Country B has increasing unmet targets for both biomass and biogas



(a) Base case

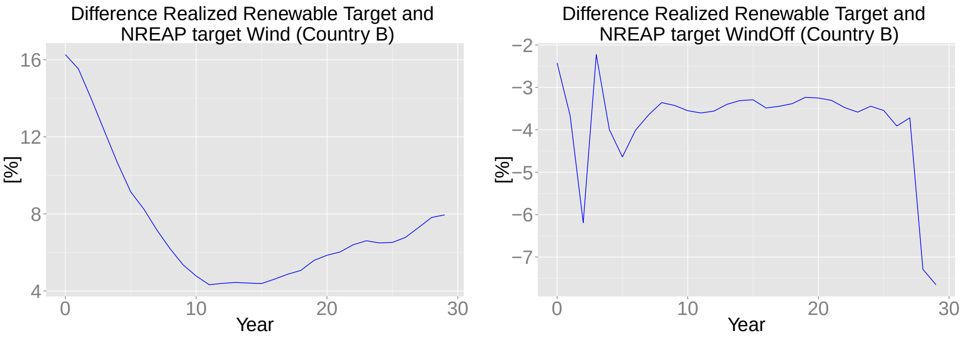
(b) Tech-Spec 1

Figure 7.33: Tender target fulfilment - Country A



(a) Base Case

(b) Tech-Spec 1 - PV



(c) Tech-Spec 1 - Wind

(d) Tech-Spec 1 - Wind offshore

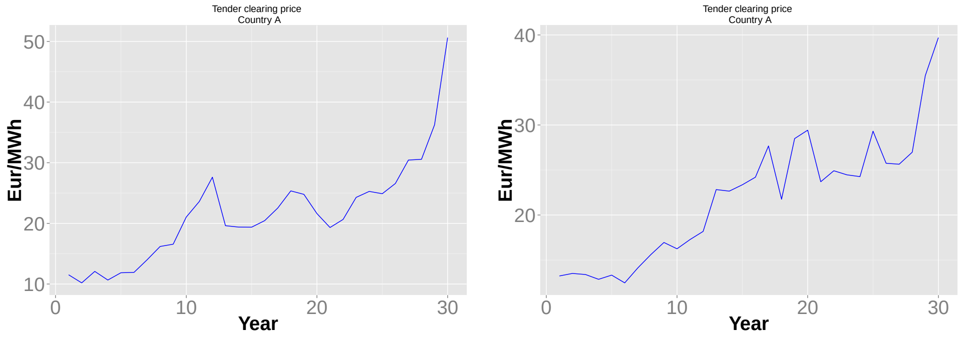
(e) Tech-Spec 1 - Biomass

(f) Tech-Spec 1 - Biogas

Figure 7.34: Tender target fulfilment Base Case and Tech-Spec 1 - Country B

Tender performance: clearing prices The tender clearing prices are incorporated in figures 7.35 for country A and in figure 7.36 for country B.

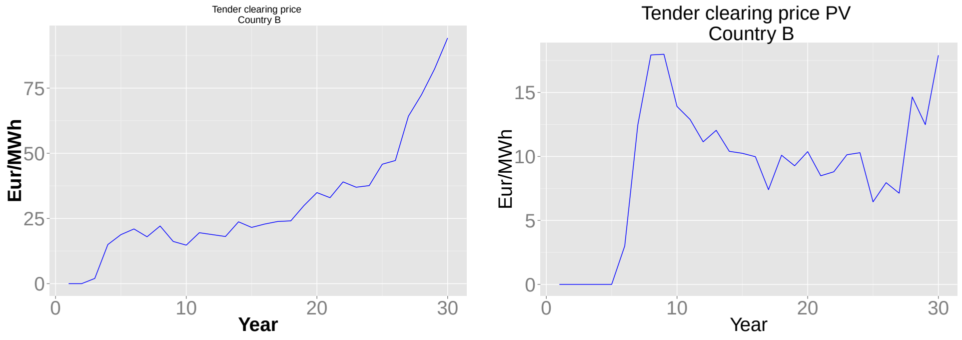
- With the implementation of a technology-specific design in country B, the overall clearing prices are lower in country A with an upwarding trend and increased volatility around year 18
- Wind offshore has high tender clearing prices in the first years
- Tender clearing prices are higher for the technology-neutral tender compared to the individual technology clearing prices
- Biomass and biogas have a few clearing points with low clearing prices compared to the other technologies



(a) Base case

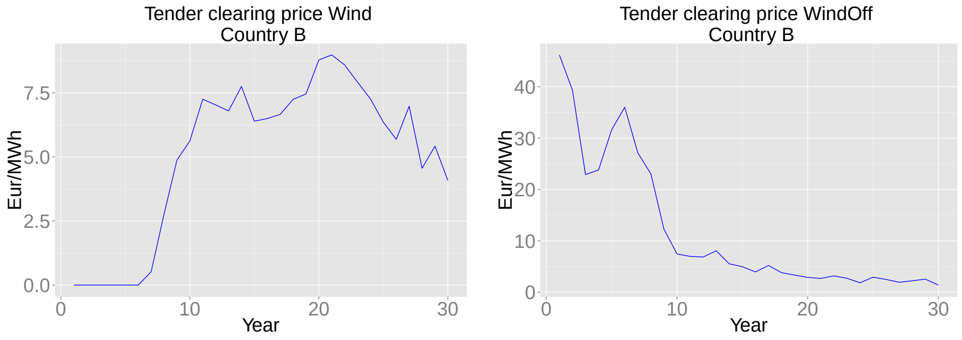
(b) Tech-Spec 1

Figure 7.35: Tender clearing prices - Country A



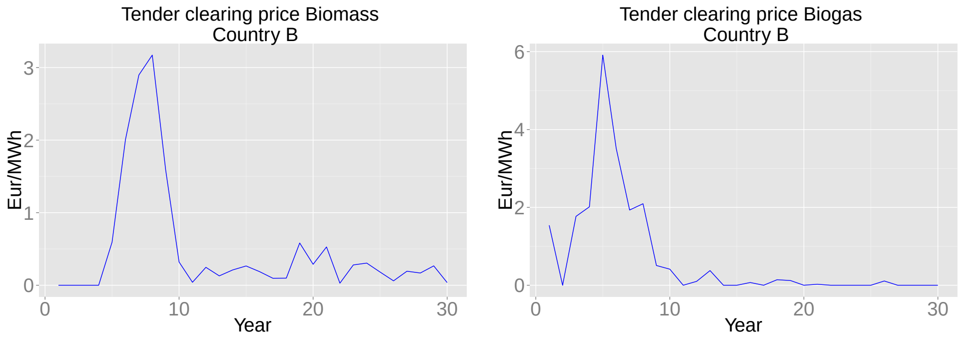
(a) Base Case

(b) Tech-Spec 1 - PV



(c) Tech-Spec 1 - Wind

(d) Tech-Spec 1 - Wind offshore



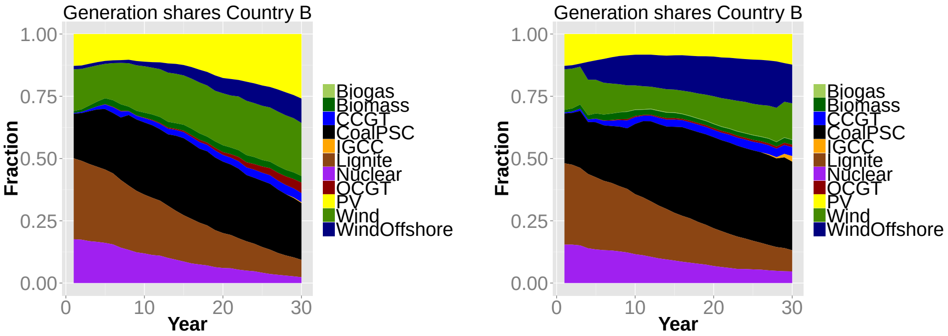
(e) Tech-Spec 1 - Biomass

(f) Tech-Spec 1 - Biogas

Figure 7.36: Tender clearing prices Tech-Spec 1 - Country B

Generation and capacity shares

- Country A does not show significant changes in its generation mix [H.19]
- When country B switches to a technology-specific tender, it shows a more equal distribution of intermittent RES-E technologies, but the total RES-E generation share is less [7.37].



(a) Base case (b) Tech-Spec 1

Figure 7.37: Generation shares - Country B

7.3.2. Interpretation

Overall welfare of consumers have decreased while producers welfare is increased. However, a profit reduction was expected in the technology-specific tender because of less windfall profits. The electricity prices have been increased as compared to the Base Case, which thus explains the increase in profits. The increases prices originates from the higher presence of conventional energy in the generation mix than in the previous scenarios.

Moreover, it is observed that the share of RES-E in the generation mix is considerable lower than with a technology-neutral tender in the Base Case. If one looks at the technology-targets for biomass and biogas: they are never met and the deviation with the pre-determined target is increasing over time. This is not line with [66] who state that technology-specificity stimulates the development of renewable energy technologies simultaneously. These non-intermittent sources were also not participating before i.e. the tender-participation-effect, but now it has direct severe effects on the achieved share of RES-E.

Although, the tender-participation-effect should not apply in the case of technology-specific tenders since each technology has its own targets and tenders. What should be expected are high clearing prices from biomass and biogas, even if their specific target is low but this did not happen. The reason for this is due to the cash flow restrictions of the investor: the energy producers creates bids for each technology of the technologic-specific tenders. However, the total downpayment for all the bids together could be too high and therefore all the bid are sorted ascending by price, and only the bids are submitted until it reaches the limit of the available cash for downpayments. Therefore, if the biomass and biogas bid prices are too high, these bids are simply not submitted and high clearing prices do not occur. The very low clearing prices for biomass and biogas that do occur are explained by the moments that the marginal costs are indeed lower in combination with shortages in segments, which makes the bid price low due to high expected returns. A snapshot of the proof of these occurrences is derived from a single run with loggers and can be found in appendix F

In contrast to this effect, [42] state that not including technology-specific tenders can result in low effectiveness and high policy costs. However, we observed that including technology-specificity can result in low effectiveness and low policy costs.

From a technology-specific tender it is also expected that subsidies are lower. The tender subsidies are indeed decreased in country B when it implements the technology-specific tender. The cost reductions are in the loan payments and the downpayments, which indicates that less investments takes place. This coincide with the observed generation and capacity mixes of country B: there is relative more generation from (and higher installed capacity) of conventional technologies because less RES-E is built.

Finally, one would expect higher generation costs since more expensive technologies are stimulated instead of the lowest costs technologies in a technology-neutral tender. However, since the technology-specific tender does not achieve its targets, less RES-E, and thus less high-cost technologies are deployed.

7.3.3. Conclusion experiment 3

A technology-specific tender is prone to the risk of low target fulfilment since each technology should contribute, which is not the case in a technology-neutral tender. Furthermore, although technology-specific tenders causes less windfall profits, it does not necessarily mean that there will be lower overall profits since this can be offset by an higher electricity price.

7.4. Experiment 4

The fourth experiments looked into the effects when a country has the same tender design and the same RES-E targets, which approximates the case of full harmonization.

7.4.1. Observations

Welfare effects

- Overall producer welfare has been increased. Country A shows a 4% increase while country B improves it by 6.3% [7.38]
- The consumer welfare improves slightly overall. For country A and B the increments are low: 0.15% and 1.14% [7.39]
- The overall level of subsidies decreases, which is mainly due to country B [7.40]
- Cash balances of producers are almost unaffected: country B shows a small increase [7.41]

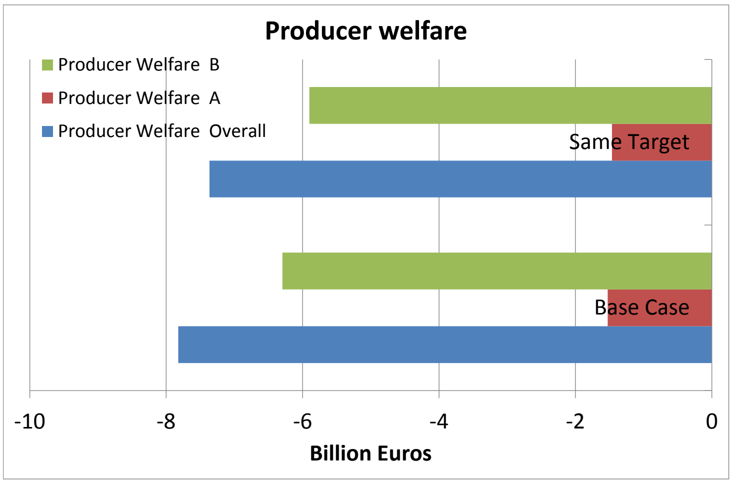


Figure 7.38: Producer profits

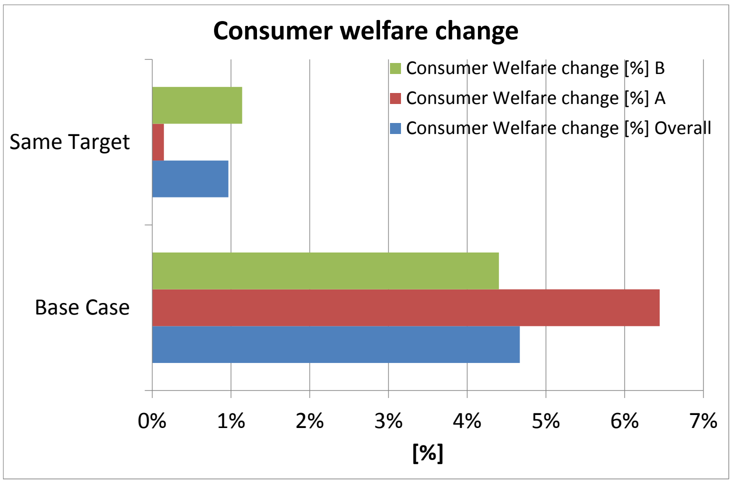


Figure 7.39: Consumer welfare change

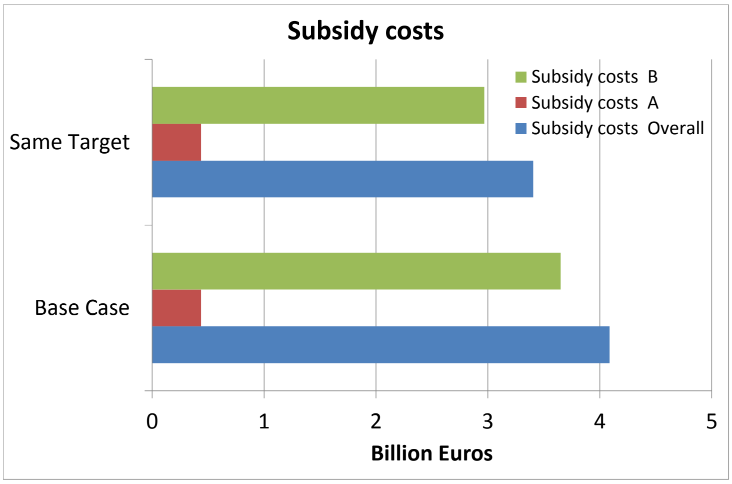


Figure 7.40: Subsidy costs

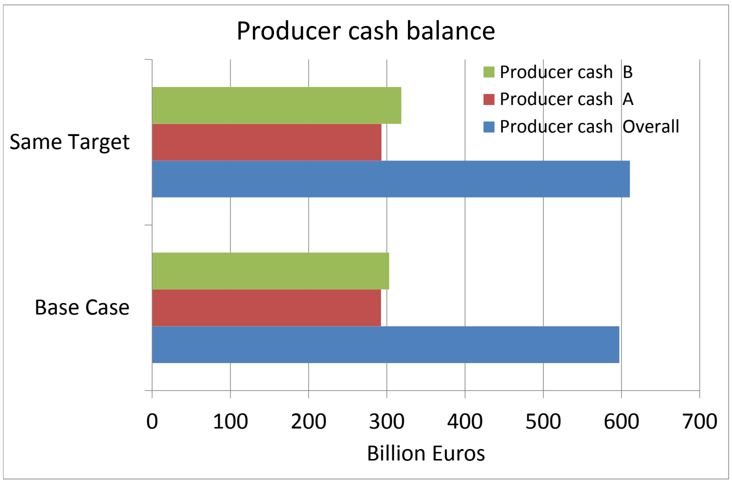


Figure 7.41: Producer cash

Costs

- Generation costs remain lowers overall by 2% after switching to Same Targets. Country B's costs of generation is lowered by 4% [7.42]
- Cost of outage decline by 0.8 billion euros compared to the Base Case [7.43]

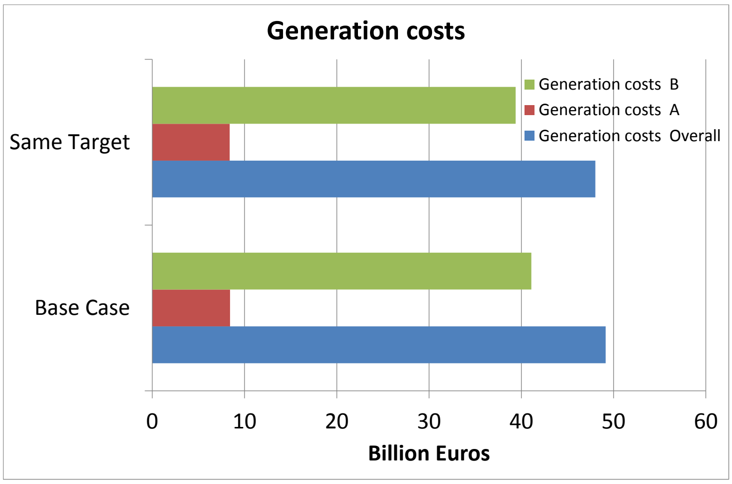


Figure 7.42: Generation costs

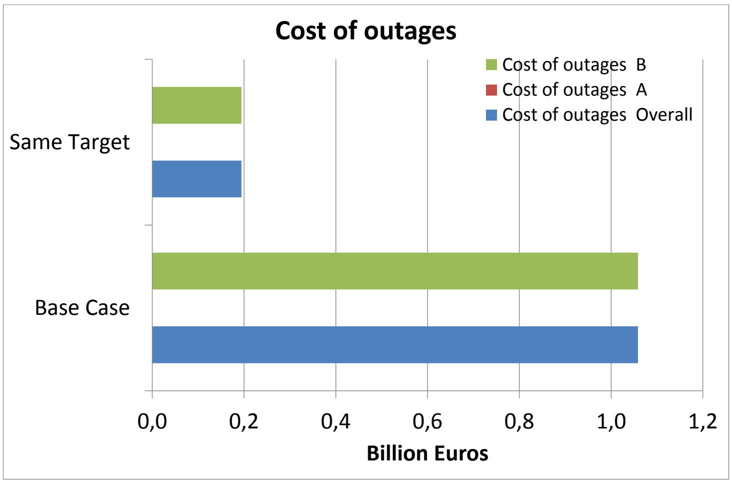
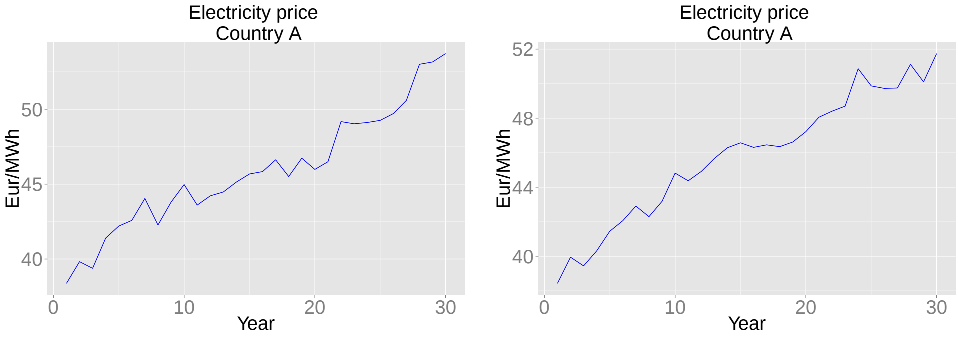


Figure 7.43: Cost of outages

Electricity market performance

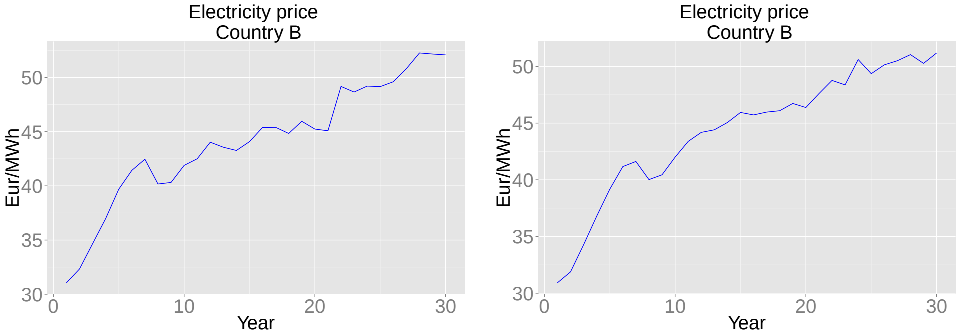
- Electricity prices are increasing in Country A and B and the median values are close to the values of the Base Case: an increase of 1.6% and 3.1% for country A and B respectively [H.3]
- Volatility of the electricity prices lowers for country A by 6% but in country B is remains close to the value of the Base Case
- Supply ratios are decreasing for both countries to a value of 1.10 [H.25]



(a) Base case

(b) Same Target

Figure 7.44: Median weighted average electricity prices - Country A



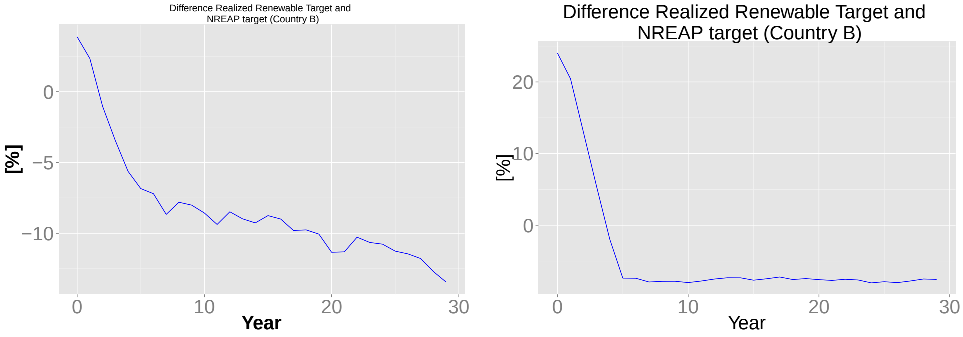
(a) Base case

(b) Same Target

Figure 7.45: Median weighted average electricity prices - Country B

Tender performance: target fulfilment Both countries follow the targets of country A now, which is gives country B overall lower targets compared to the other scenarios.

- It is observed that the target fulfilment of country B is constantly not met, but does not decline around year 25 as compared to the Base Case [7.46]



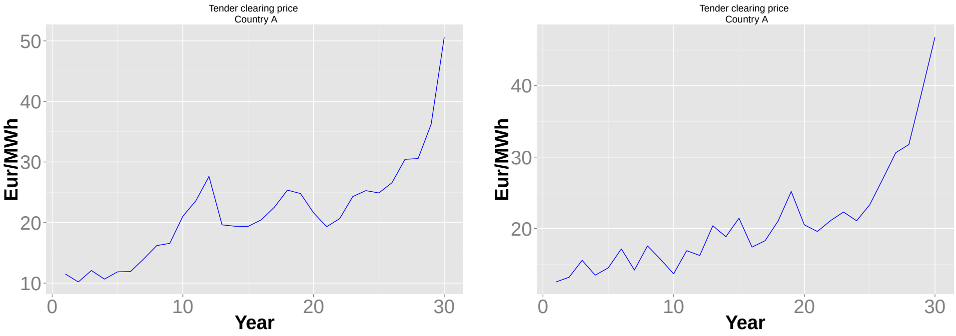
(a) Base Case

(b) Same Target

Figure 7.46: Tender target fulfilment - Country B

Tender performance: clearing prices

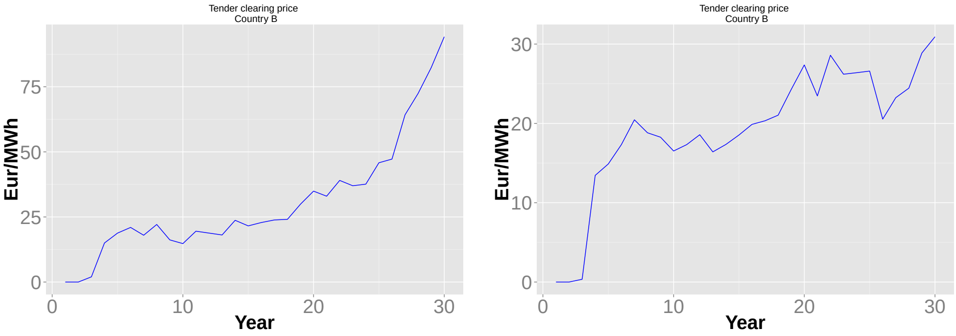
- The tender clearing prices of country A are similar but they exhibit a more volatile character in the Same Target scenario [7.47]
- Country B shows lower clearing prices over time [7.48]



(a) Base Case

(b) Same Target

Figure 7.47: Tender clearing prices - Country A



(a) Base Case

(b) Same Target

Figure 7.48: Tender clearing prices - Country B

Generation and capacity shares

- Country A does not show significant changes in its generation mix [H.28]
- Country B ends with lower shares of RES-E in the Same Target scenario [H.29].

7.4.2. Interpretation

Having the same targets for both countries, both based on the (lower) targets of country A, results in that country B fulfils his target more often. The targets for a country can thus set too high, which resulted before in higher unfulfilled targets in the case of country B. The lower tender clearing prices for country B follow the same logic, since targets are lower there are less bids necessary to clearing the tender. This all culminates in a higher electricity price compared to the Base Case, since more conventional energy, which has non-zero marginal costs, are present in the system. Finally, the decline in generation costs is also attributed to the lower target: less RES-E investments is accompanied by less downpayment costs and loan payments. The regulator can thus influence the generation costs to a certain extent by setting the RES-E target. However, considering this scenario as full harmonized it corroborates the statement of [26], which pointed out that system costs i.e. generation costs and subsidy costs will reduce under harmonized policies compared to less harmonized policies.

7.4.3. Conclusion experiment 4

Firstly, it needs to be admitted that this scenario aimed to test the effect of full harmonization but it actually looked more at the effect of a change in RES-E target ambitions in one of the countries. In despite of this, the reduction of the tender target in country B gives some insightful conclusions: a country can be too ambitious in setting its RES-E target, meaning that if a RES-E target is not met, it results in higher clearing prices since a higher target needs to be fulfilled next year. The final effect is a higher burden on society due to high tender subsidies. It also shows that the regulator can control the generation costs to a certain extend by setting the RES-E target.

7.5. Sensitivity Analysis

The sensitivity analysis has thus been carried out to observe the forecasting power of the regulator of the expected renewable generation in the market of one year up to five years ahead and its effect on the renewable energy target realization and subsequent economic indicators.

7.5.1. Observations

Forecasting of expected generation Firstly, the forecasting of the expected generation is reviewed. Recall formula 6.1:

$$\text{Estimation error} = \frac{\text{Actual renewable generation - Expected renewable generation}}{\text{Actual renewable generation}} \tag{7.1}$$

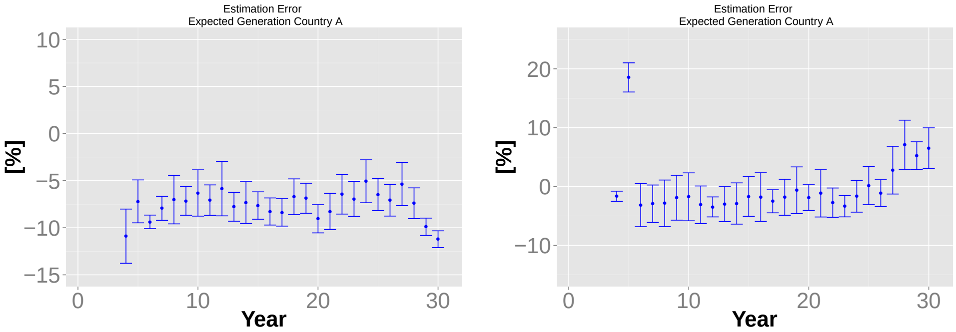
If the percentage is higher than 0% it indicates undershooting (expected generation is lower than actual generation). A value lower than 0% represents overshooting (expected generation is higher than actual generation). The perfect value would be 0 % since no overshooting or undershooting of the expected renewable generation occurs, which implies that the regulator has perfect foresight. The following observations that are made, are based on figure 7.49 for country A and 7.50 for country B.

Country A

- The negative percentages for one to two years ahead represents overshooting of expected generation
- Undershooting becomes more present in four and five years ahead as observed by more positive percentages
- The regulator estimates the generation the best for three years ahead
- Around year 25 for two - five years ahead, the regulator suddenly makes undershooting errors (actual minus expected generation) that deviates from the trend
- Country A has dramatic undershooting outliers (100 - 300%) at the beginning of the simulation if he looks more years ahead. These are not visible in the graphics below due to visualization reasons, but can be obtained in figures I.1 and I.2 in the appendix.

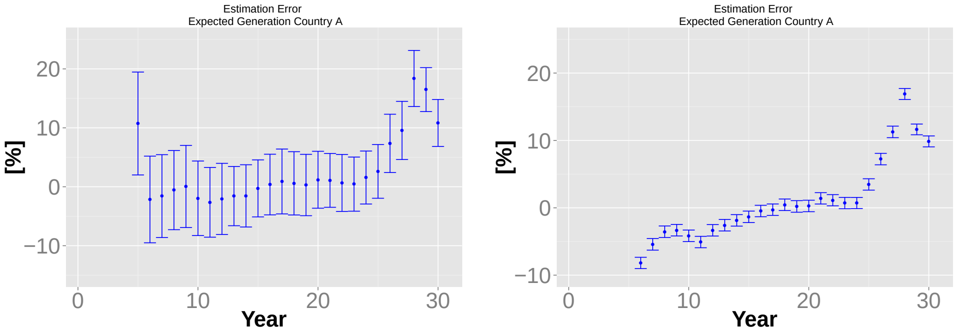
Country B

- Country B has overshooting (negative values) in one and two years ahead
- It has undershooting (positive values) for four and five years ahead
- For three years ahead, the regulator minimizes its forecast error



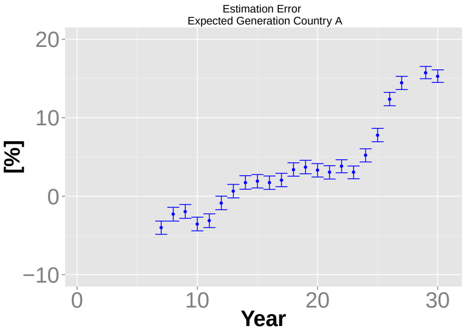
(a) 1 Year ahead

(b) 2 Years ahead



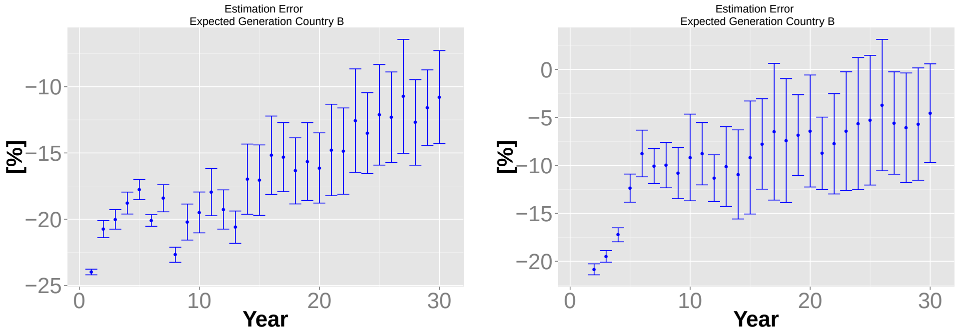
(c) 3 Years ahead

(d) 4 Years ahead

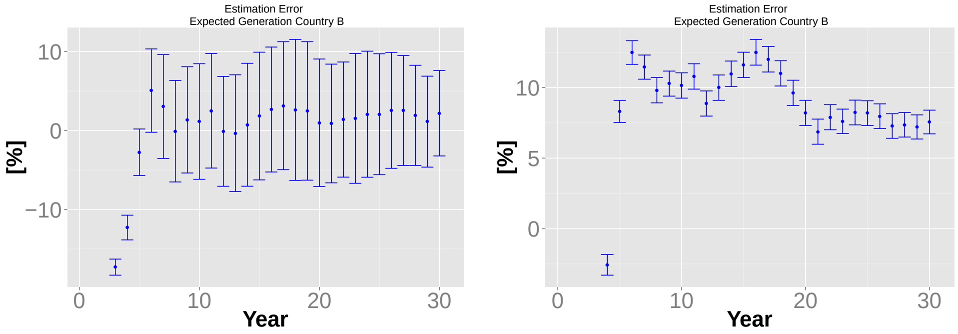


(e) 5 Years ahead

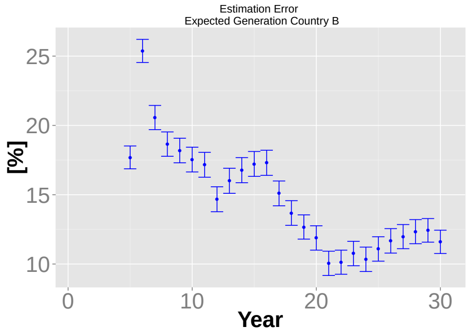
Figure 7.49: Deviation from expected generation - Country A



(a) 1 Year ahead (b) 2 Years ahead



(c) 3 Years ahead (d) 4 Years ahead



(e) 5 Years ahead

Figure 7.50: Deviation from expected generation - Country B

Tender target fulfilment The next step is to look at the tender target fulfilment, which is related to the prediction of expected generation:

$$\text{renewable energy target} = \text{gross renewable energy target} - \text{expected renewable generation} \quad (7.2)$$

If the renewable generation is predicted wrong, it will thus affect the renewable energy target i.e. the tender quota. If the quota for the tender is too low (high) it implies that the regulator does not meet its RES-E targets derived from the NREAP, or is over fulfilling them, which leads to higher yearly subsidy costs than necessary. The difference between the realized target and the predetermined NREAP target is given in figures 7.51 and 7.52 with the following observations:

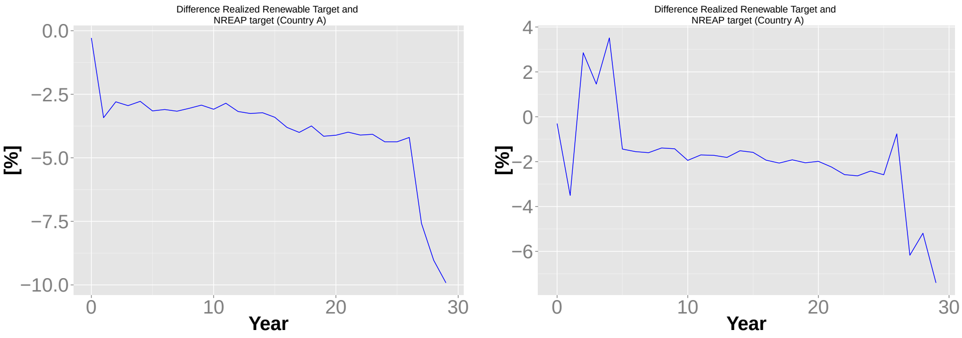
Country A

- The trends of fulfilments are similar with the exception of the one year ahead scenario
- For the two to four years ahead, a peak deviation is occurring around the beginning and end of the simulation
- The target deviations for all forecast scenario has a maximum deviation of around 8% and a minimum deviation of around 10%

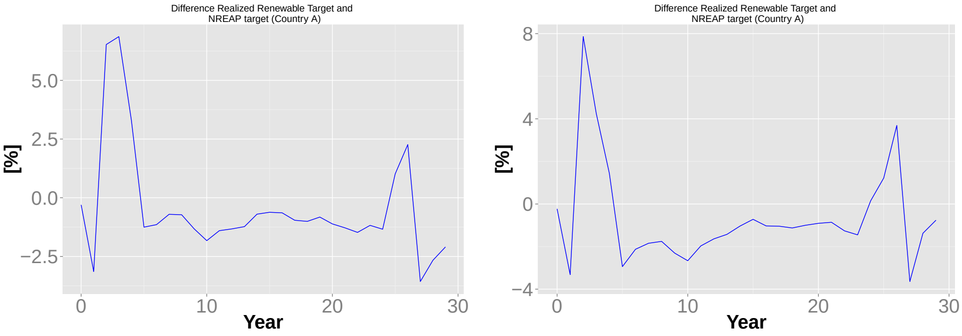
- The minimum (maximum) deviation becomes less (higher) if the regulator looks further into the future
- For the one years ahead scenario the deviation is never positive
- For the two to four years ahead only the peaks result in a positive deviation

Country B

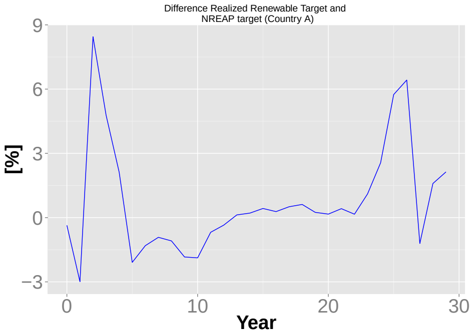
- For all forecast the trends are having similar downward trends
- The deviation of the target has a maximum of around 4% and a minimum of around -17%
- For one to three years ahead the target is most of the simulation unmet
- For four and five years ahead the targets are always met until year 20 and 25 respectively, after that it starts to decline



(a) 1 Year ahead (b) 2 Years ahead

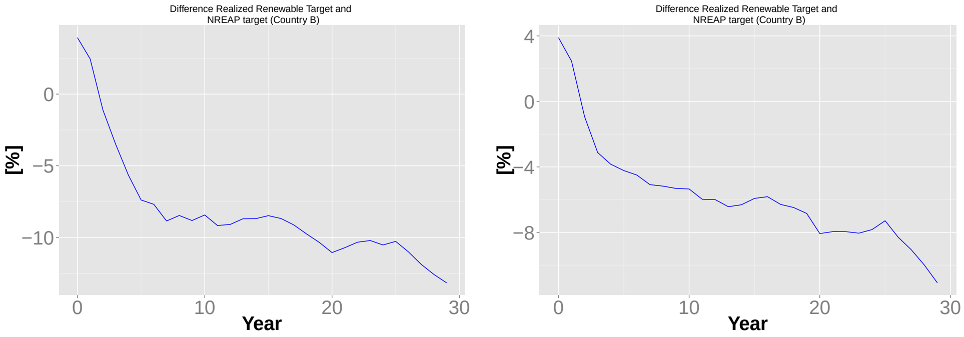


(c) 3 Years ahead (d) 4 Years ahead

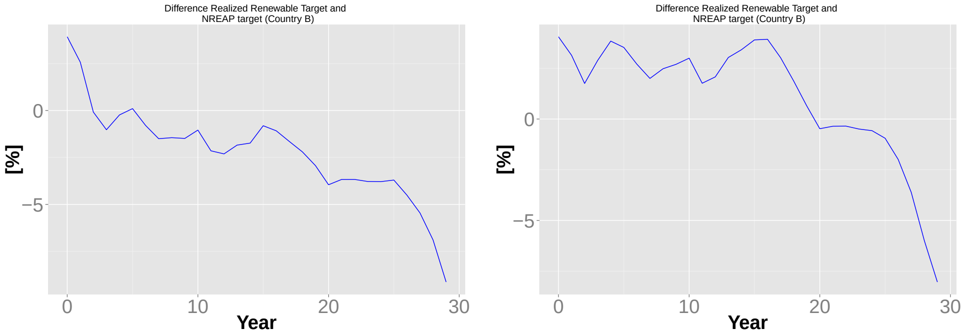


(e) 5 Years ahead

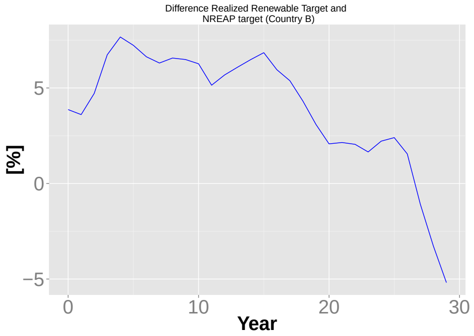
Figure 7.51: Tender target fulfilment - Country A



(a) 1 Year ahead (b) 2 Years ahead



(c) 3 Years ahead (d) 4 Years ahead



(e) 5 Years ahead

Figure 7.52: Tender target fulfilment - Country B

Tender clearing prices The tender clearing prices are stored in the appendix and represented by figures I.3 and I.4.

Observations Country A

- In all forecast experiments the tender clearing price remains relatively stable until year 25 and starts to increase
- In the relative stable regions (up to 25 years) for all outcomes the clearing prices are between 10 Eur/MWh and 30 Eur/MWh
- With increasing years ahead, the very first clearing price becomes higher

Observations Country B

- Also country B has upward trends in the tender clearing prices, and reaching higher clearing price levels with increasing years looking ahead and has in the relative stable regions (up to 25 years) clearing prices around 25 Eur/MWh

Generation and capacity shares The observations of the generation and capacity shares are visible in figures I.5, I.7, I.6 and I.8.

Observations Country A

- For all years ahead the trends in development of generations are similar
- For each scenario around year 25 a local investment peak in Coal is observed and IGCC starts to enter the merit order more often
- OCGT is relatively more in the merit order after 20 years
- It takes around 25 years before photovoltaics start to develop for all scenarios
- Wind onshore grows from the beginning in all of the five simulations and declines after 25 years
- Biomass and biogas share are very low
- Relative high capacity shares corresponds with relative lower generation shares for intermittent RES-E
- Relative low capacity shares corresponds with relative high generation shares for conventional power plants

Observations Country B

- For all years ahead the trends in development of generations are similar
- All generation from conventional technologies, except for OCGT, declines over time
- Installed capacities of conventional power plants decline over time
- Photovoltaics and wind onshore becomes the dominant technologies over time
- Biomass and biogas share are very low

Other indicators

- Producer welfare [I.9] and consumer welfare [I.10] are affected negatively when the regulator forecasts the expected generation further in the future
- Cash balances reduces for country B with increasing years looking ahead. Those of country A remain stable [I.11]
- Generation costs [I.12], cost of outages [I.14] and subsidy costs increase [I.13] with increasing forecast years
- Electricity prices increases over time for each scenario towards 50 - 55 Eur/Mwh in country A [I.16]
- The electricity prices increases over time with increasing years looking ahead I.16
- Volatility in the electricity price becomes higher for each country when looking more years ahead. However, it slighly declines after the 4 years ahead scenario I.15
- Both countries show similar decreasing supply ratio trends approaching a value of 1.10 for each sensitivity scenario [I.18, I.19]

7.5.2. Interpretation

It appears hard for the regulator to predict the actual generation from RES-E in the merit order right for both countries except for three years ahead. Overshooting (generation > actual generation) is more present for both countries in one and two years ahead, while the undershooting (generation < actual generation) is dominant in looking four and five years ahead.

Overshooting implies that the regulator predicted more generation than actually is occurring. He creates this error because he expects the renewable power plants that are under currently under construction, but operational at the future time point, to be in the merit order at the future time point. A plant, especially intermittent RES-E, could be unavailable at certain moments. The undershooting becomes less over time since the share of RES-E is increased by the tender and more RES-E is in the merit order [I.5].

Undershooting means that there is actual more renewable generation than the regulator foresaw, which is attributed to the lead time of power plants. Because when the regulator predicts the generation for a time point relative far in the future, he does not include new power plants that are being built in the mean time. If the regulator predicts for a shorter interval, his forecast will be updated more often and thus more accurate. Thus the regulator should not look further into the future than the lead time of a technology.

The consequence of overshooting (undershooting) renewable generation is setting the renewable energy targets lower (higher) than necessary. The lower tender target is reflected by a lower tender target fulfilment. The high tender target fulfilments are a result of setting the targets to high as reflected in figures 7.51 and 7.52. Recall that a negative percentage indicates that the renewable target is not met for the current year, and a positive percentage shows that more generation comes from renewables than is required.

Literature confirms that setting the target right is important. It adds to this discussion that when actual RES-E generation is larger than the RES-E target, it impedes the financial plans of a conventional power plant investor. Since, this producer was expecting to compete with less RES-E and thus had higher expected profits [67].

The effect of high tender targets is especially well reflected for country B by the high tender clearing prices in figure I.4 and the increased RES-E shares [I.7]. The higher tender clearing prices clearly affect the subsidy costs as shown in figure I.13. Next to this, an overshoot affects producer welfare negatively and cash balances are being reduced. Moreover, costs in generation and outages rise and electricity prices increase accompanied with more volatility.

7.5.3. Conclusion sensitivity analysis

The sensitivity analysis showed that setting the right RES-E target is prone to uncertainty and doing this wrongly, it will affect the effectiveness of the tender or it imposes a larger cost burden on society than necessary. If the expected generation is too high compared to the actual generation, it leads to higher tender quotas than necessary and it over-fulfils the pre-determined tender targets. Subsequently it leads to higher tender clearing prices which increases the yearly subsidy costs more than needed, which is passed on to society. The other way around: if the expected generation is too low, tender targets are fulfilled less than required and thus impedes the goals of a country to shift to higher RES-E shares. Also the economics indicators are affected (negatively) when the regulator looks further into the future. However, a future time point of one year ahead would also not be optimal in terms of achieving RES-E targets. A balance needs to be established between the effects on the electricity market and fulfilling RES-E targets when predicting the expected generation.

7.6. The best scenario configuration

This section presents the best scenario for a two country system under harmonization from the perspective of an EU policy-maker and from a Member State policy maker, based on the previous findings. The EU policy makers view the two countries as a whole an thus looks at the overall effects instead. His main assessment is the core of EU energy policy: (1) affordability and competitively priced energy, (2) environmentally sustainable energy, and (3) secure energy for everybody [13]. This is translated into the indicators (1) the lowest electricity prices, (2) the highest RES-E generation shares and (3) a supply ratio higher than 1 in combination with minimum cost of outages. The policy makers of the Member States have a nation-wide interest where it is assumed that they seek the optimal configuration of the scenario outcomes that improve welfare and reduces costs in their country the most.

The EU policy maker Electricity prices are the lowest with perfect integrated markets, RES-E shares are the highest in the Base Case and in the Infinite Interconnector scenarios. The supply ratios are sufficient in each case, and the overall cost of outages are substantial lower than the Base Case in the other scenarios, and almost non-existent in the case of a technology-specific tender in country B. Assuming that the relative low cost of outages are acceptable, it tells that the EU policy maker will choose to improve market integration under soft harmonization, which means that Member States using a tender a RES-E policy with the same design, but that it can set their own targets.

From the Member States perspective - Country A However, on a country specific level, the best improvement compared to the Base Case is when country A has very low RES-E targets combined with infinite interconnector capacity. However, low targets are no most likely no long-term option, so the best option reduces for country A to have a large interconnector and achieving its original NREAP targets. Country A benefits from its neighbouring country, that has higher RES-E targets, by importing lower electricity prices and thus increases consumer welfare. However, this gain is largely offset since it also imports the volatile prices and the lower electricity price induces higher subsidy costs in the end. For country A it is better to have similar targets as its neighbouring country in terms of volatility and subsidy costs. With similar targets, the consumer welfare change is less but still positive. The decrease in producers profits is one of the highest and improves thus market conditions for investors. It also has producer cash balances on reasonable levels. For country A, the well balanced option under RES-E policy harmonization, is to have the same tender design and RES-E targets as its neighbouring country i.e. full harmonization although it needs to accept the relative high electricity price.

From the Member States perspective - Country B For country B, a high improvement in producer profits is obtained, creating better market conditions as compared to the Base Case, comes from implementing a technology-specific tender in the country. Although technology-specific tenders are expected to cause less windfall profits, it showed that this can be offset by an higher electricity price. In terms of fulfilling RES-E targets, a technology-specific tender is a less favourable choice as has been pointed out before. Adding a large interconnector is beneficial for country B, since it 'exports' its price volatility to country A. Less beneficial for country B is having high RES-E target ambitions since it bears the risk of higher clearing prices and thus higher subsidy costs. Moreover, it was shown that a country B increases its yearly generation costs with increasing RES-E target ambitions. Switching to full harmonization leaves the country with a positive consumer welfare change, relative low subsidy costs and a reasonable improvement of producer welfare. It seems that full harmonization is also the best option for country B, if it accepts the relative higher electricity price and increased cost of shortages.

7.7. Validation of results

Validation of an Agent-Based model is difficult. Due to the many possible future states that the model produces, it cannot always be compared with reality [29]. For the model to be validated it should be compared with historical outcomes of tenders in liberalized electricity markets. This is rather complicated since soft or full harmonization has not taken place yet, renewable energy policies are operational since 2000 and the elecitricity market has been liberalized at the beginning of 1990, meaning that there is not sufficient data or exact comparable data to validate the tender model in an electricity market under harmonization. Moreover, if there would be sufficient data available on this, it would take another master thesis, or maybe even a PhD thesis, to tune historical parameters and conditions of the markets, tenders and harmonization settings. However, other options are available and discussed in the next subsections

However, what can be done is compare the results of the tender in country A (The Netherlands) with the SDE+, the Dutch support scheme that is based on a tender. For the Netherlands in the model the average yearly subsidy costs of around 0.5 - 1.5 billion Euros were found, which is reasonable compared to the recent budget anouncement of the SDE+ 2016 [46], which amounts to 8 billion Euros. For Germany in the model yearly subsidy spending was found between 3 to 16 billion Euros, whereas the spending in 2012 were estimated around 25 billions euros over four years [47], which is thus a yearly average of 6.25 billions euros. However, since biomass and biogas did not participate significantly in the tender, the subsidy costs are expected to be higher than the aforementioned numbers. A predetermined cap on the subsidy would be advised since it also controls the total costs, which was one of the main advantages of a quantity-based support scheme.

Tender clearing prices in paragraph 5.1of the verification chapter it was already observed that the electricity prices plus the tender clearing prices should reflect the current LCOE of wind. The LCOE of wind onshore in 2012 was found range between 60 - 110 Euro per MWh [47] and for both, country A and B, the sum of the electricity price and tender clearing price is in the range of 60 - 110 Euro per MWh, implying that the tender reflects the extra amount needed to be profitable in the electricity market. Since the other two intermittent RES-E technologies are modelled in the same way as wind onshore, it is assumed that those prices also reflect reality.

The LCOE for biomass ranges from 50 - 200 Euro per MWh [47]. In the simulations, very low clearing prices were found between 0.50 - 5 Euro per MWh. Or very high 180 Eur per MWh. The electricity price for the scenarios was around 44 Eur per MWh. This means that the very high bid prices were out of range, explained by the tender-participation-effect, but that the low prices are in the ball park of the LCOE estimations.

Electricity prices Historical wholesale electricity prices from 2007-2010 are on average 49.1 Eur/Mwh for the Netherlands [68], while for Germany averages ranging from 26.30 to 54.52 Eur/Mwh between 2002 - 2007 [69]. Historical validation is limited as stated in the beginning. Still these numbers tell that the simulation values are in the ball park of reality. A recommendation is to look at studies that predict future electricity price and compare these results with the model outcomes.

7.7.1. Conclusion

The validation was done by comparing the subsidy costs, clearing and bid prices with observed electricity prices, and historical wholesale electricity prices for the spot market were compared. The outcomes reflected reality except the very high bid prices of biomass, which is related to the tender-participation-effect.

8

Conclusions

This chapter presents the main findings of the work done, and derives from there its recommendations and contribution to literature.

8.1. Primary objective

The primary objective is to answer the main research question: *What are effects of RES-E tender support policies on the electricity markets of an interconnected two-country situation in the long run under harmonization?*

Effects of harmonized RES-E tenders Is was found that RES-E tenders stimulates investments in renewable energy technologies that leads to lower electricity prices, creates higher welfare for consumers, but decreases welfare for producers. The lower prices are accompanied with higher volatility.

Furthermore, a rapid development of RES-E creates high yearly generation costs, and high tender clearing prices result in high subsidy costs. Next to the objective of de-carbonisation, it is important for the regulator to deal with technologies that do not participate in the tender, to make sure no high clearing prices occur due to yearly increasing targets.

Effects of high interconnector capacity The increase of interconnector capacity under high penetration of RES-E lowers the overall cost of outages. A country with relative high RES-E energy targets increases the subsidy costs for renewables in the neighbouring country under perfect market integration, and subsequently leads to increased cost burden for society in the importing country. The importing country can offset this by implementing low RES-E targets. However, the consequence is that high differences in RES-E targets between countries, leaves the less ambitious country to serve basically as a 'back-up-country' for its neighbour.

Effects of a technology-specific tender The research showed that a technology-specific tender leads to lower RES-E target fulfilment when one or more RES-E technologies do not participate in the tender. A technology-neutral tender is thus more effective in stimulating RES-E since the regulator is indifferent of which technologies are participating, as long as these are the lowest cost technologies.

Effects of high RES-E ambitions A country can be too ambitious in setting its RES-E target, meaning that if a RES-E target is not met, it results in higher clearing prices and subsequently imposes a burden on society due to high tender subsidies. It also shows that the regulator can control the generation costs to a certain extent by setting the RES-E targets since RES-E is accompanied with high generation costs.

Setting the RES-E targets right Regarding the regulator, it is concluded that setting the right RES-E target is is of paramount importance but prone to uncertainty due to expectations in renewable generation in the market.

Overshooting expected generation leads to high higher tender quotas than necessary, which leads to over fulfilment of the pre-determined tender targets. Subsequently, it causes higher tender clearing prices which increases the yearly subsidy costs more than needed, which is passed on to society. Moreover, overshooting also affects producer welfare and cash balances negatively, costs in generation and outages rises and electricity prices increase accompanied with more volatility.

While undershooting the expected generation, results in lower RES-E target fulfilments and thus more carbon intensive technologies in the market than demanded. This can be overcome to let the regulator predicts for a shorter interval such that he does not look further into the future than the lead time of a technology.

It is concluded that setting the targets wrong will affect the success of the tender or that it imposes a larger cost burden on society than necessary.

8.2. Secondary objective

The secondary objective aimed to find what policy conditions and configurations are most beneficial from an EU and Member State perspective based on the results. It was found that soft policy harmonization and improving market integration i.e. increasing interconnector capacity are the best scenarios for the EU policy maker, while full harmonization is the best scenario configuration on the level of both Member States. This implies that a conflict can arise between the interest of the EU and the Member States. Moreover, one also needs to take into account that the importance attributed to a certain welfare or cost indicator, can be different among the two national policy makers. Full harmonization would be less feasible if countries do not agree on design variables of tenders, or the priority of certain indicators. Both could lead to different policy configurations, which is in most cases will be moving away from full harmonization. This concludes that full harmonization of RES-E policies is unlikely to succeed.

8.3. Policy recommendations

On harmonization The electricity markets of the two countries have been analysed under perfect market integrated and different forms of harmonization in the tender design and RES-E targets. By plainly stating that harmonization is something that should be pursued, one will lack the necessary context and omits country specific effects in the discussion. Unfortunately, this research could not compare the results with a scenario that reflect the current Dutch and German situation. This would have been insightful to reflect on switching from the current situation to an harmonized support scheme approach.

However, the insights are helpful on the effects of different configurations of harmonization and add to the debate how certain policy configurations affect Member States in the EU. The outcome of the secondary objective shows that harmonization as a top-down approach, should be meet with caution since different interests among stakeholders exists. This experiment was 'only' an analysis of two countries that have a strong intertwined economy and have a long positive history since 1956 in cooperating with each other. Imagine less greater ties between countries, and more divergent interests. How could one politically establish one harmonized energy policy for the whole of Europe with so many context and country specific characteristics if for two similar countries it is already difficult?

A strong recommendation is to relax the top-down approach and think in a bottom-up approach to increase welfare, reduce costs and improves RES-E policy success like the co-operation between Sweden and Norway, and the future joint project between Ireland and UK on [16].

Government budget constraints In the tender module no budget constraints were added. This meant that the government was tendering as long as it did not reach the tender quota in despite of the yearly subsidy spent. A predetermined cap on the subsidy would be advised since it also controls the total costs, which was one of the main advantages of a quantity-based support scheme.

Context specificities Technology-specificity was modelled as one of the context specificities. According to theory this should stimulate all eligible technologies to participate in support schemes while reducing windfall profits. A technology-specificity should lead thus to higher economic efficiency. However, one needs to be careful in setting the targets and selecting eligible technologies. If they do not contribute, the overall RES-E target is impeded.

A size-specific support could also be introduced to stimulate small scale power plants, which have higher average cost due to low economies of scale and are ’beaten’ by large scale power plants in terms of bid prices. EMLab focuses on large scale installations, but in practice one should also allow small investors to enter support schemes, which is what size-specific tenders could establish.

The location-specific support could also be introduced, since certain locations are more costly to invest in, but might have high capacity limits. To achieve RES-E targets, these more expensive sites needs to be accessed to when other locations are already having installed capacity. It might deter investor from participating in tenders to create installations in these nodes since the risk of not winning the tender is high due to high bid prices, which could be solved to make tenders site-specific.

Penalties for non-compliance In the model each winning tender bid resulted in a power plant. It was modelled this way that no agent ever deterred from building. However, in practice bid prices (due to strategic behaviour) might be underbid and power plants might never be built because these competitive investor do not recover their costs. The SDE+ has a penalty when constructions are delayed or cancelled. This penalty has to be set at the right level: a penalty that is too low does not scare investors from deterring while a high penalty might deter them from participating in the tender.

Generation adequacy policies The shortage-effect had severe consequences in the model as discussed before. In practice, intermittent RES-E does create shortages if their are no flexible back up power plants, storage, excess energy from neighbouring countries or capacity mechanisms. Since the EU aims to achieve 80% electricity produced by renewables, a method has to found to incentivize back up capacity or any other technology that qualifies as renewable and thus not emit CO2.

8.4. Insights for science

The merit order effect has been an important debate: whether it will lead to low or high average electricity wholesale prices in the long run. Low prices can be expected when intermittent RES-E sources are the marginal generators in the merit order leading to zero prices in segments (as observed in my work, shown in appendix F). High prices can be expected when intermittent RES-E sources are alternating with peak power plants with high marginal costs [70]. From this thesis work it can be stated that the electricity price increases on average over time due to the created shortages by RES-E when no sufficient power plants are built in time.

The sensitivity analysis showed that the regulator has trouble to set the right target due to errors in forecasting generation. This had two severe effects: overshooting the target and thus not able to reach RES-E targets or undershooting and impose high cost burden on society and deteriorate welfare. The undershooting could be solved by if the regulator predicts less years ahead: his forecast will be updated more often and is more accurate, which is due to the lead time of a technology. In this work it was found that announcing the tender 3 years ahead, which means estimating generation from renewables for three years ahead, is the well balance choice between overshooting and undershooting expected generation.

8.5. Future Research recommendations

Cooperation mechanisms From literature it was found that harmonization as top-down approach is hard to establish politically [15]. There are other methods to improve welfare and cost efficiency in this regard, and that is via co-operation, which is a bottom-up approach. A recent example happened between Sweden and Norway, and a joint project between Ireland and UK is in the pipeline [16]. This give results to similar effects, only the countries make their own decisions and thus take into account regional and local aspects, which could lead to even higher effectiveness and efficiency than the top-down approach.

Extension of countries To asses the effects of costs and welfare in two countries, it does not take the interaction with the other neighbouring countries into account. Europe becomes more interconnected and the characteristics of countries are different e.g. generation mix and national policies. The interaction between more countries can results in new insights and different effects.

Current electricity market design One should think about the impact of RES-E: whether they create very low prices or high volatile prices, it will impede electricity markets returns and stability. This deteriorates investments and pose a risk on security of supply. So I advice to start explore the following research question: ”Is the current electricity market design capable of dealing with security of supply, stable prices and high shares of RES-E, and if no what alternative can be proposed?” An alternative market design could be derived from the telecom market, which is contract based. The EU is currently organizing consultation with stakeholders and their view on this. The first results of these gathering can be found here `https://ec.europa.eu/energy/en/consultations/public-consultation-new-energy-market-design`

Risk The effects of risk aversion [71] could be included in the calculation of the tender bid price. Since this price is based on the expected generation in the future, one could add different risk averse agents and look at their bidding behaviour and the resulting tender clearing prices.

Other support schemes Another support scheme could be modelled and simulated under the same scenarios like Tradable Green Certificates or a Feed in Premium if obtained via competitive bidding process. The EMLab model has a working storage and capacity mechanism algorithm as well a CO2 module. All three options could be switched on to look into the interactions between these mechanisms under policy harmonization.

Other recommendations A further extensive list of detailed future recommendations specifically for this model and research questions are:

- Abolish the tender-participation-effect: thus improve the tender bid computation part such that biomass and biogas also bid sufficiently in the tender.
- Abolish the shortage-effect that occurred due a statement in the standard investment algorithm. It could be switched off or relaxed such that no shortages arise. This was outside the tender environment, so one should look at more interactions with the existing model.
- Solve the negative profits issue in the model. One expects to obtain average profits to be zero over time when investors are profit maximizing agents, which is the assumption in the model [53]. It is used as verification: once the model is debugged well, profits are on average zero. However, this was not the case for my model including and excluding the tender module. Although the profits were more negative with the tender model.
- Instead of handing out a fixed amount per year as subsidy based on the expected generation, one could chose to give only the subsidy amount accordingly to the actual generation to overcome under or overshooting.
- Congestion rents is not taken into account, which normally should adds up to welfare calculations.
- When should the regulator stop tendering i.e. when does RES-E reach the point of grid-parity? The calculation of the market value of RES-E can be incorporate to determine this.
- It was not observed whether RES-E producers recovered their costs due to time constraints, which is very important to determine the success of the support scheme. One should calculate the income that the RES-E producer receive for a certain plant from the market, plus the tender subsidy, and deduct average costs.
- Take size-specific support, location-specific support and penalties for non-compliance into account.
- A real Base Case should be established. Now the Base Case was based on an harmonized situation and taken as anchor. A Base Case that reflects the current situation of the Netherlands (tenders with feed in premium) and Germany (feed in tariff) leads to a better benchmark for comparisons.
- The Same Target scenario approximated the full harmonization case. However, a joint tender support scheme where all agents can bid in and one overall RES-E target is a better reflection of this type of harmonization. Create joint weighted RES-E targets based on the relative potential of each country.
- Create statistical noise in the data of the full load hours to decorrelate their production patterns.

- Germany is phasing out nuclear and lignite, and recently the Netherlands agreed to phase out coal plants. However, these recent policies are not reflected in the model scenarios. One should incorporate these decisions to increase the link with reality.
- Make sure that investors do not compete with their own power plants when bidding for renewable plants in the tender since they will push their own plants simply out of the merit order.
- Include CO2 market or carbon tax

9

Reflection

This part looks from a distance to the thesis work and looks at future improvements and the process I have been gone through. The following parts will elaborate on the reflection of the model, the methodology and my personal process of the thesis.

9.1. About the model and methodology

During the process I have asked myself whether Agent-Based modelling was really necessary to use as modelling paradigm, to test the performance of different configurations of harmonization on costs and welfare among others. The main criticism is that standard economic theory could have sufficed here to something about the efficiency and welfare effects in the long run when countries start to collaborate (harmonization) and open their border completely (infinite interconnector capacity). The conflict of interest between Member States or the EU could have simply derived from stakeholder analysis. And in addition, an optimization dispatch model could have sufficed to observed price volatilities.

Having said that, what would have been lost were the insights of the uncertainty at the regulator side setting the targets right (or wrong) by uncertain predictions in expected generation. Also the effect of technologies not participating in the technology-specific tender would not have been observed. Moreover, the investments made in the past constraints agents to make new investments i.e. path dependency if there cash flow is not sufficient. Also the shortages in RES-E generation that arise after many renewable plants are dismantled in a certain year depends on past decisions. These very specific effects would not have been easily observed in another type of model.

The validation of the model structure and the results was very short. Due to limited validation options and time I could not put the quality in that I would have liked: comparing the Dutch tender SDE+ and other renewable tenders around the world with the modelled tender and its quantitative outcomes.

9.2. About the process

At the beginning of the master thesis I stated the following goals for myself:

1. Increase my programming and modelling skills
2. Improve my critical view and research attitude
3. Learn about integration of renewable energy in an European context

I definitely achieved the first goal: coding was a very large part of the thesis, which I underestimated at the beginning in time and complexity. Before I was able to run a scenario with the tender model and analyse my first reasonable results. I experienced a steep learning curve where I learn new software and languages in a small amount of time: from using Linux, AgentSpring and Github, learning Java and Gremlin, and improving my skills in R and LaTeX.

The second goal is achieved as well. When I compare the phase of the thesis definition with the end phase, I observe that I learned a great deal in solving problems in a systematic and structured way, learned to have more patience and I became more critical.

In terms of the last goal I learned especially about RES-E tenders. I was very happy to hear that during my thesis process, the Environmental State Aid guidelines suggested using competitive bidding processes as support schemes. And that RES-E tenders are getting more attention these day in the EU (`http://auresproject.eu/`). These developments make my work very relevant.

A disappointment during the thesis was the lack of collaboration with other master students working with EMLab. Working together could have lead to synergies, improved models and scenarios and solving errors more efficient. I was glad that I arranged office space at the department of my professor and the other researchers that worked on EMLab or related energy policies. This became quite useful in solving problems. I would recommend new students on EMLab to work together as groups for the synergy on problem solving and the social aspect. Besides that, social interaction during the thesis is a very important drive to keep on going and work hard.

9.3. Conclusion

In general, this project has been challenging for me. I spent quite some resources on learning new programming languages, syntax and developing the model. Nonetheless, I am very happy that I did this project. I met inspiring enthusiast new people, I learned a great deal about myself and I developed new skills. I am also glad that I could make a contribution to EMLab with the tender module and with that help others in their research.

A

Main RES-E policies

There a two approaches for these policies; a quantity-based and a price-based support approach. In the first approach a quantity or target is set by the government that needs to be achieved. Two main examples are given in the paragraphs below.

Competitive bidding process In this case the government sets a quantity target that should be generated from RES-E. Producers can bid quantities of RES-E, which they are able to produce. Next, the bids based on the price per kWh are collected in increasing order. The producers with the lowest costs will receive a long-term contract with constant prices to supply electricity (Finon & Menanteau, The Static and Dynamic Efficiency of Instruments of Promotion of Renewables, 2004). The terms auction and tender are often used interchangeable. The aim of an auction is to offer services, and a tender asks for services. In this case services are RES-E investments (Klessmann, Managing Consultant Policy Design and Evaluation at Ecofys, 2013).

Green Tradable Certificates (GTC) A fixed amount of electricity, which will be sold by energy suppliers, should be generated from a renewable energy source. For each specific quantity sold, a green certificate is received. This implies that RES-E producers create certificates, whereas fossil fuel suppliers need to obtain them. Hence, a market for certificates arises. In this market, energy suppliers can buy or sell the certificates for a certain price. In a market with perfect competition, the equilibrium price should equal the price of the FIT, and RES-E suppliers generate revenue in this case (Finon & Menanteau, The Static and Dynamic Efficiency of Instruments of Promotion of Renewables, 2004).
In the second approach the price is fixed by a public authority (Menanteau, Finon, & Lamy, 2003). The

distinction between these two approaches can be important because when investors risk is taken into account, a quantity based approach can pose price, volume and balancing risks whereas a price-based apprach provides lower risk due to its price stability (Burer & Wustenhagen, 2009). The main example of a price-instrument is given below.

Feed-In-Tariff (FiT) A RES-E producer receives a certain price on top of the current electricity price. This works as a subsidy and is exploited until the marginal costs of RES-E producers equal the tariff price, and hereby determines the quantity that is generated (Finon & Menanteau, The Static and Dynamic Efficiency of Instruments of Promotion of Renewables, 2004).

B

Full load hours, capacity limits and hourly demand

B.1. Deriving full load hours and capacities

The different full load hours per RES-E technology and its capacity limits are derived from the data of the Green-X toolbox [51]. To obtain the full load hours per cost level, one can look at the energy cost per unit and via reverse engineering, knowing the detailed cost like O& M, variable cost and investment cost Next, the maximum capacity (MW) per node is obtained by dividing the amount of potential obtainable energy by full Load Hours. The following example calculation shows how the data is obtained for Wind from Austria. The same method is applied to the renewable technologies for country A (NL) and country B (DE). The data in table B.1 is used.

Table B.1: Variables and units

variable	Unit/Content	Description
C	Euro / MWh	Generation costs per kWh
C_{fuel}	Euro / MWh	Fuel costs per energy unit
$C_{O\&M}$	Euro / kW * a	Operation and maintenance costs per energy unit
I	Euro /kW	Investment cost per kW
CRF		capital recovery factor
z	%	interest rate
H	h/a	Full-load hours per annum
$Capacity$	MW	Capacity
$Potential$	GWh / a	Potential generation per annum

1. The following cost curve is given, and let's take the third level at C = 70 Eur/MWh for LRMC, and 21 Eur/MWh for SRMC for Austria (AT)

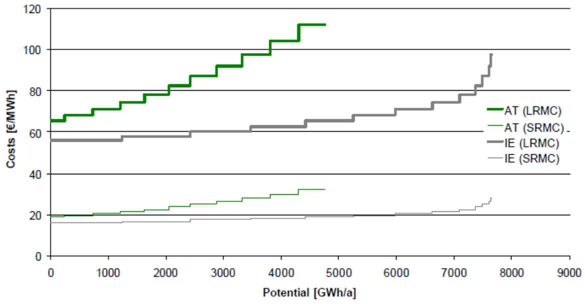


Figure B.1: Cost curve AT

2. Using the following formula we can calculate H by rewriting it for full load hours

$$C = C_{fuel} + (\frac{C_{O\&M}}{H} \cdot 1000) + \frac{1000 \cdot I \cdot CRF}{H} \tag{B.1}$$

3. Rewriting for full Load Hours gives

$$H = \frac{1000}{C}(C_{O\&M} + I \cdot CRF) \tag{B.2}$$

with CRF

$$CRF = \frac{z(1+z)^{PT}}{(1+z)^{PT} - 1} \tag{B.3}$$

4. Using the long run marginal costs (LRMC) gives 644 full load hours. For the LRMC between a potential of 800 and 1100 GWh / year = 300 GWh / year [B.2]
5. With the following calculation the capacity node limit is obtained:

$$Capacity = \frac{Potential}{FLH} \tag{B.4}$$

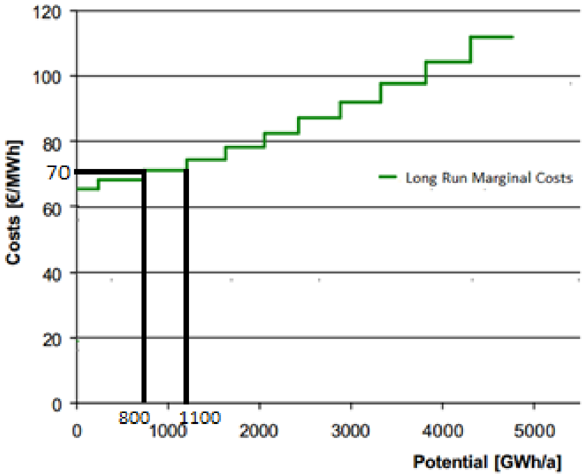


Figure B.2: Cost curve again LT only

B.2. Application

Now a method for deriving the full load hours and capacity limits is derived, we need to arrive at three full load hours times series and three capacity node limits for each intermittent RES-E technology. Hence, the three nodes. For biomass and biogas one capacity node limit is sufficient, since it production is not highly depending on its location. The following steps explains the procedure. The file names are referring to the data, which can be obtained via `https://www.dropbox.com/sh/v2dqz8ehcgq5hzr/AACzGpAuEK4jHYQkTyahRS5Ca?dl=0`. Access can be granted by the author of this thesis.

1. Via reverse engineering (`cost_curves_reverse_engineering.pdf`) of the static cost curves of the Green-X toolbox the following was obtained per band:
    - Full load hours
    - Potential capacity up to 2020
    - Generation potential up to 2020
2. The static cost curves are based on a Business As Usual scenario i.e. no harmonization and with 'current' (2004) policies in place. See file `ActionplanforderivingdynamicRES-Epolicies-Green-X.pdf` - chapter 6

3. The bands were compressed in 3 bands, which represent the three nodes in EMLab per zone. The three node limits of each (intermittent) technology corresponds with the capacity of the three bands. See `Compressed3_Potential_capacity_generation_FLH_perBand_de_nl_solar_wind.xlsx` and `Potential_capacity_generation_FLH_perBand_de_nl_biomass_biogas.xlsx`
4. Full load hour data per intermittent source of Hirth is used for the year 2010. See file `Hirth_data_ts_Load_FLH.xlsx`. This 2010-time-series is scaled up and down by the full load hours obtained in the three bands of green-X. So three different full load hours-series for each of the nodes are created. This creates the difference in costs per node. See the file `multiNodeProduction_DE_solarPV.xlsx` Also Load/Demand data from the file `Hirth_data_ts_Load_FLH.xlsx` was obtained
5. By dividing the potential per technology by the total potential, the contribution of each technology is obtained. This contribution factor is multiplied with the NREAP target in a certain year, which gives the technology specific target in a certain year. See file `Technology-Specific-targets.xlsx`
6. The major drawback is that the points are all based on projection towards 2020, while we are simulating towards 2050. Capacity and generation projections for each technology and EU country for 2020, 2030, 2040 and 2050 is found in the appendices of the file `Roadmap_2050_komplett_Endbericht_Web.pdf`. The only drawback of this is that it is harder to determine Full Load hours per band since their cost resource curves are not given. A possibility to overcome this is, is to apply the full load hours found in the green-X toolbox and attribute them to the 'regions' of page 15 and 16 of the `Roadmap_2050` file.
7. Improvements and recommendations:
    - Update the technology-specific targets by using the 2050 generation values
    - Updating the node-limits by the 2050 capacity values
    - Use the full load hours of green-X but attribute them to the 'regions' the `Roadmap_2050` file gives to have a more realistic dispersion.

B.3. Conclusion

Full load hours, capacity node limit and hourly demand data have been obtained as input for the scenarios.

C

Translation Java variables

Table C.1: Domain class list

Report domain name	Java domain name
Bid	Bid
Decarbonization agent	DecarbonizationAgent
Energy producer	energyProducer
Regulator	Regulator
Renewable target for tender	RenewableTargetForTender
Renewable tender support scheme	RenewableSupportSchemeTender
Tender bid	TenderBid
Tender clearing point	TenderClearingPoint
Clearing point	ClearingPoint

Table C.2: Role class list

Report role name	Java role name
Calculation of the renewable energy target	CalculateRenewableTargetForTenderRole
Computation and submitting of tender bids	SubmitTenderBidRole
Clearing the tender	ClearRenewableTenderRole
Constructing power plants for winning tender bids	CreatePowerPlantsOfAcceptedTenderBidsRole
Pay out successful tender bids	OrganizeRenewableTenderPaymentsRole

Table C.3: Variable list

Report variable name	Java variable name
bid amount	amount
cash	cash
eligible power generating technologies	powerGeneratingTechnologiesEligible
renewable energy target	annualRenewableTargetInMwh
renewable target factor	yearlyRenewableTargetTimeSeries
scheme	scheme
support scheme duration	supportSchemeDuration
tender future start time	futureTenderOperationStartTime
year	tick
power plant	plant
Energy producer	agent
country	zone
node	node
start year	startTime
end year	finishTime
technology	technology
current year	currentTime
status	status
scheme	scheme
clearing amount	clearingVolume
clearing price	clearingPrice
current year	currentTick
future investment time horizon	investmentFutureTimeHorizon
number of years looking back	numberOfYearsBacklookingForForecasting
cash fraction available for downpayment	downpaymentFractionOfCash
expected consumption	totalExpectedConsumption
gross renewable energy target	renewableTargetInMwh
expected renewable generation	ExpectedRenewableGeneration
number of plants	numberOfPlants
cash flow	cashFlow
down payment	downpayment
expected generation	totalAnnualExpectedGenerationOfPlant
tender quota	tenderQuota

D

Feature technology-specificity

This appendix presents the adjustments made to the original model to allow for technology-specific tenders. The central adjustment of this feature is that each role, except the filter bid role is, is now started based on the renewable energy scheme instead of energy producer or regulator. This was necessary to have technology-specific renewable energy targets and separate tenders for each technology. The overall logic presented in chapter 4 remains the same so only the flow diagrams are given with and the changes compared to the other logic are mentioned and pointed out in the flow diagrams by a red color. The diagrams for the roles ”Filter tender bids for which there is enough cashflow for downpayments” and ”Pay out successful tender bids” did not have any modification and are therefore not included here.

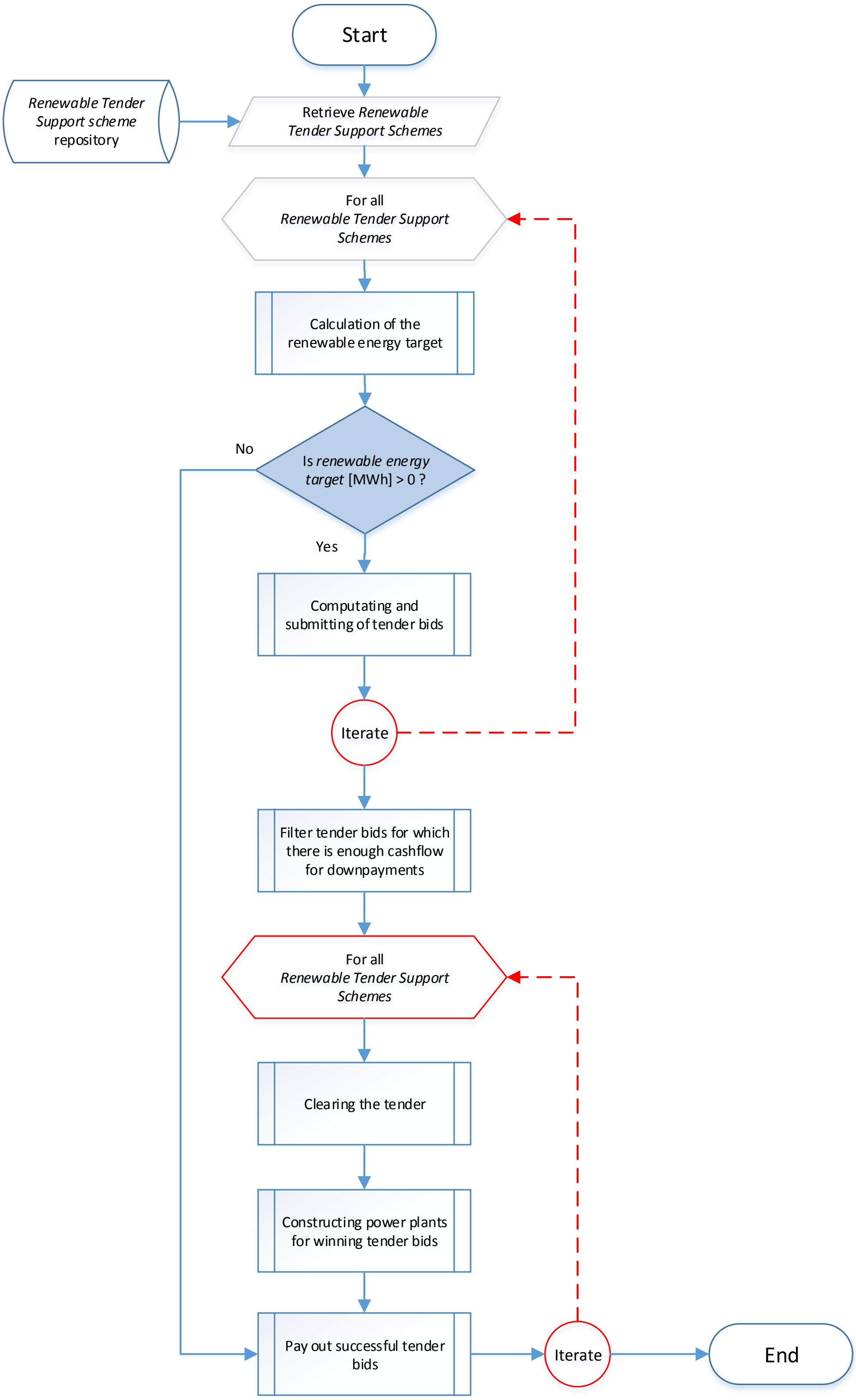


Figure D.1: Flow diagram of the main sequence of the roles

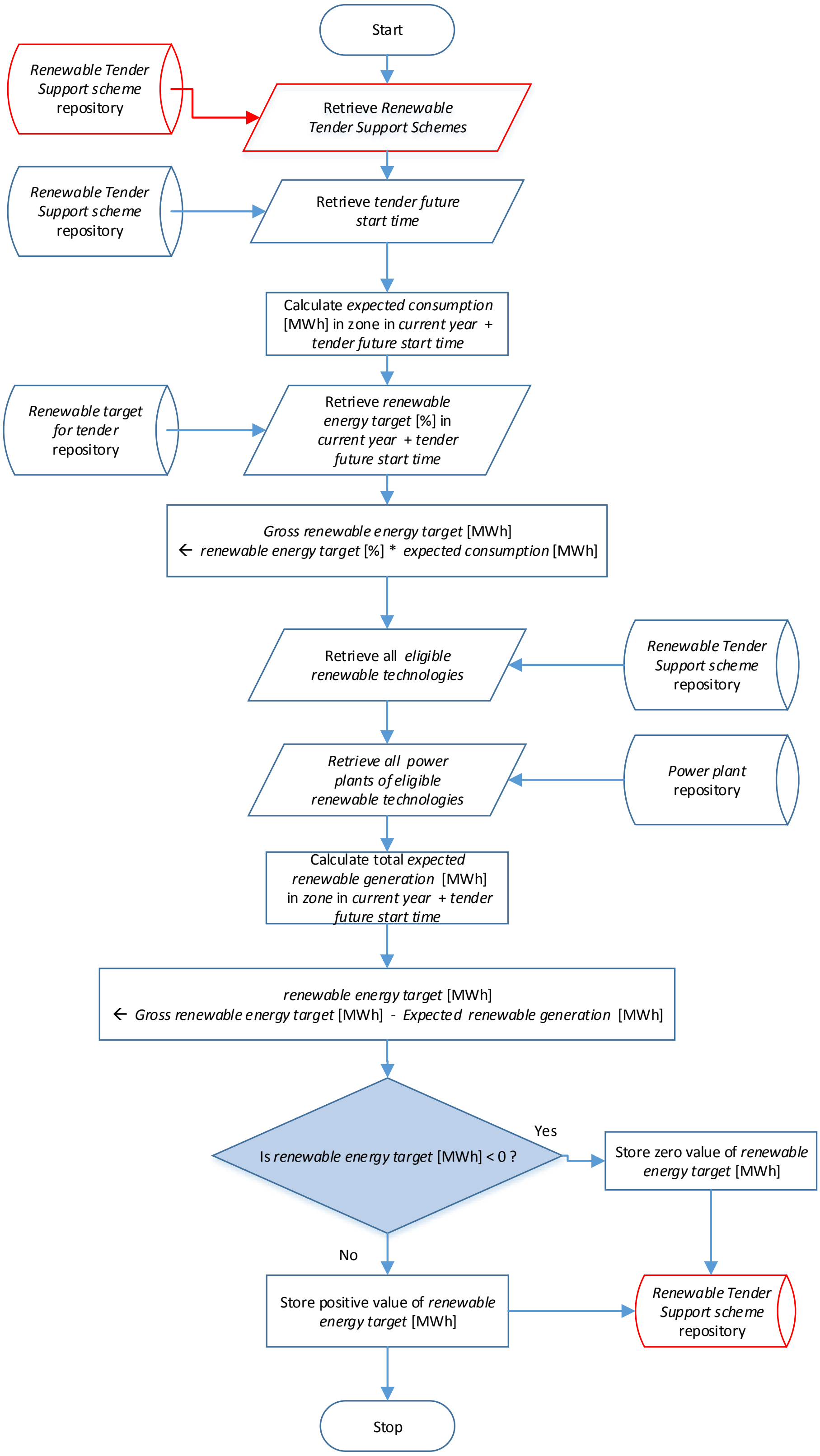


Figure D.2: Flow diagram of Calculation of the renewable energy target Role

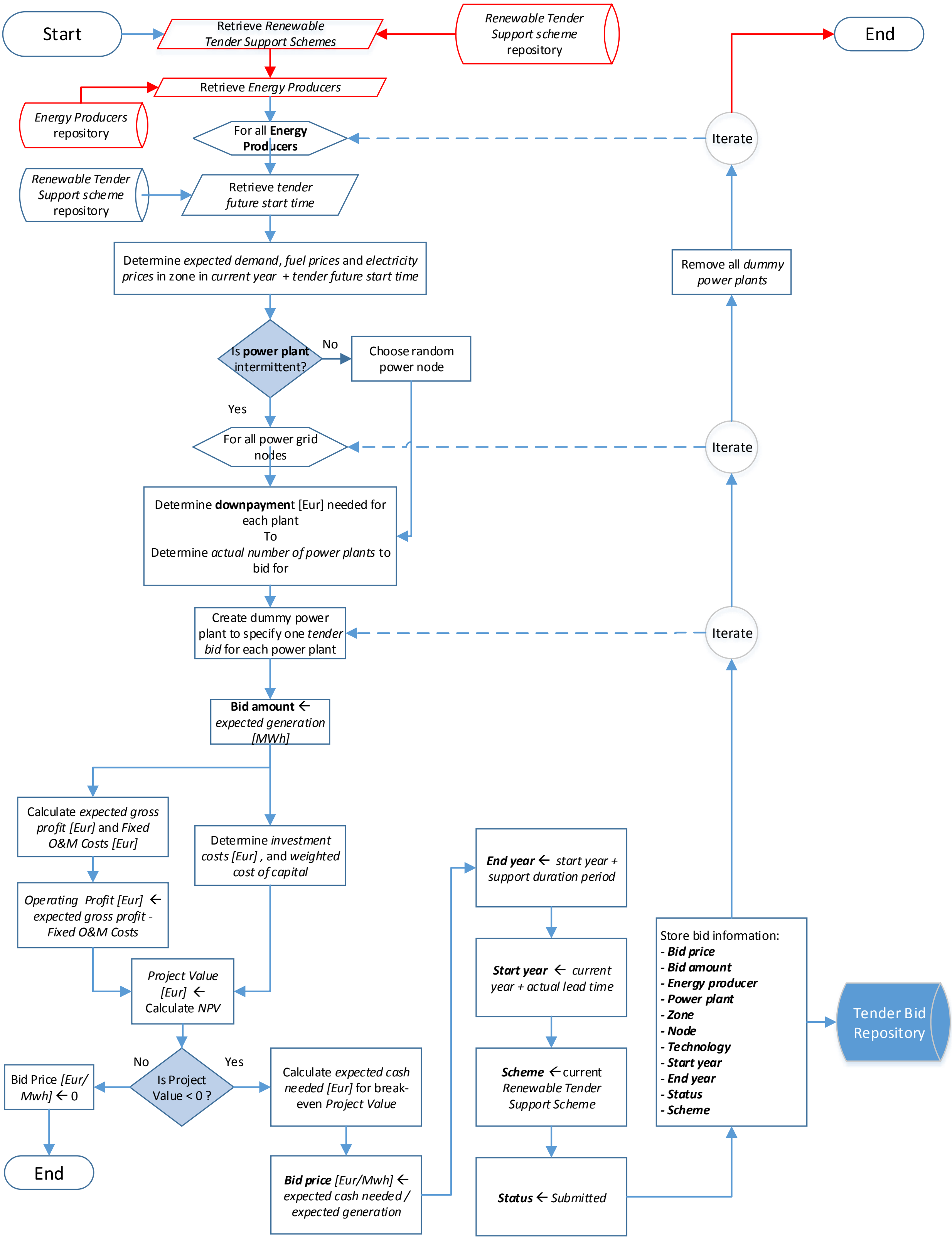


Figure D.3: Computation and submitting of tender bids

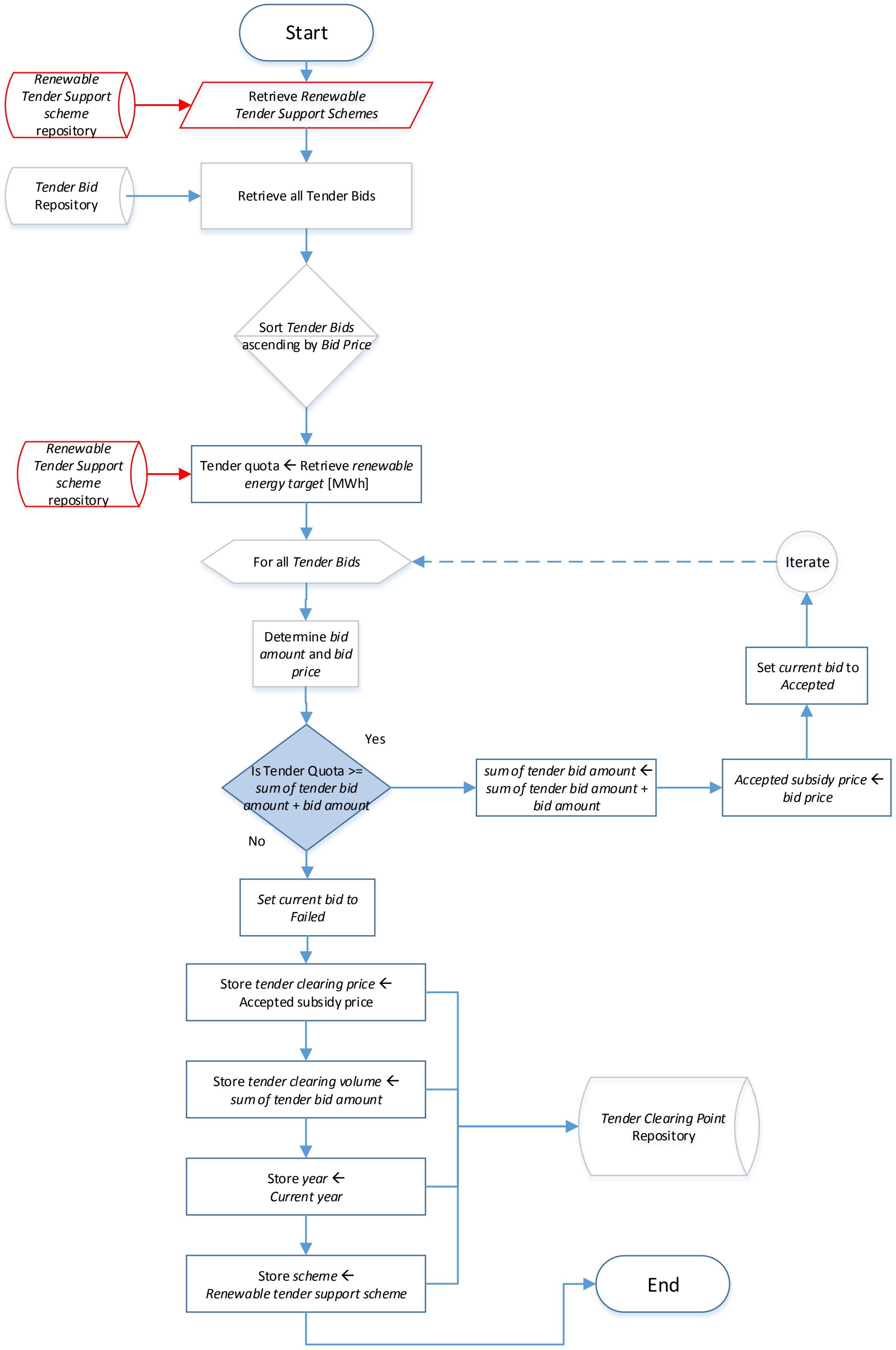


Figure D.4: Clearing the tender Role

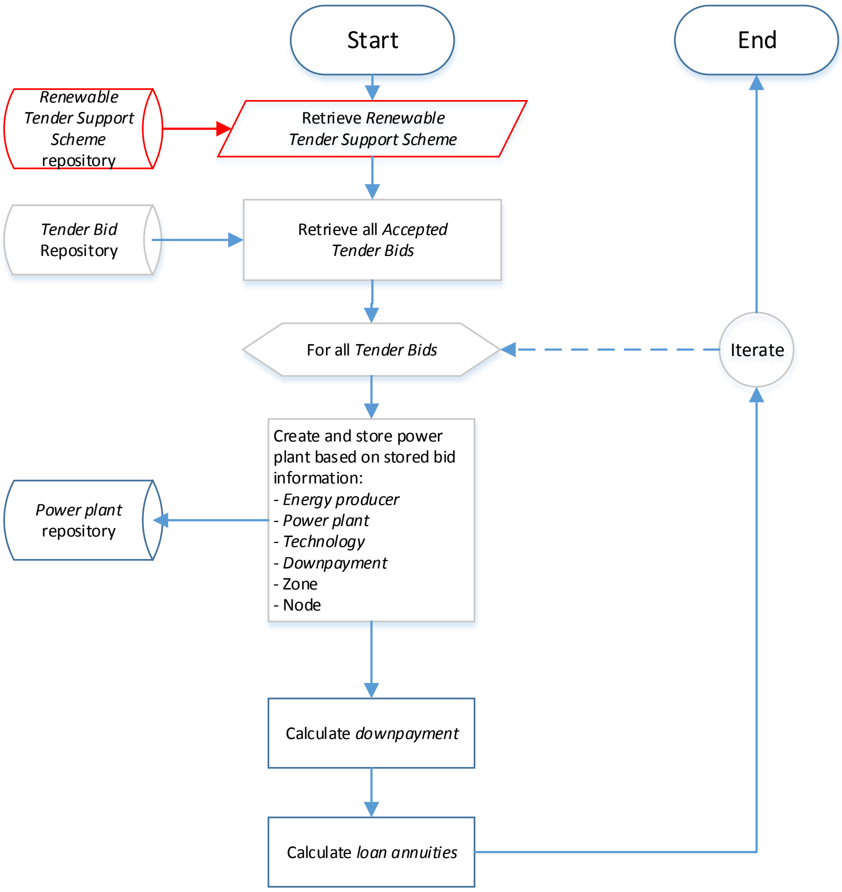


Figure D.5: Flowdiagram: Constructing power plants for winning tender bids Role

E

Appendix D

F

Tender Participation

The following two snapshots are taken to show that high bid prices that occur for the non-intermittent RSE-E sources, and the low clearing prices that occurs in combination with shortages.

The first page shows that biogas has lower marginal costs than the electricity price, which result in a high bid price. The second page shows an example for biomass were shortages occur, and consequently leading to very low bid prices.

```
WARN eligible are: Biogas
WARN expectedMarginalCost; 60.48567793136827
WARN expectedElectricityPrice; 61.70510465527282
WARN expectedMarginalCost; 60.48567793136827
WARN expectedElectricityPrice; 61.70510465527282
WARN expectedMarginalCost; 60.48567793136827
WARN expectedElectricityPrice; 61.70510465527282
WARN expectedMarginalCost; 60.48567793136827
WARN expectedElectricityPrice; 61.45059892396738
WARN expectedMarginalCost; 60.48567793136827
WARN expectedElectricityPrice; 62.604204201226786
WARN expectedMarginalCost; 60.48567793136827
WARN expectedElectricityPrice; 35.77898656604978
WARN expectedMarginalCost; 60.48567793136827
WARN expectedElectricityPrice; 37.45351076781874
WARN expectedMarginalCost; 60.48567793136827
WARN expectedElectricityPrice; 37.5760760372254
WARN expectedMarginalCost; 60.48567793136827
WARN expectedElectricityPrice; 59.698209790110695
WARN expectedMarginalCost; 60.48567793136827
WARN expectedElectricityPrice; 59.82170604394645
WARN expectedMarginalCost; 60.48567793136827
WARN expectedElectricityPrice; 60.56806705097129
WARN expectedMarginalCost; 60.48567793136827
WARN expectedElectricityPrice; 61.07080720087924
WARN expectedMarginalCost; 60.48567793136827
WARN expectedElectricityPrice; 61.19714291403633
WARN expectedMarginalCost; 60.48567793136827
WARN expectedElectricityPrice; 13.985190256114413
WARN expectedMarginalCost; 60.48567793136827
WARN expectedElectricityPrice; 0.0
WARN expectedMarginalCost; 60.48567793136827
WARN expectedElectricityPrice; 0.0
WARN expectedMarginalCost; 60.48567793136827
WARN expectedElectricityPrice; 13.985190256114413
WARN expectedMarginalCost; 60.48567793136827
WARN expectedElectricityPrice; 34.40339662956076
WARN expectedMarginalCost; 60.48567793136827
WARN expectedElectricityPrice; 35.08445048501597
WARN expectedMarginalCost; 60.48567793136827
WARN expectedElectricityPrice; 35.43001668896905
WARN expectedGrossProfit; 662757.7884810738
WARN totalAnnualExpectedGenerationOfPlant; 1077300.0
WARN fixedOMCost; 7239529.391246228
WARN operatingProfit; -6576771.602765154
WARN projectValue; -8.762609461569632E8
WARN SubmitBid 454 - Agent Energy Producer A ,generation 1077300.0 ,plant Energy Producer A - Biogas power plant ,zone Zone Country A ,node emlab.gen.domain.technology.PowerGridNode@4 ,start 13 ,finish 23 ,bid price 174.95 ,tech Biogas ,current tick 9 ,status 1 ,scheme Scheme RenewableTenderNL, cash
```

```
 WARN Submit Tender Bid Role started for: Energy Producer H
 WARN eligible are: Biomass
 WARN expectedMarginalCost; 51.84486679831567
 WARN expectedElectricityPrice; 34.51598050994906
 WARN expectedMarginalCost; 51.84486679831567
 WARN expectedElectricityPrice; 33.406523909975434
 WARN expectedMarginalCost; 51.84486679831567
 WARN expectedElectricityPrice; 33.406523909975434
 WARN expectedMarginalCost; 51.84486679831567
 WARN expectedElectricityPrice; 33.406523909975434
 WARN expectedMarginalCost; 51.84486679831567
 WARN expectedElectricityPrice; 37.82241115992489
 WARN expectedMarginalCost; 51.84486679831567
 WARN expectedElectricityPrice; 36.606675055421086
 WARN expectedMarginalCost; 51.84486679831567
 WARN expectedElectricityPrice; 36.013540622122065
 WARN expectedMarginalCost; 51.84486679831567
 WARN expectedElectricityPrice; 35.66228302512603
 WARN expectedMarginalCost; 51.84486679831567
 WARN expectedElectricityPrice; 33.406523909975434
 WARN expectedMarginalCost; 51.84486679831567
 WARN expectedElectricityPrice; 33.406523909975434
 WARN expectedMarginalCost; 51.84486679831567
 WARN expectedElectricityPrice; 2000.0
 WARN expectedMarginalCost; 51.84486679831567
 WARN expectedElectricityPrice; 2000.0
 WARN expectedMarginalCost; 51.84486679831567
 WARN expectedElectricityPrice; 92.30702405559917
 WARN expectedMarginalCost; 51.84486679831567
 WARN expectedElectricityPrice; 92.30702405559917
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 WARN expectedElectricityPrice; 92.30702405559917
 WARN expectedMarginalCost; 51.84486679831567
 WARN expectedElectricityPrice; 95.41014043458091
 WARN expectedMarginalCost; 51.84486679831567
 WARN expectedElectricityPrice; 92.30702405559917
 WARN expectedMarginalCost; 51.84486679831567
 WARN expectedElectricityPrice; 92.30702405559917
 WARN expectedGrossProfit; 2.4791352163157052E8
 WARN totalAnnualExpectedGenerationOfPlant; 3418100.0
 WARN fixedOMCost; 6873541.883539306
 WARN operatingProfit; 2.410399797480312E8
 WARN projectValue; -1.0854722031581163E7
 WARN SubmitBid 454 - Agent Energy Producer H ,generation 3418100.0 ,plant Energy Producer H - Biomass power plant
,zone Zone Country B ,node emlab.gen.domain.technology.PowerGridNode@7 ,start 13 ,finish 23 ,bid price 0.68 ,tech
Biomass ,current tick 9 ,status 1 ,scheme Scheme RenewableTenderDEbiomassPGT, cash downpayment;
4.330768126500001E9
```
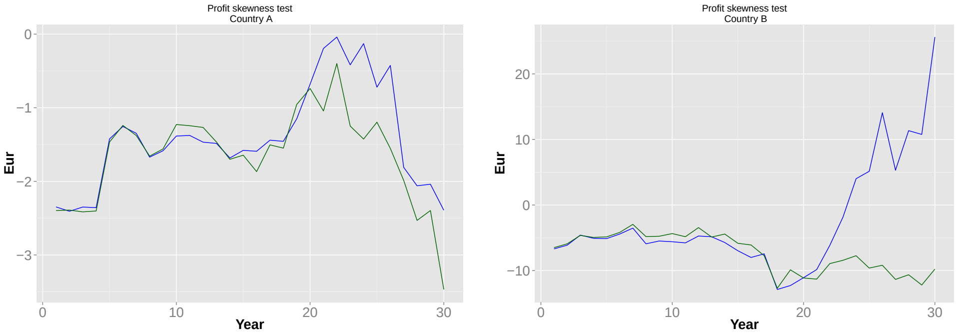

G

Mean and medians of indicators

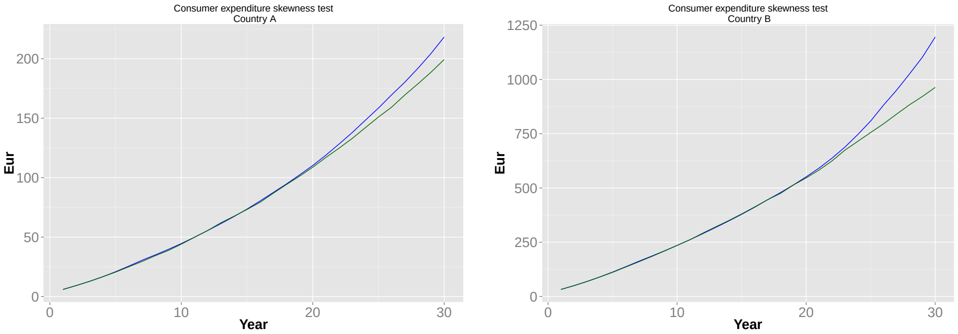
For the Base Case the skewness is reflected by the difference in the mean, given by the blue line, and the median by the green line.



(a) Country A

(b) Country B

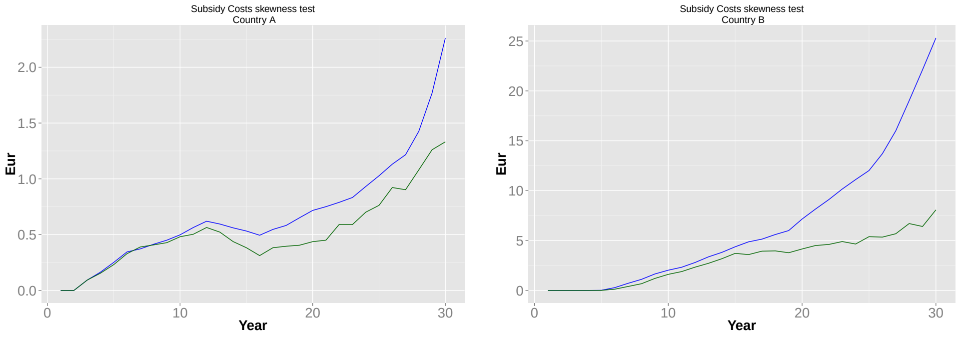
Figure G.1: Mean and median producer profits



(a) Country A

(b) Country B

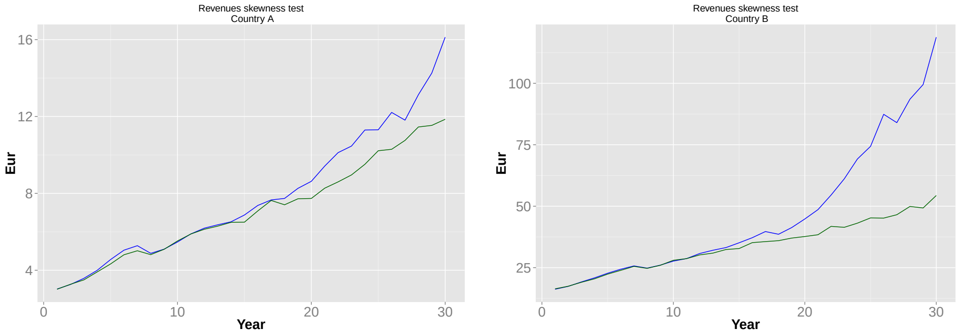
Figure G.2: Mean and median consumer expenditures



(a) Country A

(b) Country B

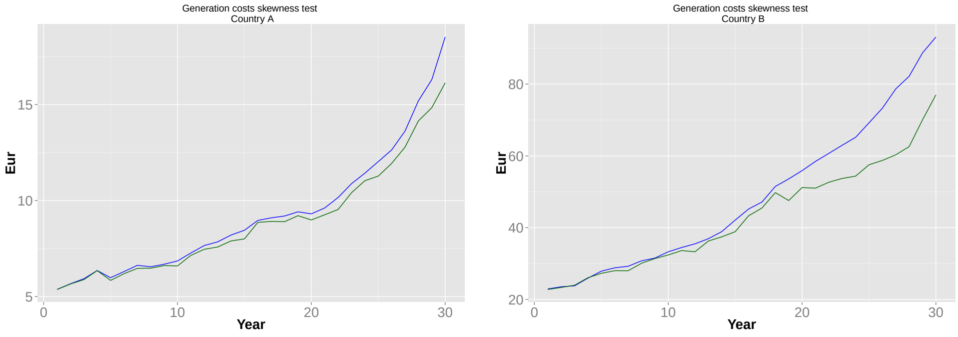
Figure G.3: Mean and median tender subsidy costs



(a) Country A

(b) Country B

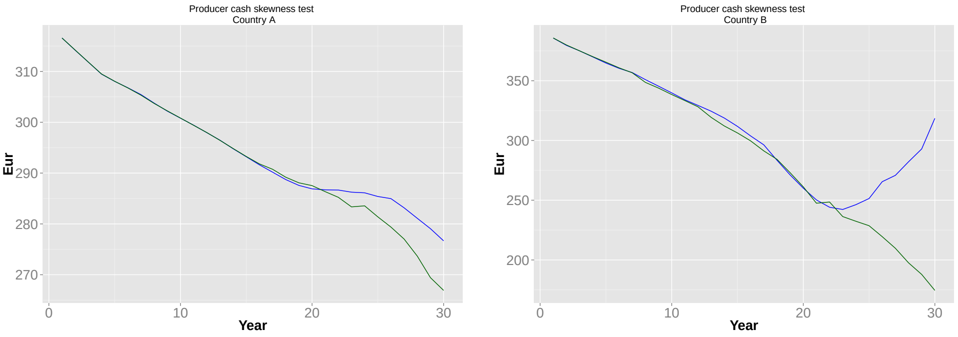
Figure G.4: Mean and median producer revenues



(a) Country A

(b) Country B

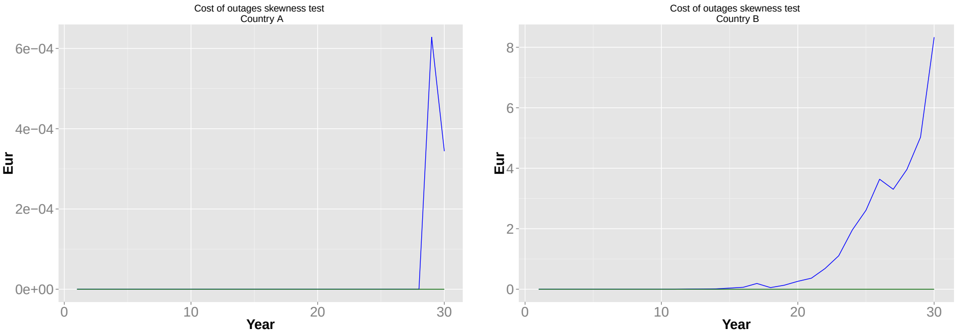
Figure G.5: Mean and median generation costs



(a) Country A

(b) Country B

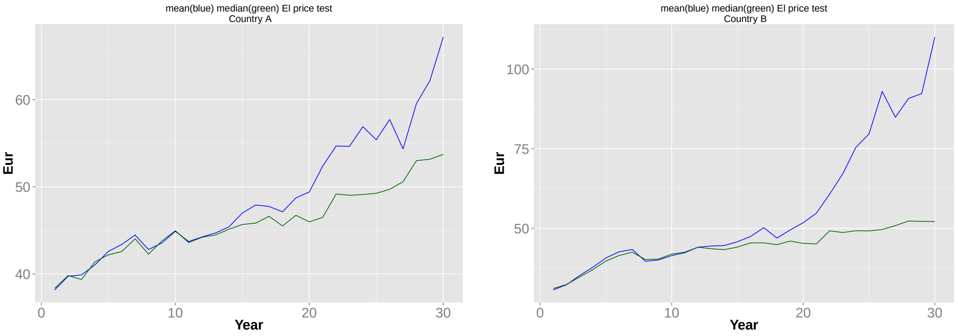
Figure G.6: Mean and median producer cash



(a) Country A

(b) Country B

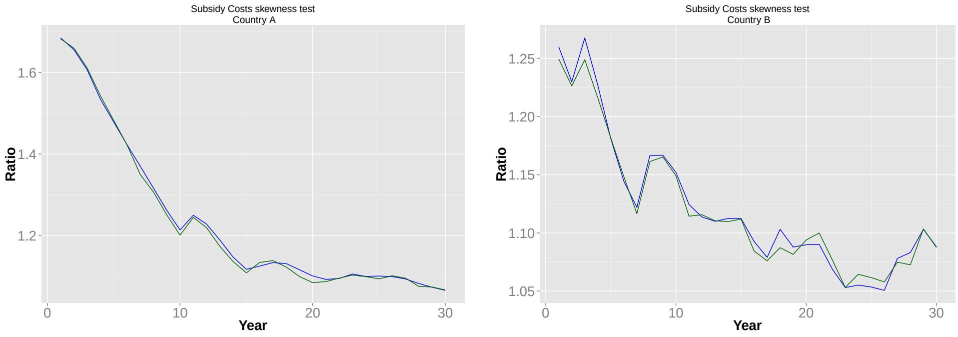
Figure G.7: Mean and median cost of outages



(a) Country A

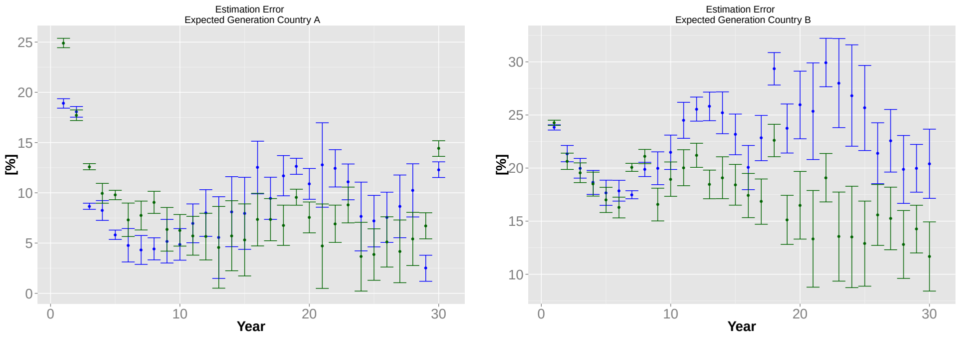
(b) Country B

Figure G.8: Mean and median weighted average electricity prices



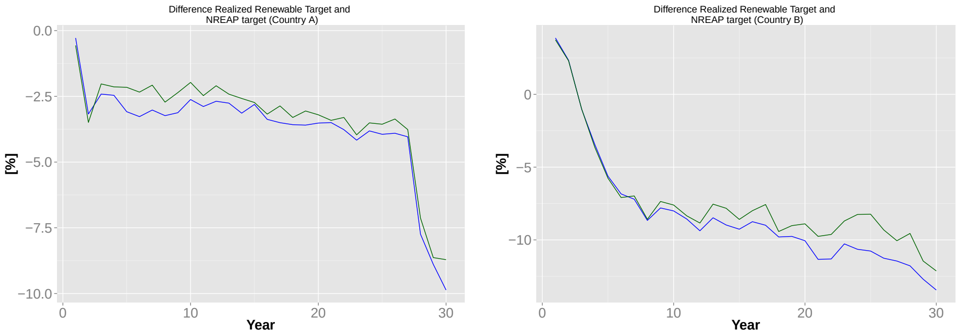
(a) Country A (b) Country B

Figure G.9: Mean and median supply ratio



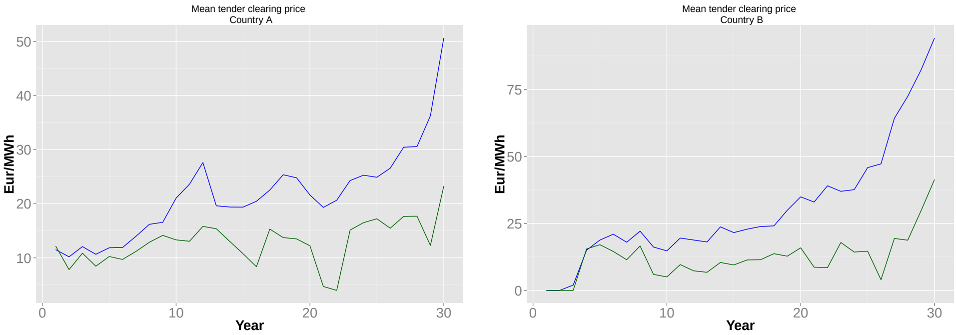
(a) Country A (b) Country B

Figure G.10: Mean and median expected generation by regulator



(a) Country A (b) Country B

Figure G.11: Mean and median tender target fulfilment



(a) Country A

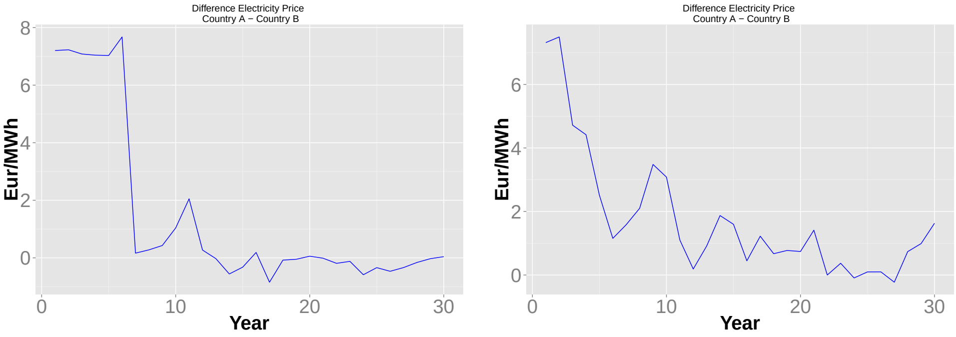
(b) Country B

Figure G.12: Mean and median tender clearing prices

H

Results

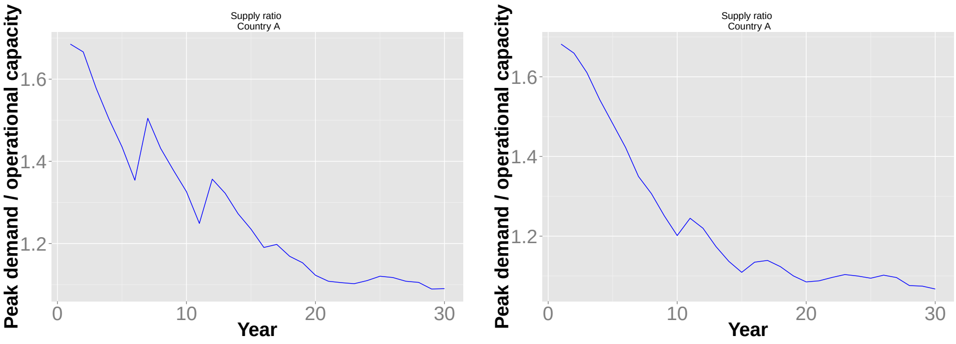
H.1. Experiment 1



(a) No Tender

(b) Base Case

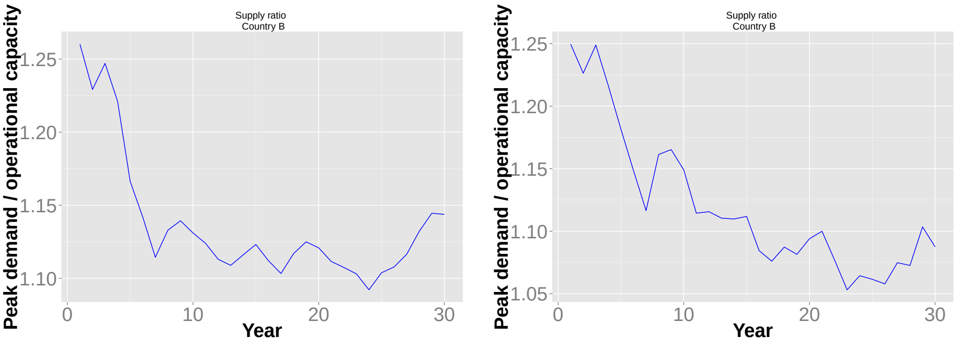
Figure H.1: Difference electricity price Country A - Country B



(a) No Tender

(b) Base Case

Figure H.2: Supply ratios country A



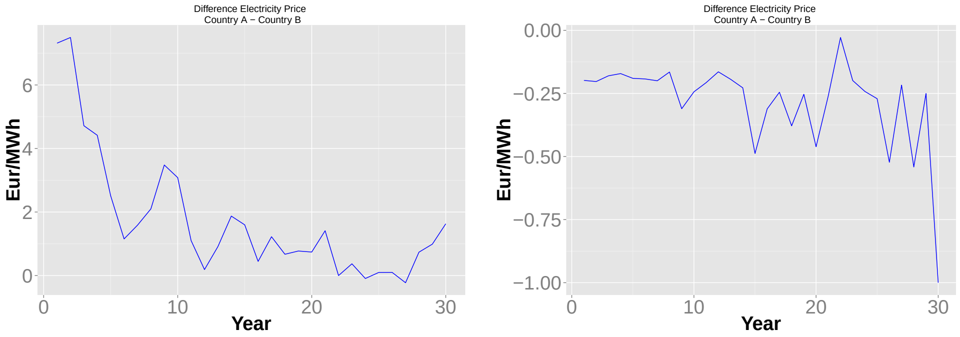
(a) No Tender

(b) Base Case

Figure H.3: Supply ratios country B

Electricity market performance

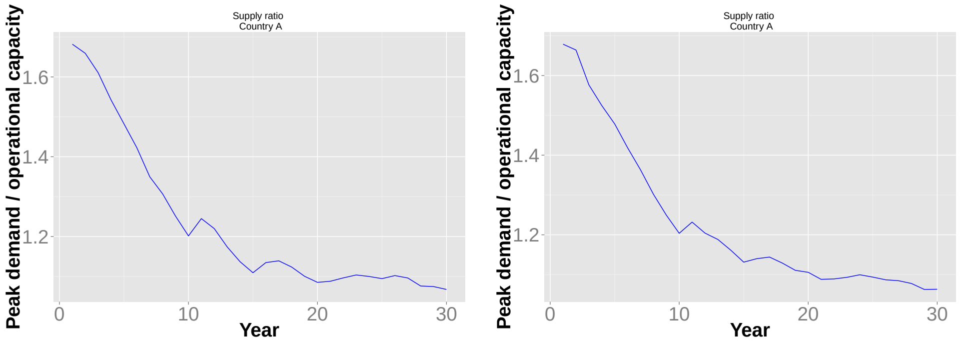
H.2. Experiment 2



(a) Base Case

(b) Infinite Interconnector

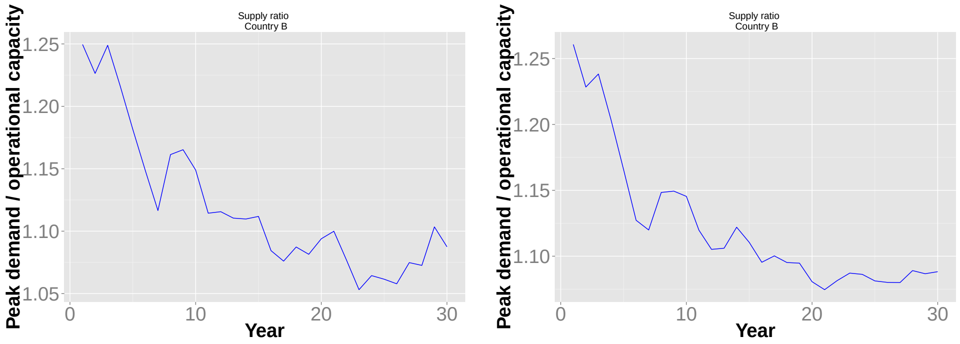
Figure H.4: Difference electricity price Country A - Country B



(a) Base Case

(b) Infinite Interconnector

Figure H.5: Supply ratios country A

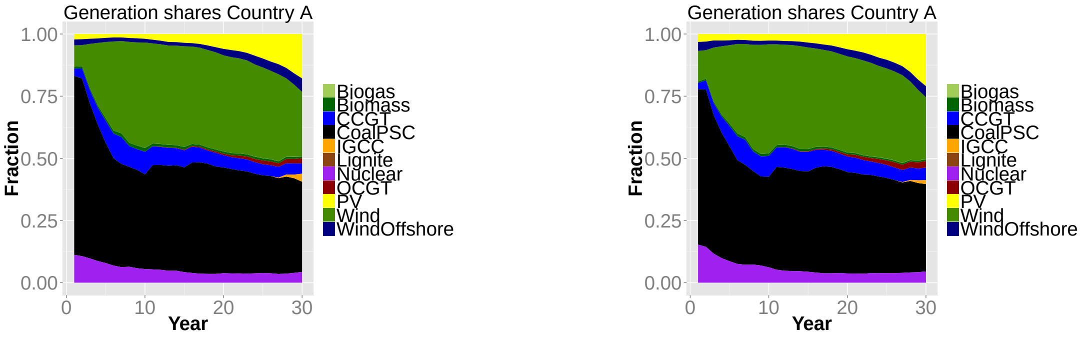


(a) Base Case

(b) Infinite Interconnector

Figure H.6: Supply ratios country B

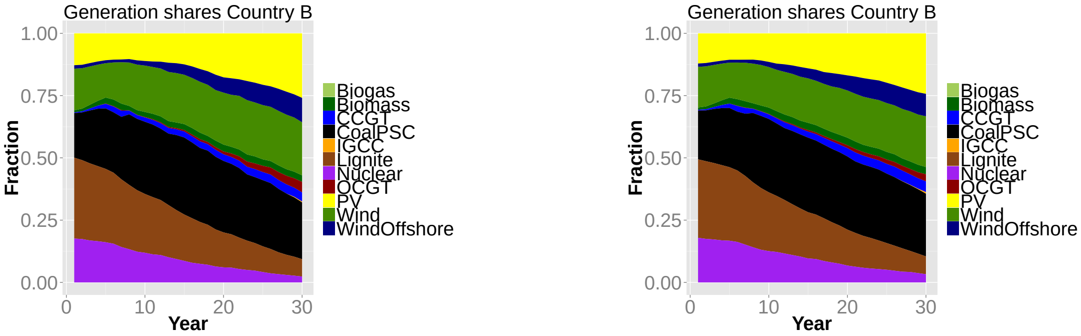
Electricity market performance 2A



(a) Base case

(b) Infinite interconnector capacity

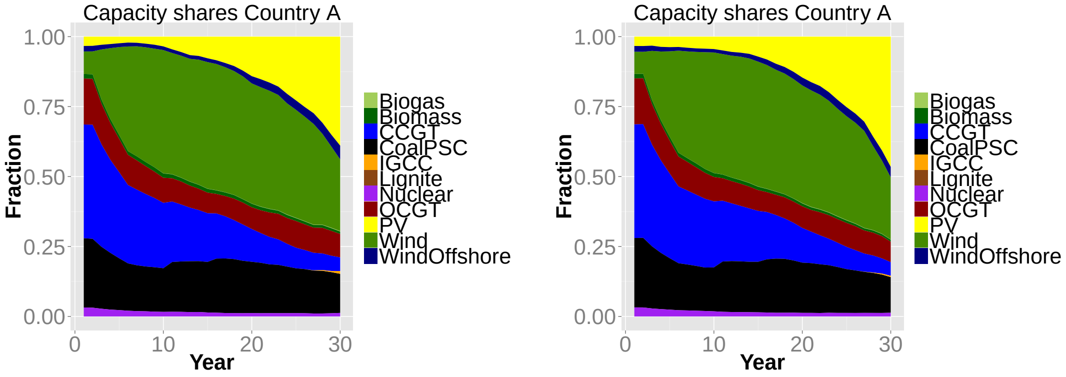
Figure H.7: Generation shares - Country A



(a) Base Case

(b) Infinite interconnector capacity

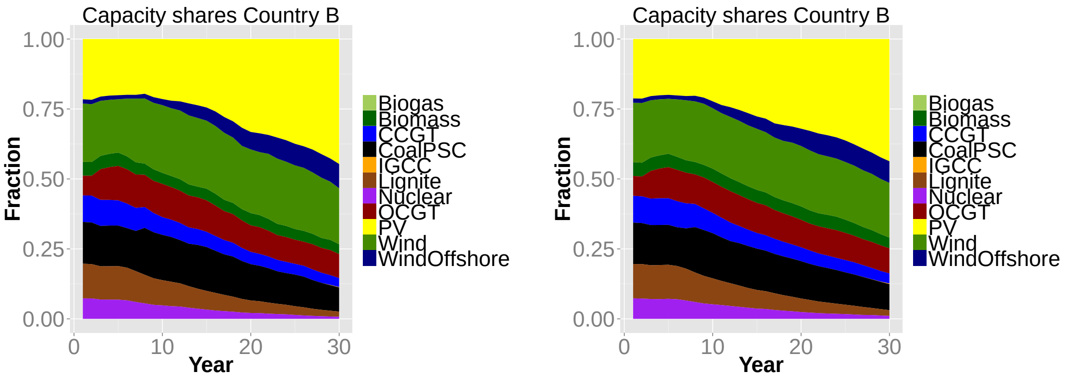
Figure H.8: Generation shares - Country B



(a) Base Case

(b) Infinite interconnector capacity

Figure H.9: Capacity shares - Country A

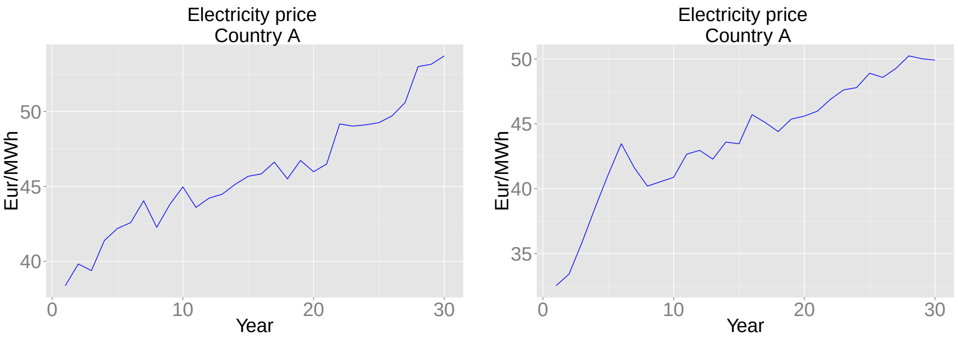


(a) Base Case

(b) Infinite interconnector capacity

Figure H.10: Capacity shares - Country B

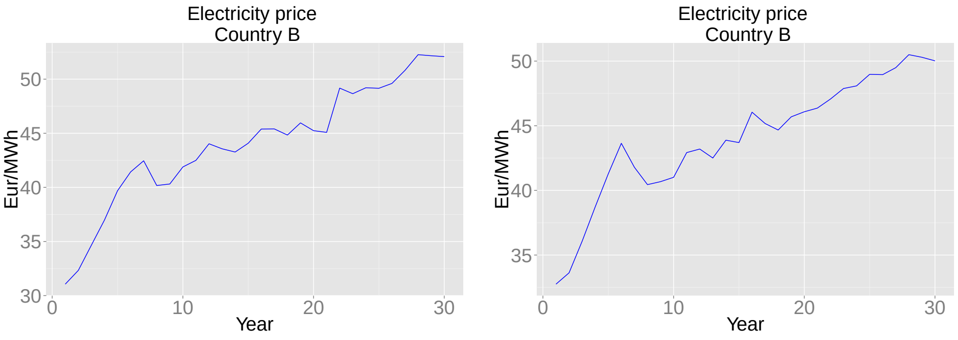
Generation and capacity shares 2A



(a) Base Case

(b) Infinite interconnector PT

Figure H.11: Median weighted average electricity prices - Country B

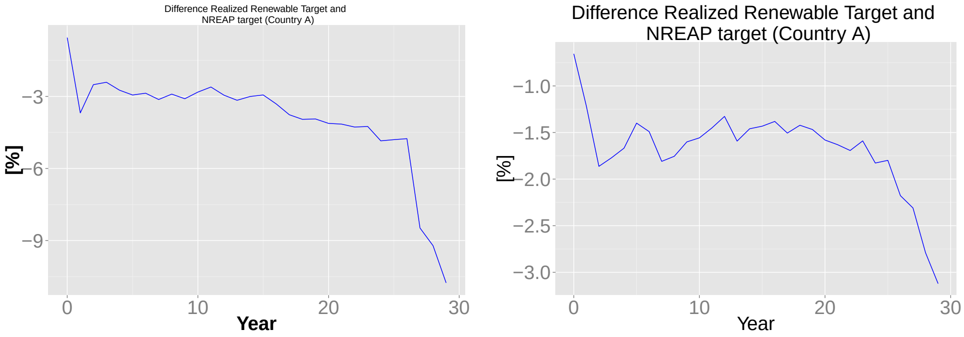


(a) Base Case

(b) Infinite interconnector PT

Figure H.12: Median weighted average electricity prices - Country B

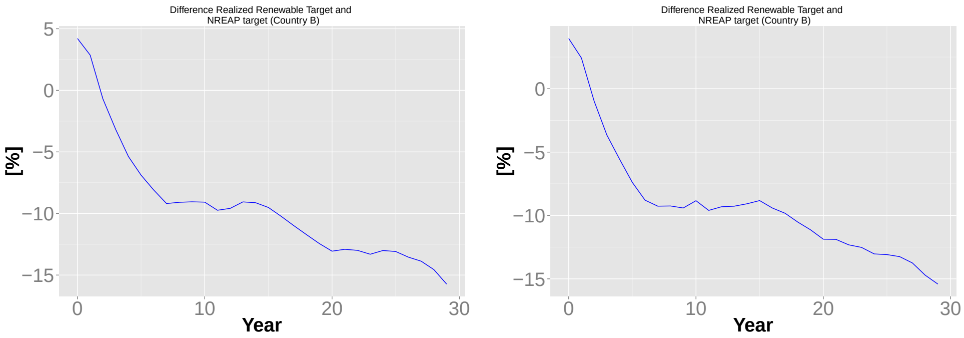
Electricity market performance 2B



(a) Base Case

(b) Infinite Interconnector PT

Figure H.13: Tender target fulfilment - Country A

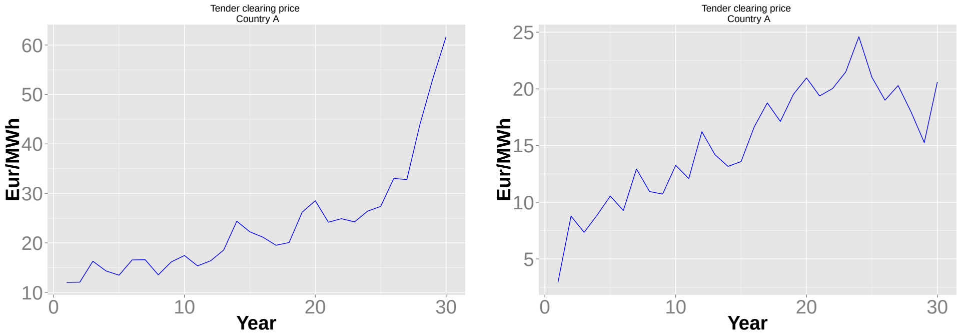


(a) Base Case

(b) Infinite Interconnector PT

Figure H.14: Tender target fulfilment - Country B

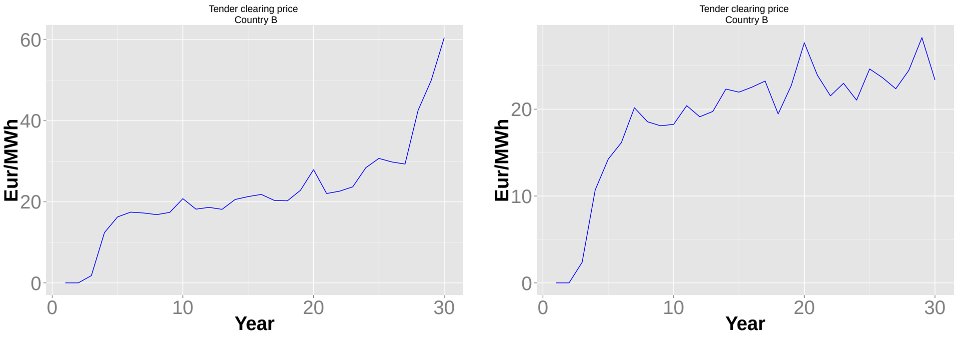
Tender target fulfilment 2B



(a) Base Case

(b) Infinite Interconnector PT

Figure H.15: Tender clearing prices - Country A

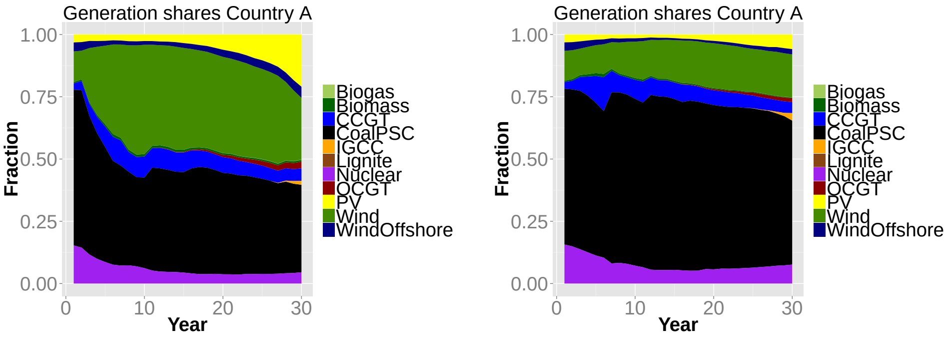


(a) Base Case

(b) Infinite Interconnector PT

Figure H.16: Tender clearing prices - Country B

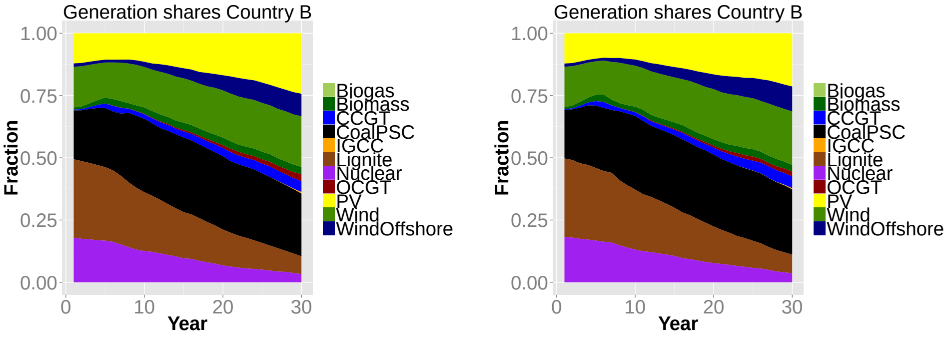
Tender clearing prices 2B



(a) Infinite interconnector capacity

(b) Paced Target ∞

Figure H.17: Generation shares - Country A



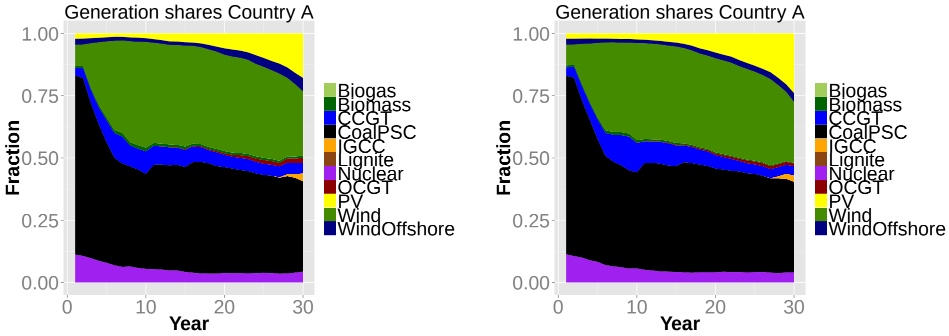
(a) Infinite interconnector capacity

(b) Paced Target ∞

Figure H.18: Generation shares - Country B

generation shares 2B

H.3. Experiment 3

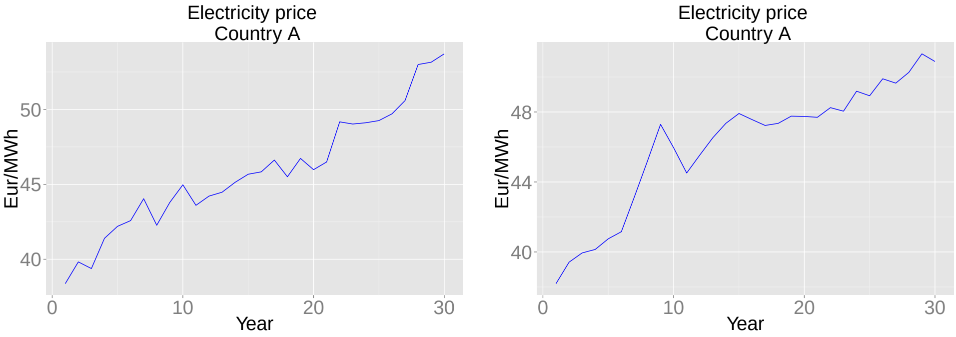


(a) Base case

(b) Tech-Spec 1

Figure H.19: Generation shares - Country A

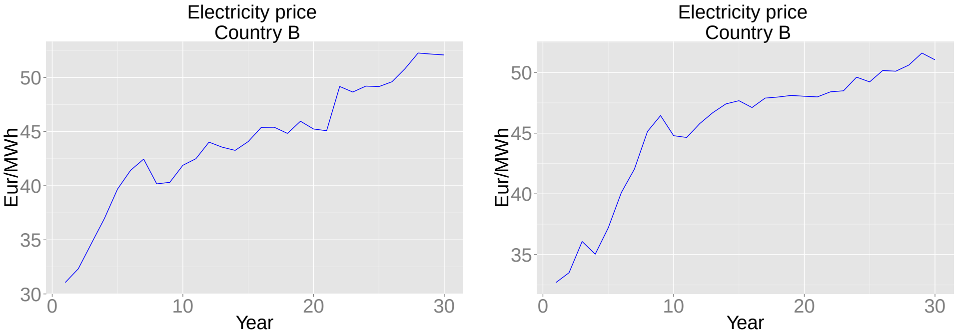
Capacity and generation shares



(a) Base case

(b) Tech-Spec 1

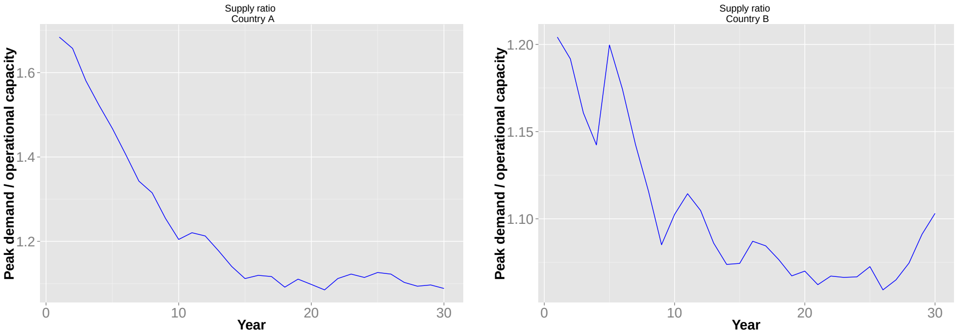
Figure H.20: Mean weighted average electricity prices - Country A



(a) Base case

(b) Tech-Spec 1

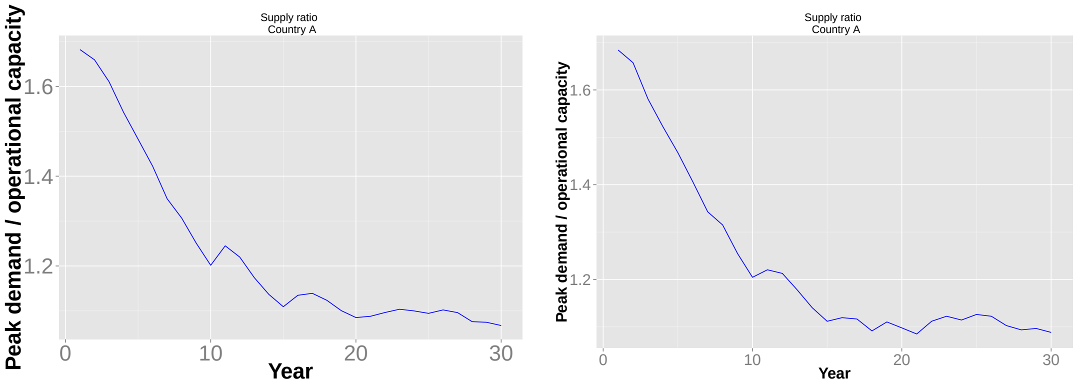
Figure H.21: Mean weighted average electricity prices - Country B



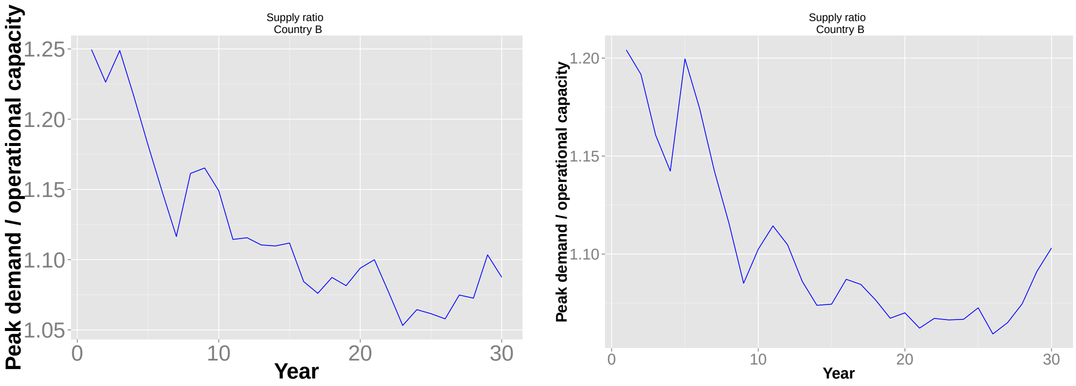
(a) Country A

(b) Country B

Figure H.22: Supply ratios



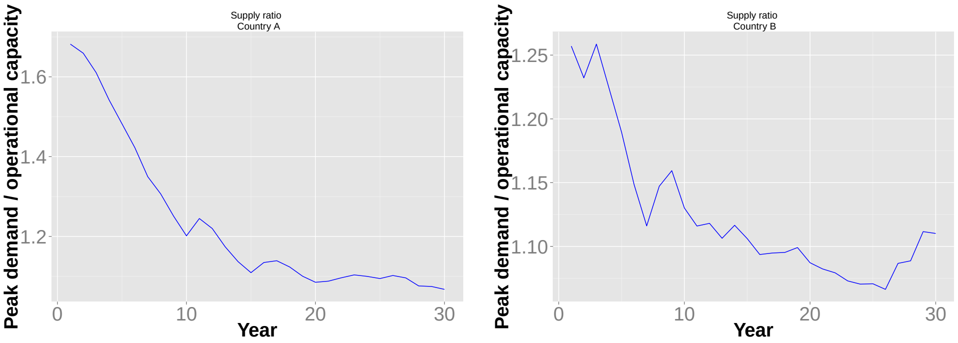
(a) Base Case (b) Tech-Spec 1



(a) Base Case (b) Tech-Spec 1

Electricity market performance

H.4. Experiment 4

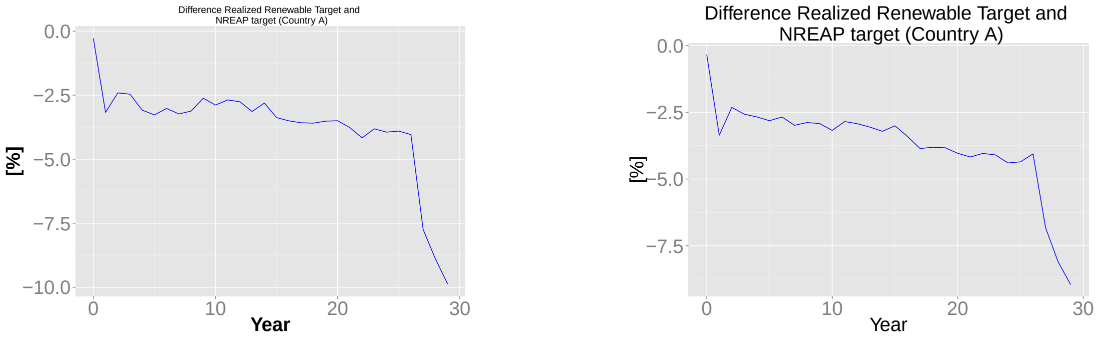


(a) Country A

(b) Country B

Figure H.25: Supply ratios

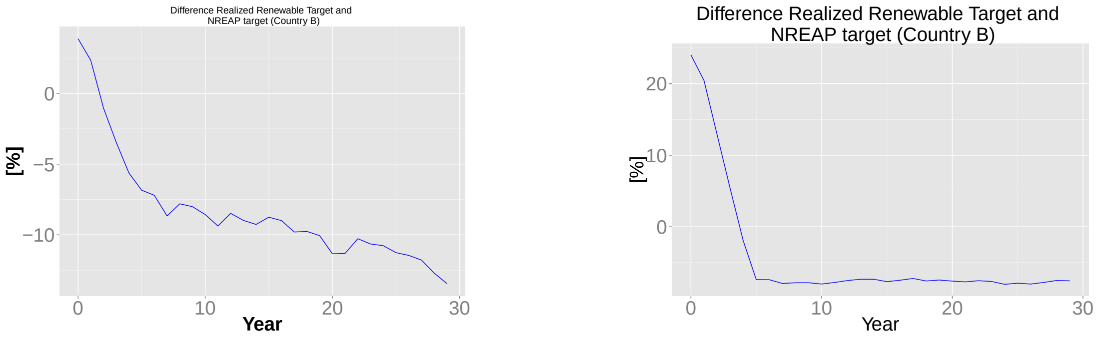
Electricity market performance



(a) Base Case

(b) Same Target

Figure H.26: Tender target fulfilment - Country A

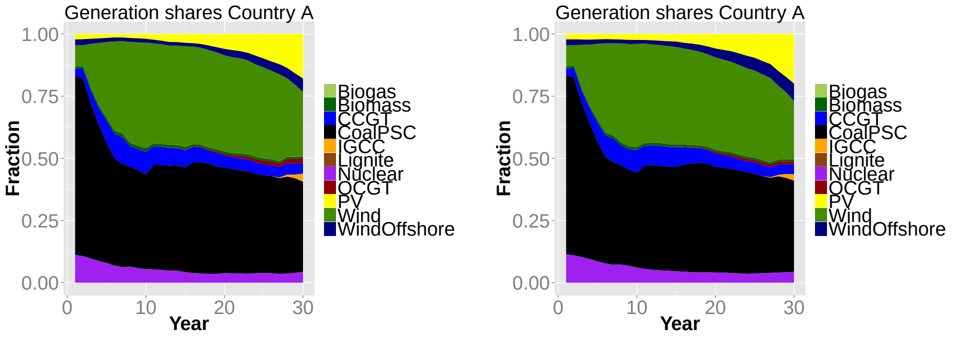


(a) Base Case

(b) Infinite interconnector capacity

Figure H.27: Tender target fulfilment - Country B

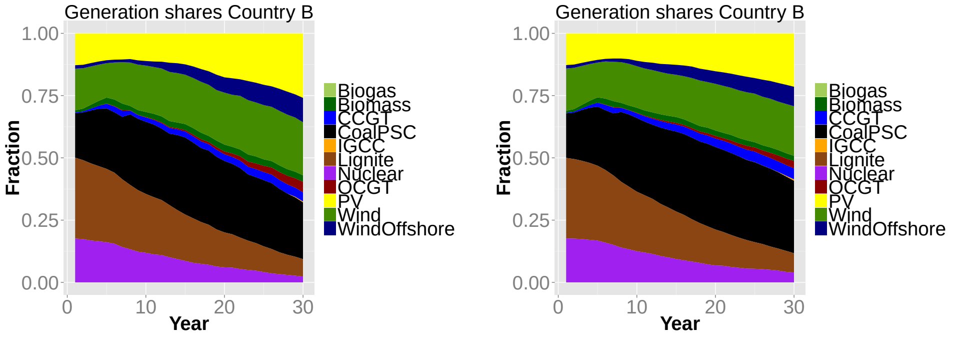
Tender target fulfilment



(a) Base case

(b) Same Target

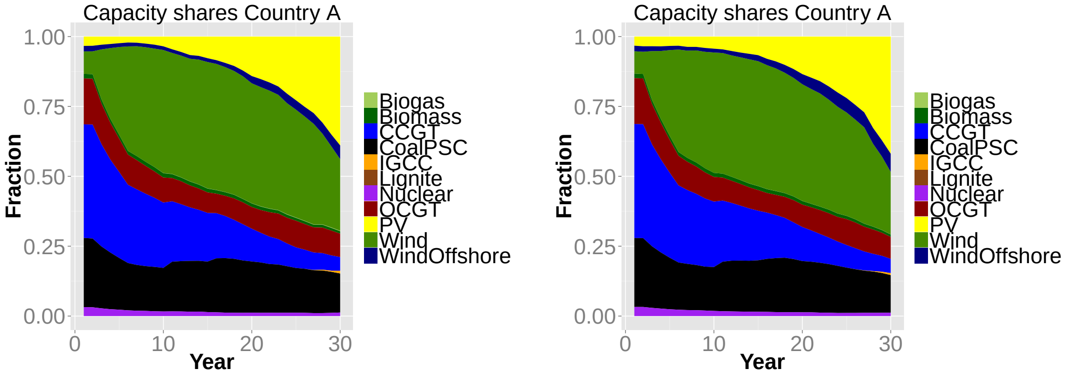
Figure H.28: Generation shares - Country A



(a) Base case

(b) Same Target

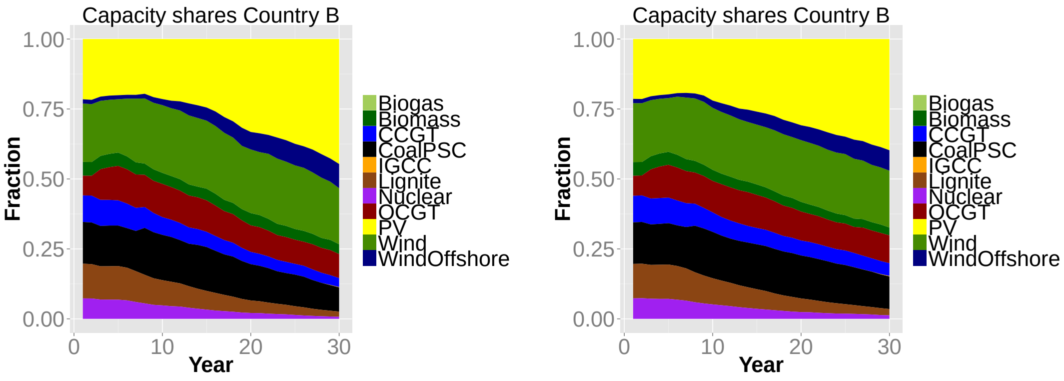
Figure H.29: Generation shares - Country B



(a) Base Case

(b) Same Target

Figure H.30: Capacity shares - Country A



(a) Base Case (b) Same Target

Figure H.31: Capacity shares - Country B

Generation and capacity shares

H.5. All results compared

Table H.1: Welfare and subsidy costs of all scenarios

	Producer Welfare [BEuro]			**Consumer Welfare change [%]**			**Subsidy costs [BEuro]**		
	Overall	**A**	**B**	**Overall**	**A**	**B**	**Overall**	**A**	B
No Tender	-1.629	-1.002	-0.468	na	na	na	0.000	0.000	0.000
Base Case	-8.592	-1.527	-6.297	4.67%	6.45%	4.40%	4.087	0.437	3.650
Infinite Interconnector	-8.870	-1.617	-6.760	0.31%	9.46%	-1.36%	3.949	0.460	3.490
Infinite Interconnector PT	-8.052	-1.234	-6.391	0.92%	13.31%	-1.26%	3.581	0.126	3.455
Tech Spec 1	-6.095	-1.509	-4.549	-3.46%	-4.60%	-3.02%	3.377	0.600	2.777
Same Target	-8.295	-1.464	-5.901	0.97%	0.15%	1.14%	3.405	0.437	2.968

Table H.2: Other costs and cash of all scenarios

	Generation costs [BEuro]			**Cost of outages [BEuro]**			**Producer cash [BEuro]**		
	Overall	**A**	**B**	**Overall**	**A**	**B**	**Overall**	**A**	**B**
No Tender	37.59	7.37	30.18	0.00	0.00	0.00	688.42	303.78	388.00
Base Case	49.14	8.43	41.08	1.06	0.00	1.06	597.28	292.54	302.98
Infinite Interconnector	49.68	8.29	41.28	0.15	0.00	0.15	609.16	290.71	319.24
Infinite Interconnector PT	48.57	7.26	40.96	0.06	0.00	0.06	611.20	296.32	315.48
Tech Spec 1	47.23	8.68	38.10	0.01	0.00	0.01	637.31	295.99	344.03
Same Target	48.02	8.39	39.39	0.19	0.00	0.19	610.72	293.11	318.54

Table H.3: Electricity market performance indicators for all scenarios

	Electricity price [Eur/Mwh]		**Volatility Electricity price [Eur/Mwh]**		**Supply ratio**	
	A	**B**	**A**	**B**	**A**	**B**
No Tender	48.342	47.945	3.492	5.708	1.216	1.122
Base Case	45.591	44.457	3.974	5.554	1.136	1.107
Infinite Interconnector	43.783	44.052	4.449	4.536	1.142	1.103
Infinite Interconnector PT	43.997	44.276	4.646	4.668	1.223	1.102
Tech Spec 1	47.350	47.540	3.648	5.402	1.124	1.086
Same Target	46.325	45.829	3.730	5.596	1.129	1.108

Table H.4: Breakdown of generation costs for all scenarios

	Fixed O&M Costs [Beuro]		**Loan Costs [Beuro]**		**Commodity Costs [Beuro]**		**Downpayment costs [Beuro]**	
	A	**B**	**A**	**B**	**A**	**B**	**A**	**B**
No Tender	1.05	5.19	1.47	8.36	4.49	17.06	0.47	1.86
Base Case*	1.28	6.74	3.30	15.78	2.77	11.69	0.86	5.21
Infinite Interconnector	1.30	6.91	3.29	16.06	2.68	11.92	0.90	4.63
Infinite Interconnector PT	1.12	7.02	2.08	16.94	3.41	11.67	0.60	4.44
Tech Spec 1	1.30	7.18	3.40	13.79	2.88	12.79	0.92	3.66
Same Target	1.30	6.54	3.28	15.05	2.78	12.52	0.85	4.19

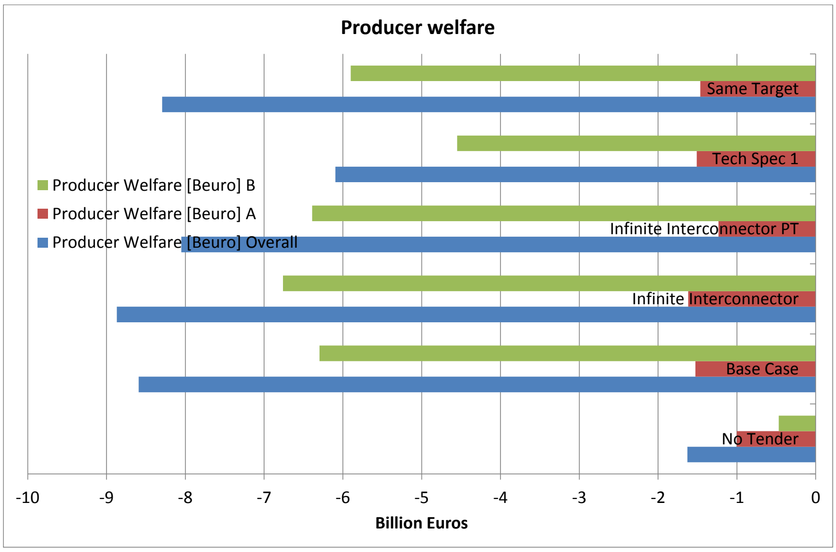


Figure H.32: Producer welfare in terms of profits

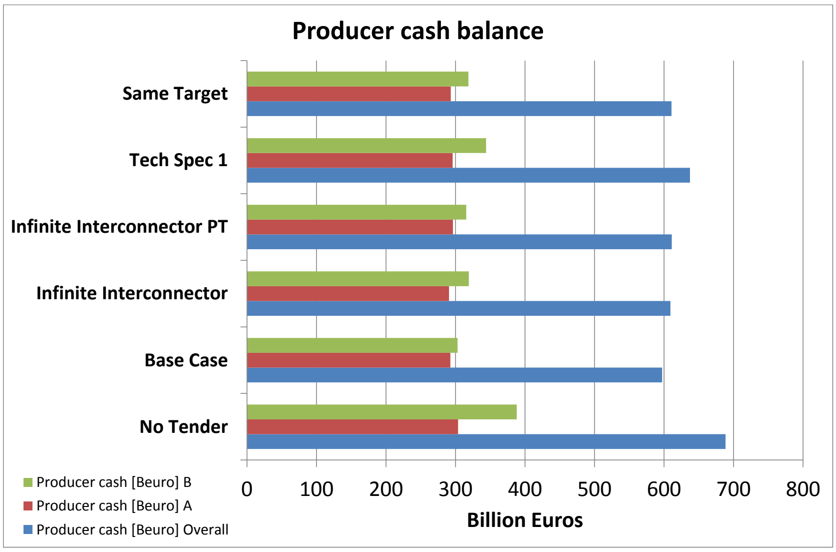


Figure H.33: Producer welfare in terms of cash

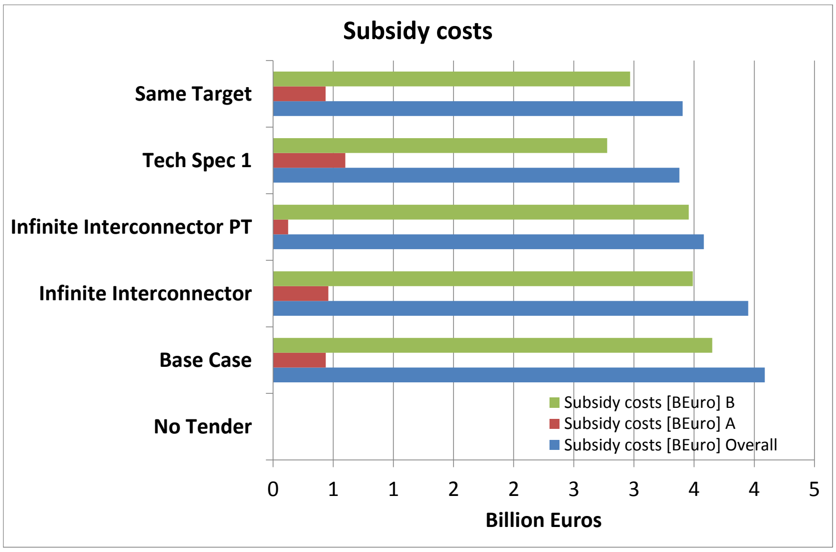


Figure H.34: Subsidy costs

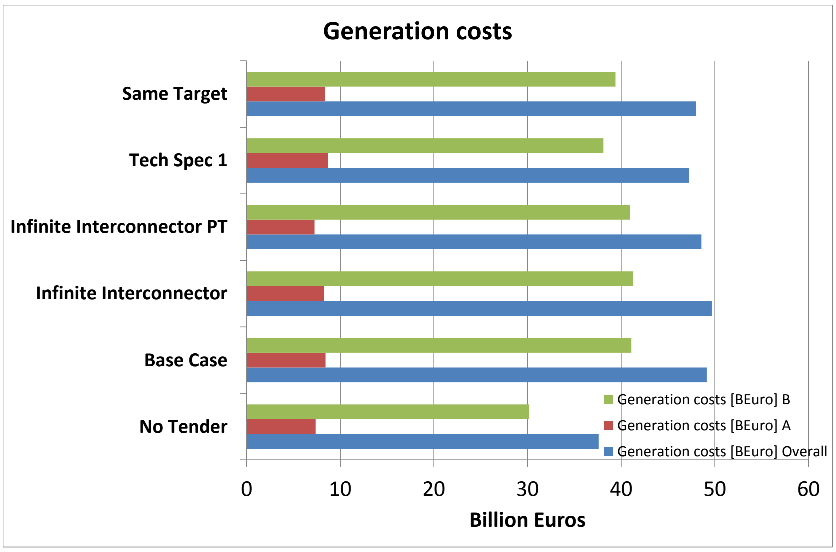


Figure H.35: Generation costs

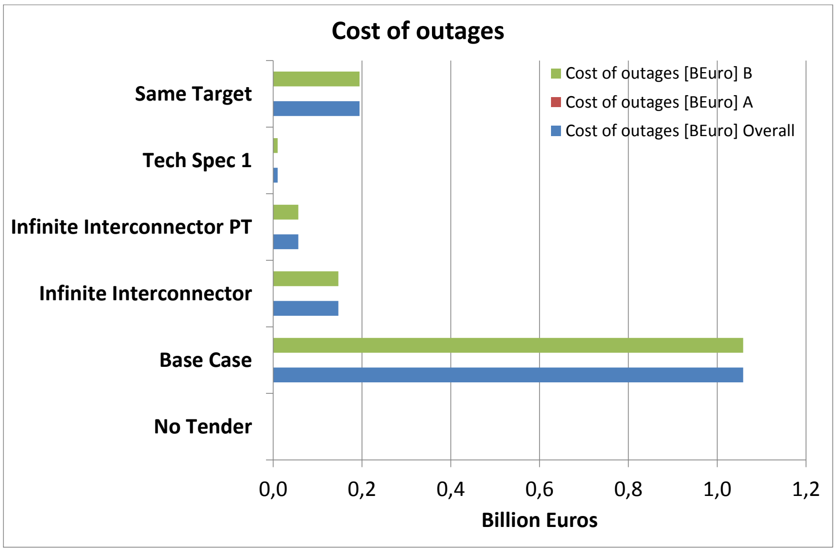
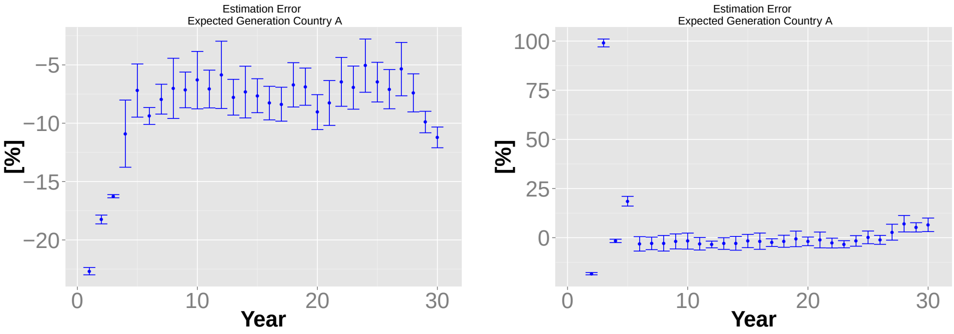


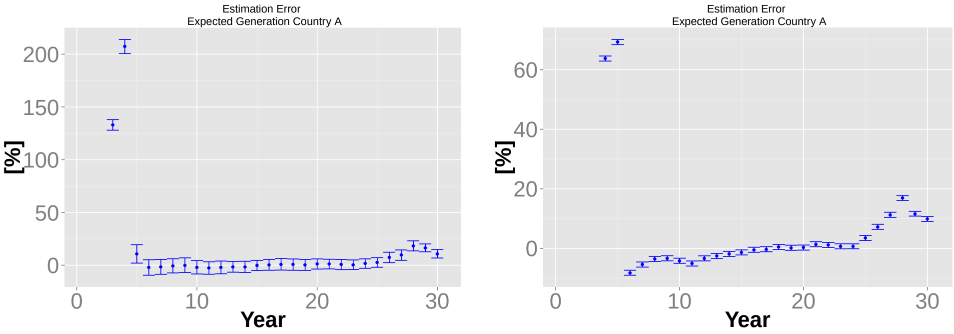
Figure H.36: Cost of outages

Sensitivity Analysis

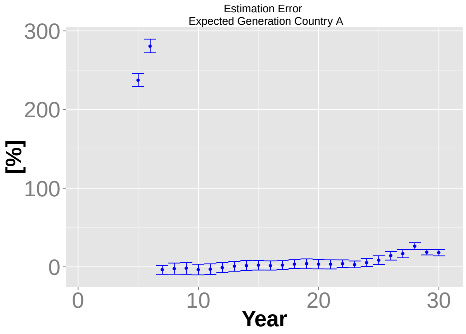
I.0.1. Forecasting errors in expected generation



(a) 1 Year ahead (b) 2 Years ahead

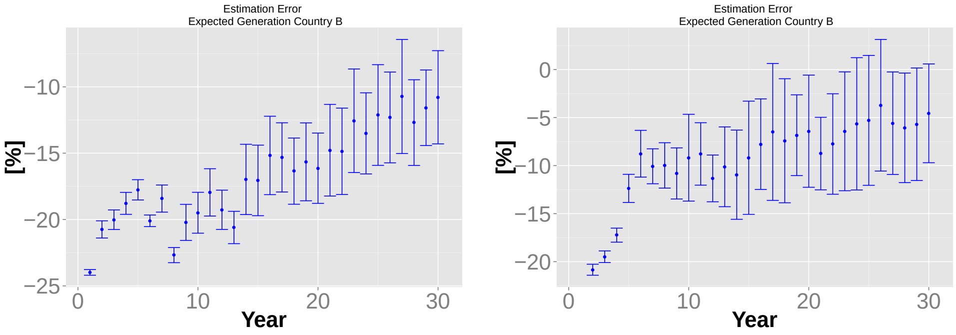


(c) 3 Years ahead (d) 4 Years ahead



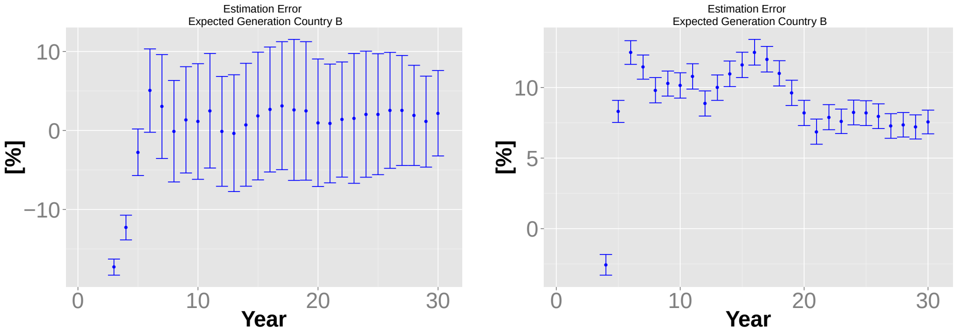
(e) 5 Years ahead

Figure I.1: Deviation from expected generation - Country A



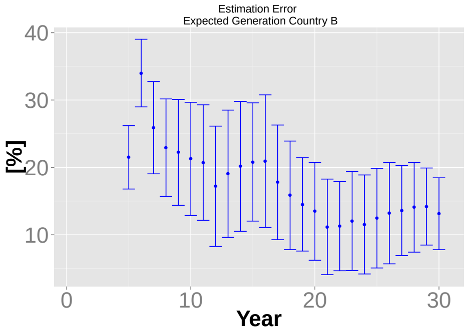
(a) 1 Year ahead

(b) 2 Years ahead



(c) 3 Years ahead

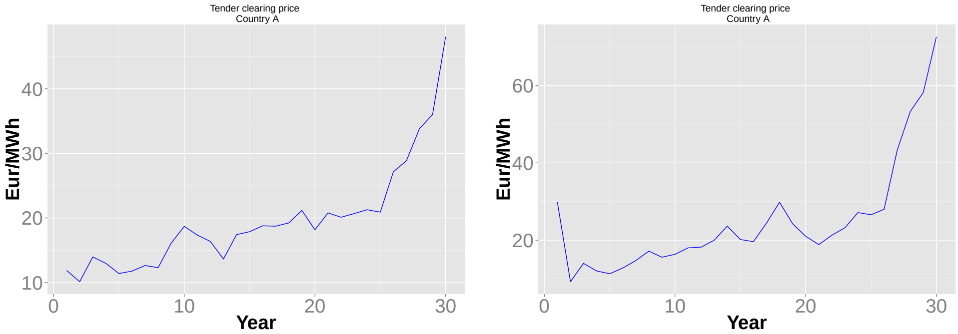
(d) 4 Years ahead



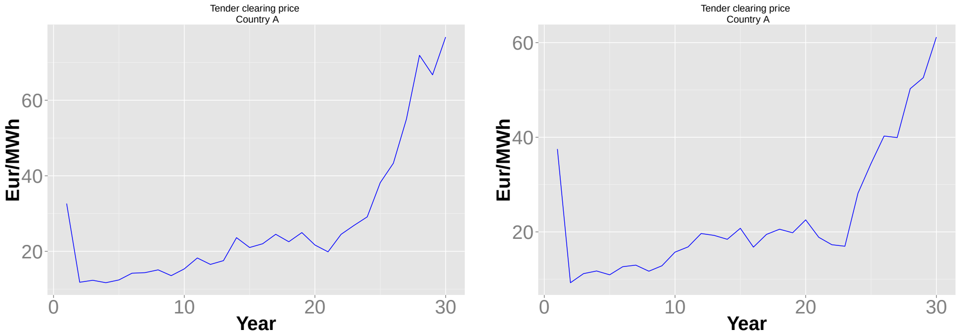
(e) 5 Years ahead

Figure I.2: Deviation from expected generation - Country B

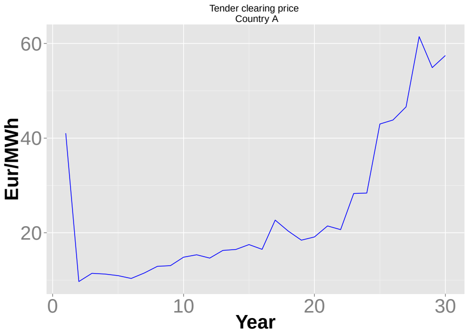
I.0.2. Tender clearing prices



(a) 1 Year ahead (b) 2 Years ahead

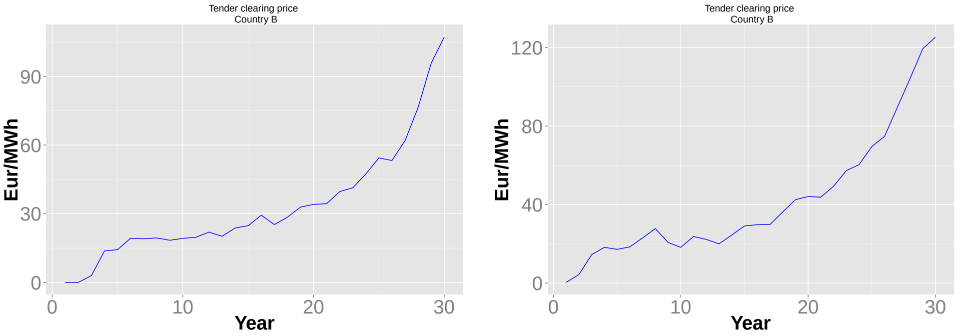


(c) 3 Years ahead (d) 4 Years ahead



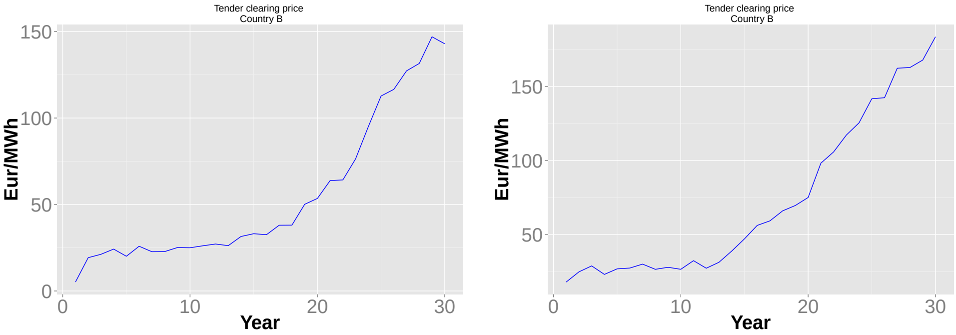
(e) 5 Years ahead

Figure I.3: Tender clearing prices - Country A



(a) 1 Year ahead

(b) 2 Years ahead



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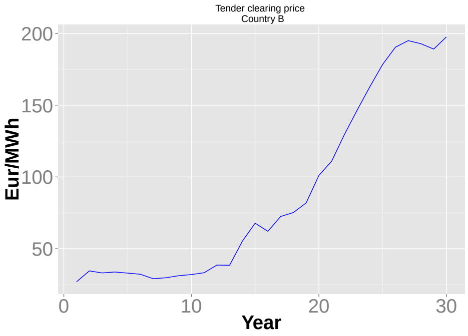
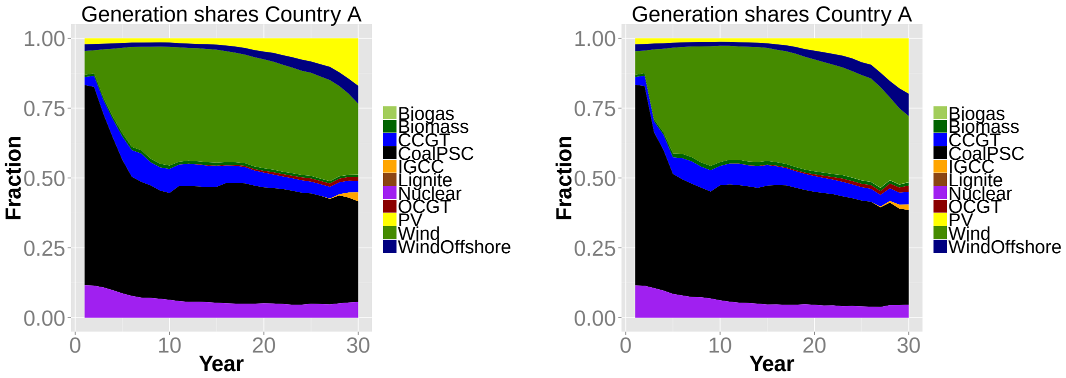
(d) 4 Years ahead



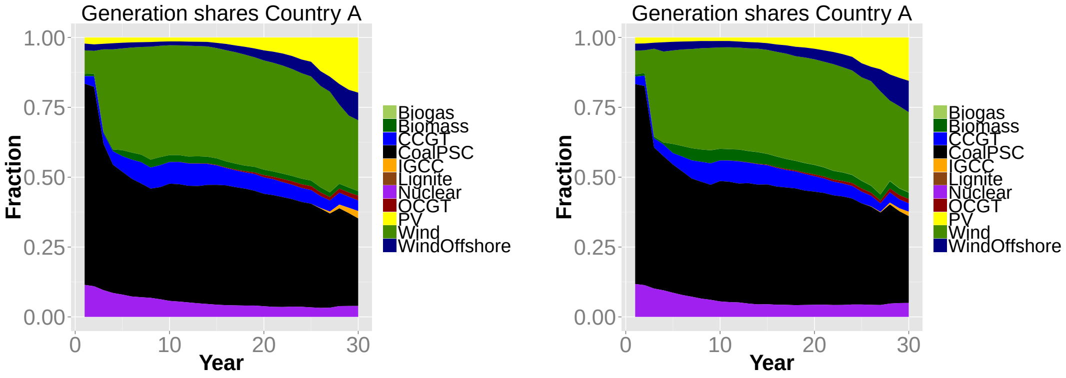
(e) 5 Years ahead

Figure I.4: Tender clearing prices - Country B

I.0.3. Generation and capacity shares



(a) 1 Year ahead (b) 2 Years ahead



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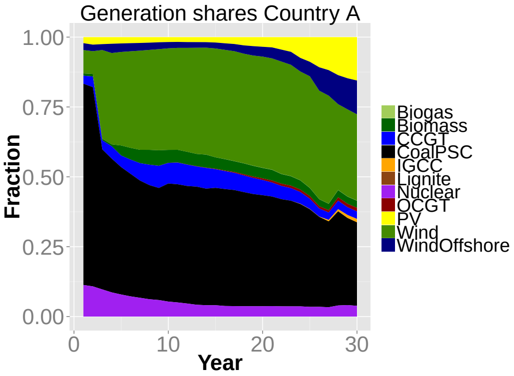
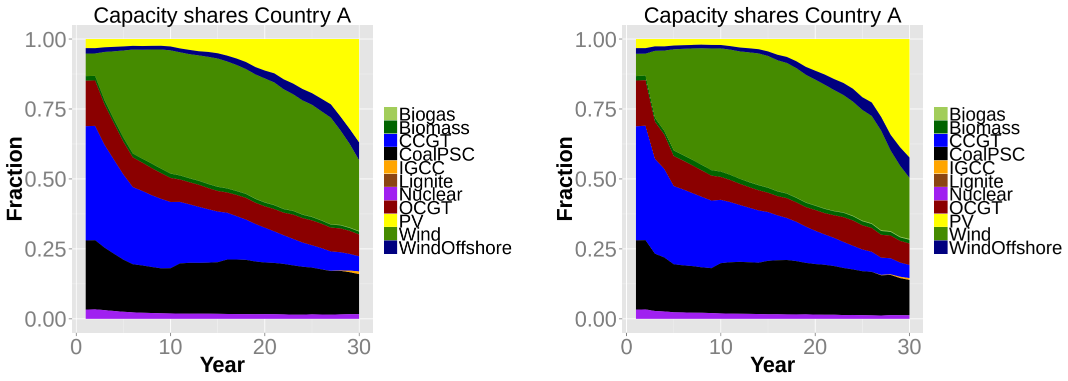


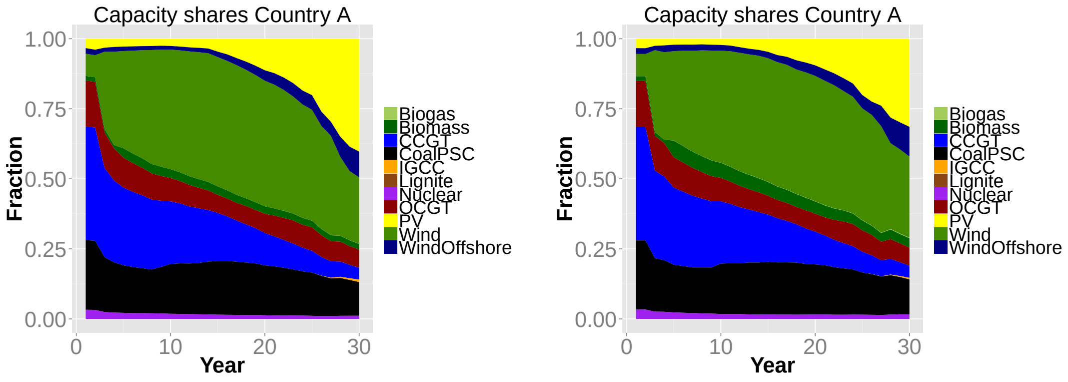
(e) 5 Years ahead

Figure I.5: Generation shares - Country A



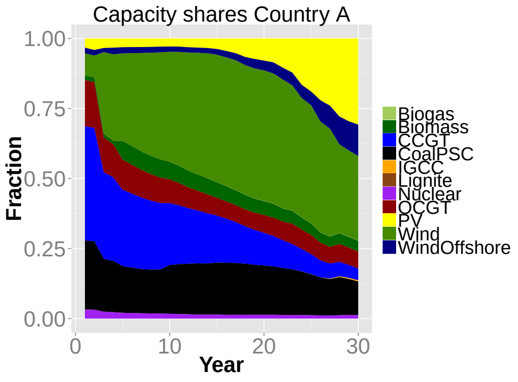
(a) 1 Year ahead

(b) 2 Years ahead



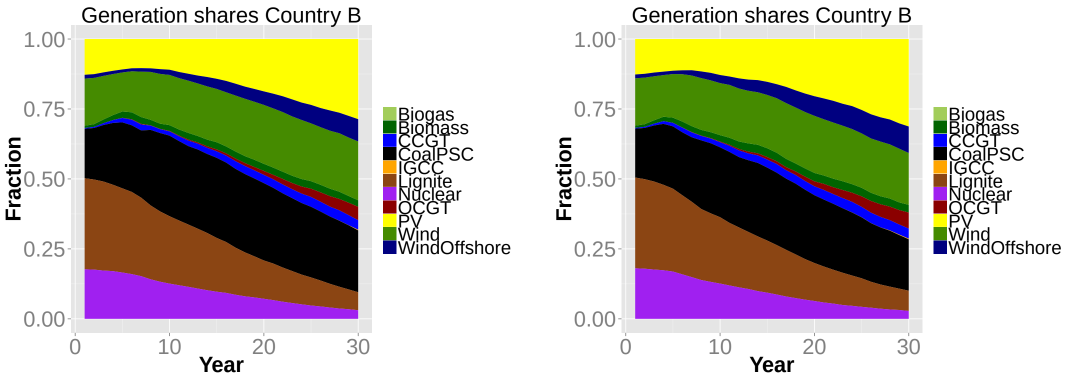
(c) 3 Years ahead

(d) 4 Years ahead

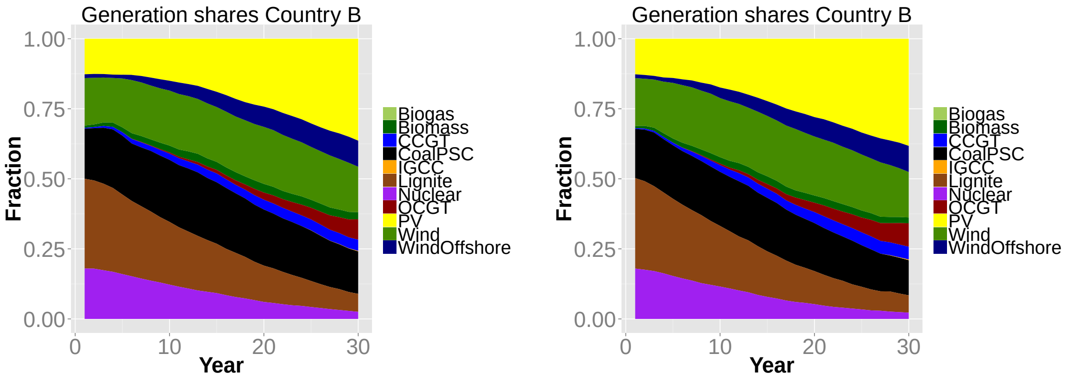


(e) 5 Years ahead

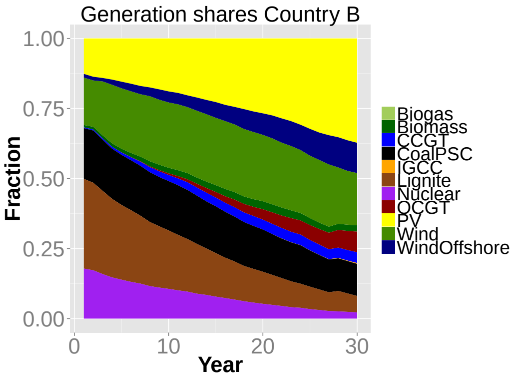
Figure I.6: Capacity shares - Country A



(a) 1 Year ahead (b) 2 Years ahead

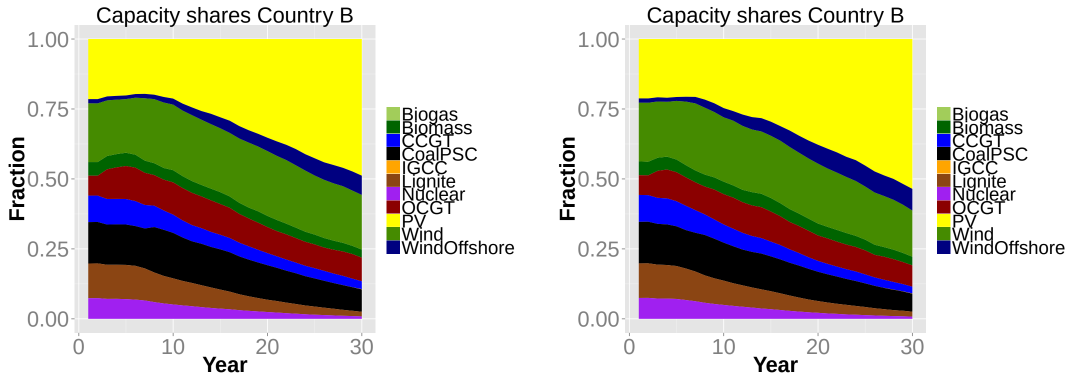


(c) 3 Years ahead (d) 4 Years ahead



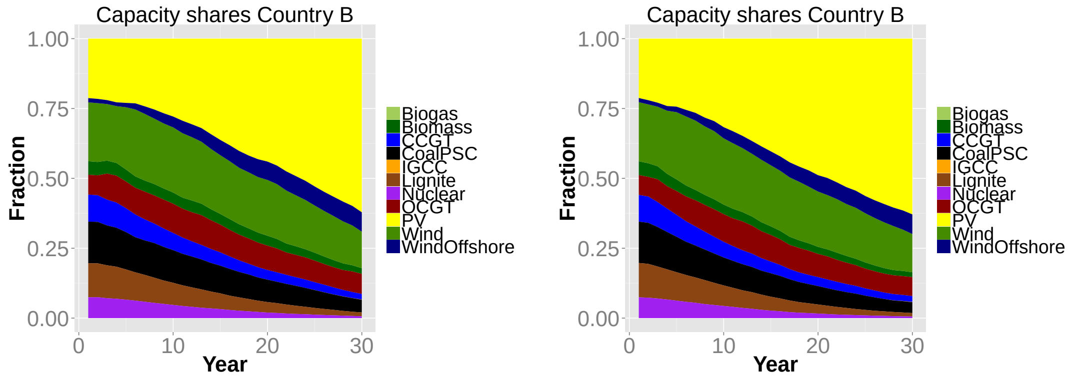
(e) 5 Years ahead

Figure I.7: Generation shares - Country B



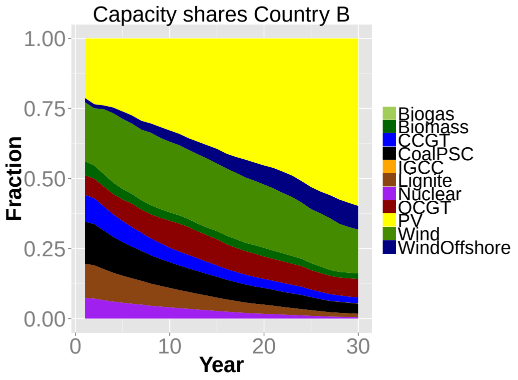
(a) 1 Year ahead

(b) 2 Years ahead



(c) 3 Years ahead

(d) 4 Years ahead



(e) 5 Years ahead

Figure I.8: Capacity shares - Country B

I.0.4. Other economic indicators

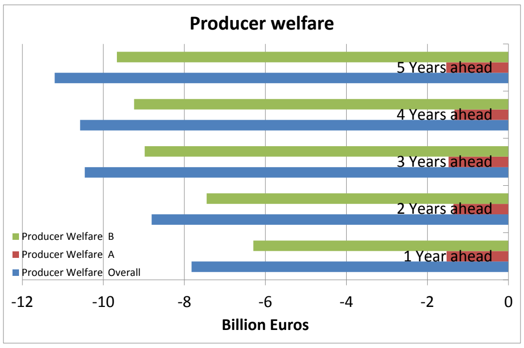


Figure I.9: Producer profits

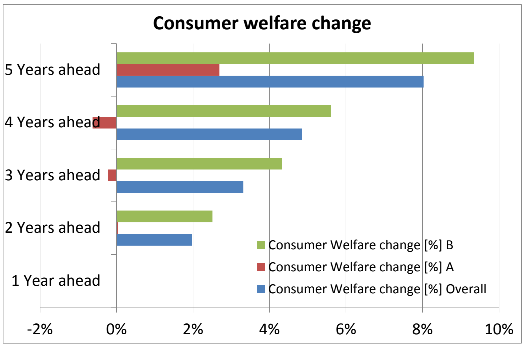


Figure I.10: Consumer welfare change

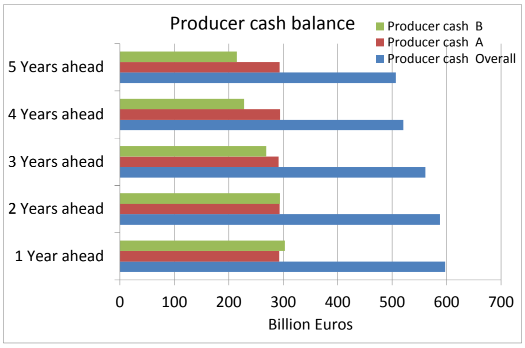


Figure I.11: Producer cash

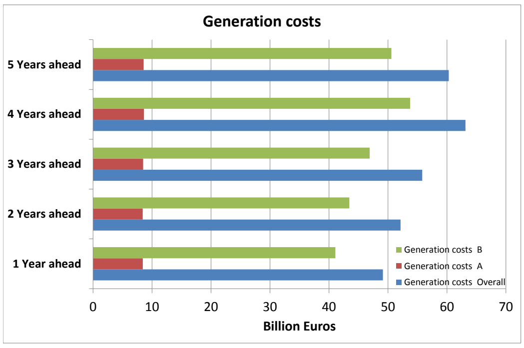


Figure I.12: Generation costs

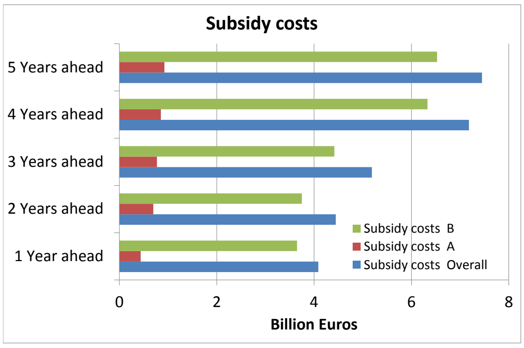


Figure I.13: Subsidy costs

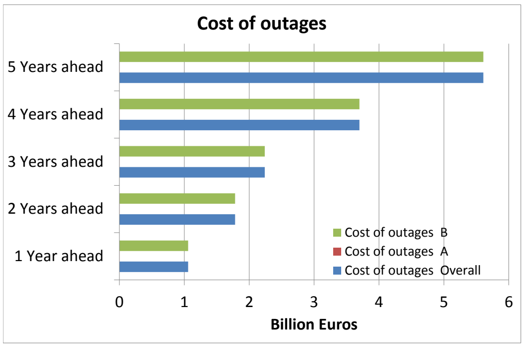


Figure I.14: Cost of outages

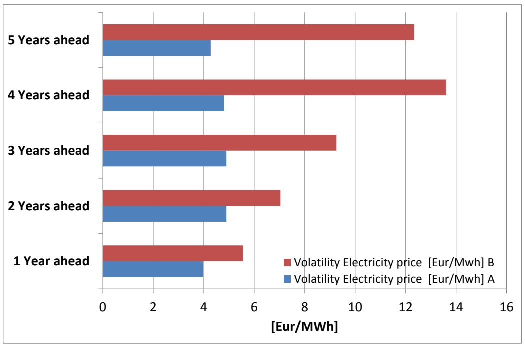
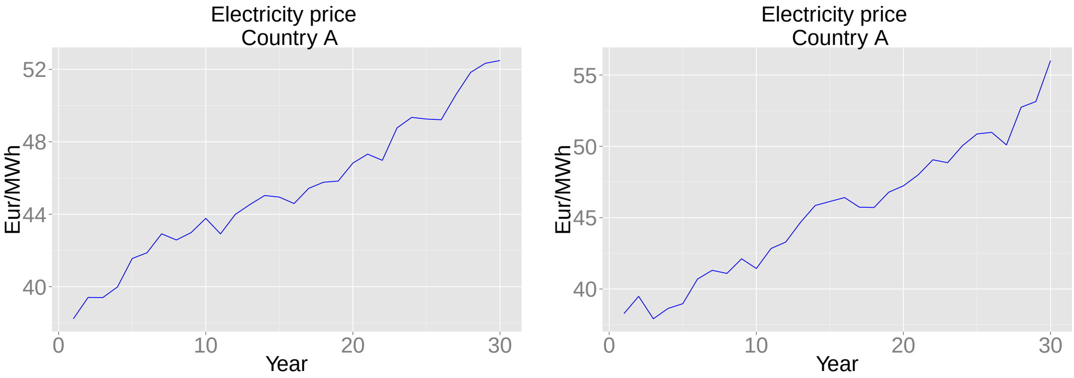


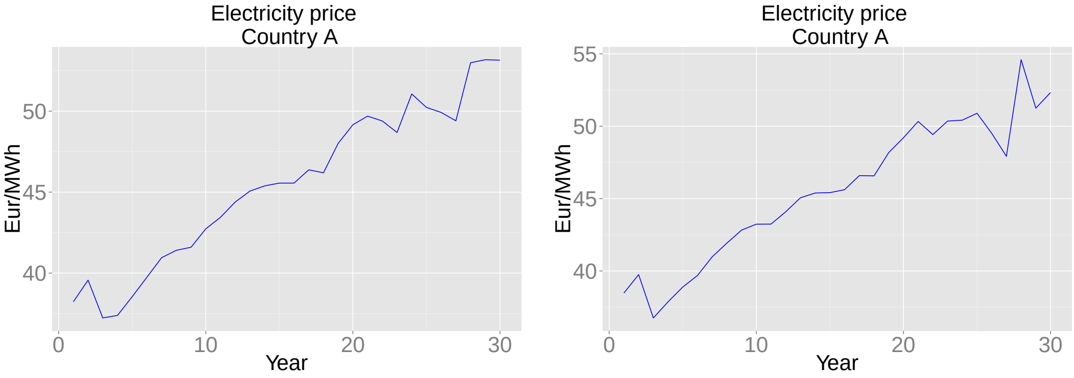
Figure I.15: Electricity market performance: electricity price volatility

I.0.5. Electricity market prices



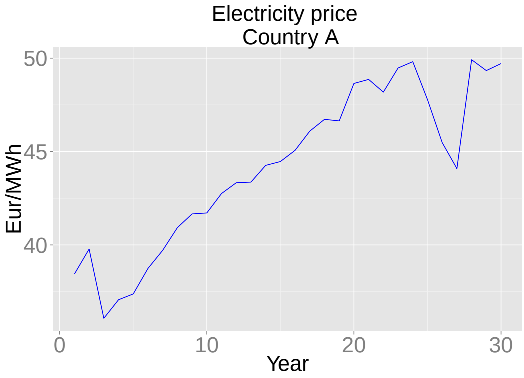
(a) 1 Year ahead

(b) 2 Years ahead



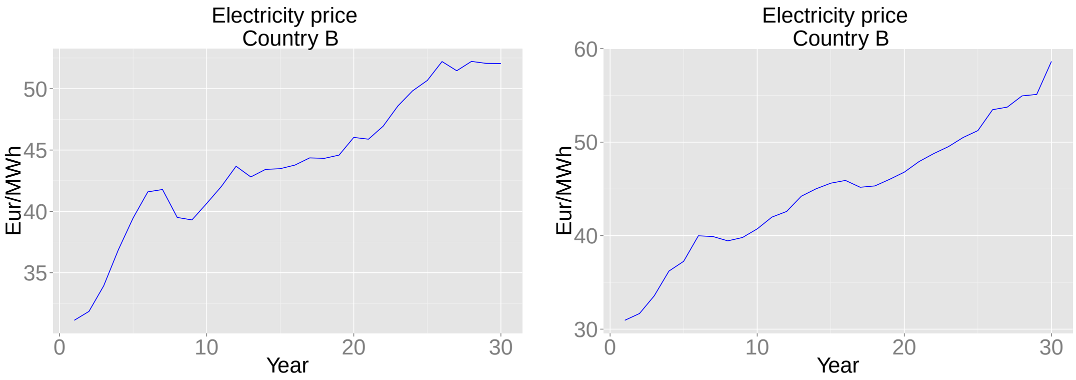
(c) 3 Years ahead

(d) 4 Years ahead



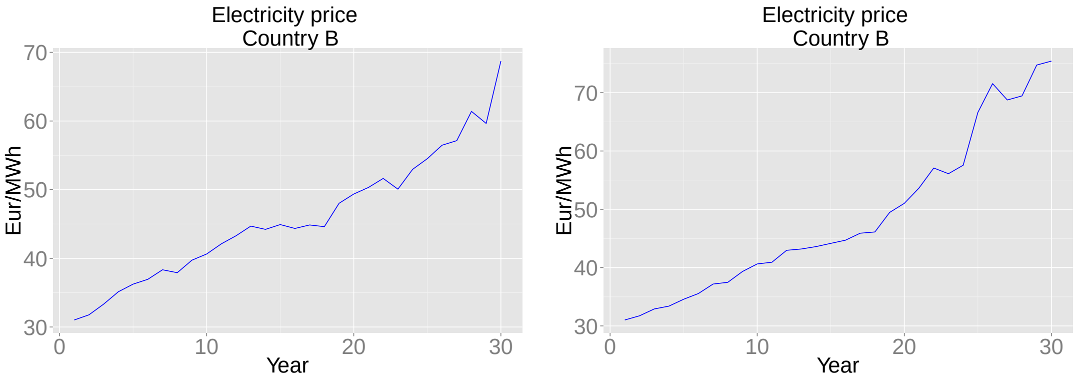
(e) 5 Years ahead

Figure I.16: Median weighted averaged electricity price - Country A



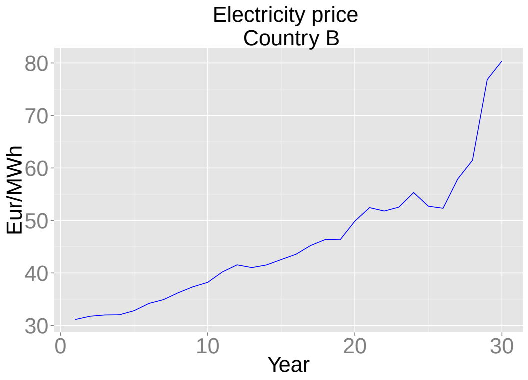
(a) 1 Year ahead

(b) 2 Years ahead



(c) 3 Years ahead

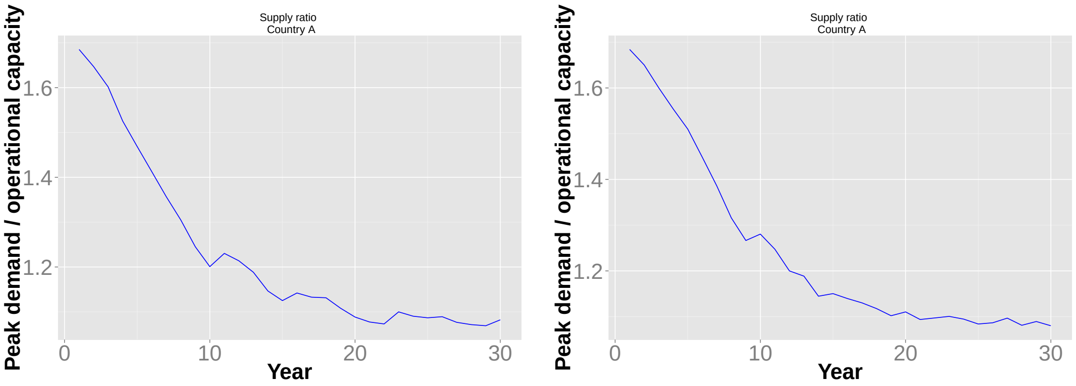
(d) 4 Years ahead



(e) 5 Years ahead

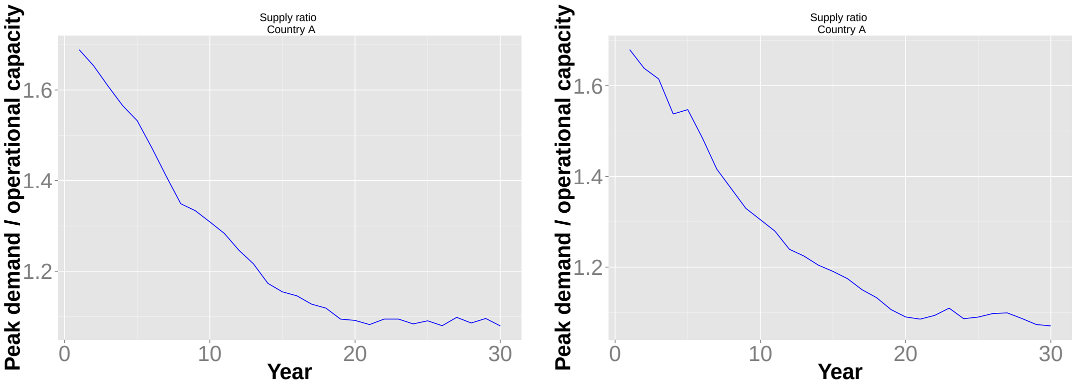
Figure I.17: Median weighted averaged electricity price - Country B

I.0.6. Supply ratios



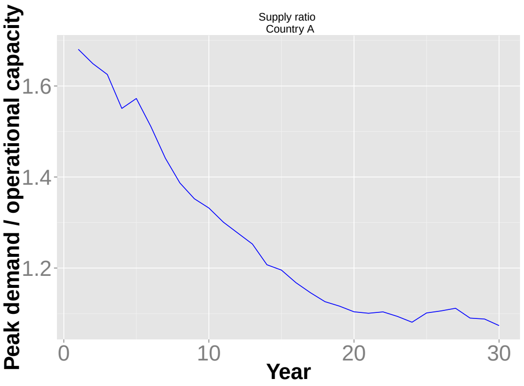
(a) 1 Year ahead

(b) 2 Years ahead



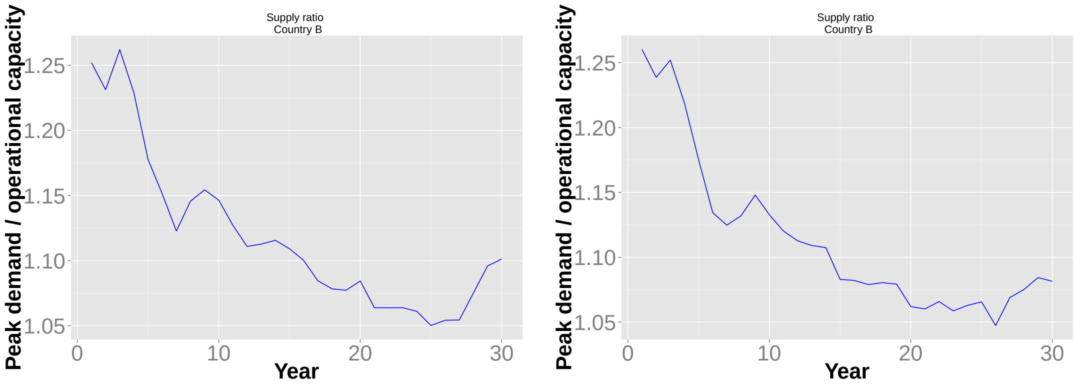
(c) 3 Years ahead

(d) 4 Years ahead

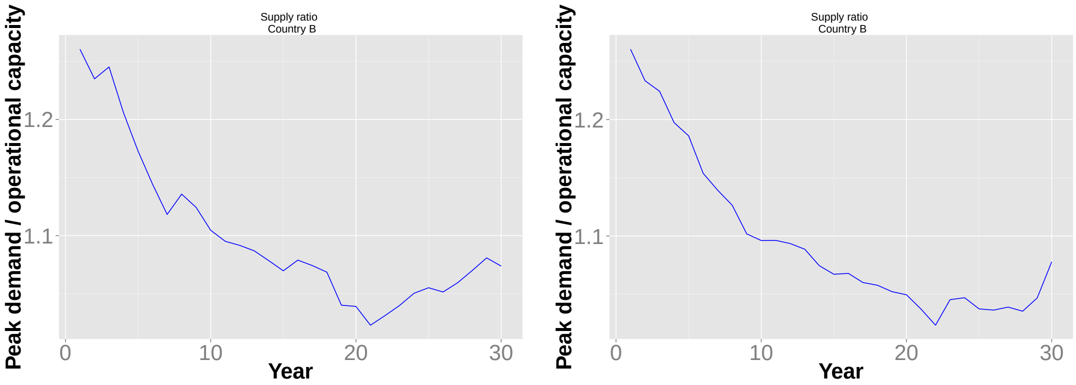


(e) 5 Years ahead

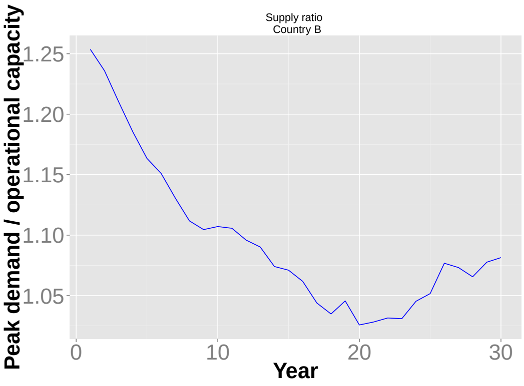
Figure I.18: Supply ratios - Country A



(a) 1 Year ahead (b) 2 Years ahead



(c) 3 Years ahead (d) 4 Years ahead



(e) 5 Years ahead

Figure I.19: Supply ratios - Country B

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