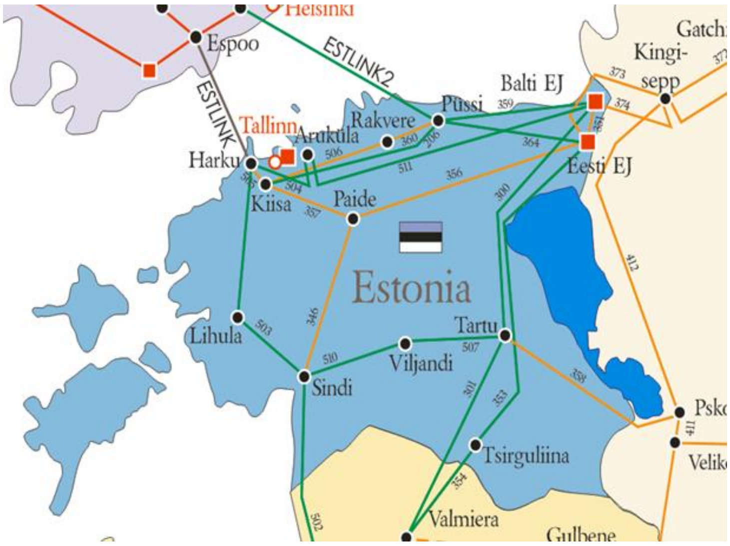
# Wind Power in Estonia

## An analysis of the possibilities and limitations for wind power capacity in Estonia within the next 10 years



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# Eleringi kommentaarid uuringu tulemustele

Uuringu eesmärk oli analüüsida tehnilisi piiranguid tuulest toodetud elektri integreerimiseks Eesti ja Balti riikide elektrisüsteemiga ning mõju elektrituru toimimisele aastani 2016. Käesolevas töös ei ole vaadeldud üldist sotsiaalmajanduslikku mõju arvestades võimalikke subsiidiumide stsenaariume..

Uuringu teostamise põhjuseks on tuulelektrijaamade suur huvi liituda elektrisüsteemiga. Käesolevaks ajaks on Elering saanud liitumistaotlusi 4000 MW ulatuses. Arvestades asjaolu, et Eesti elektrisüsteemis on tarbimine vahemikus 400-1600 MW, ei ole soovitud mahus võimalik elektrituulikuid elektrisüsteemiga liita.

Käesoleva uuringu teostas EA Energianalyse (Taani) ajavahemikul jaanuar-mai 2010. Varem pole tehtud sellist uuringut, kus on vaadeldud elektrituulikute Balti elektrisüsteemiga integreerimise eri aspekte:
elektrisüsteemi tehniline analüüs arvestades elektritootmisseadmete ja elektrivõrgu tehniliste karakteristikutega ning elektrituulikute toodangu muutlikkusega ajas;
elektrituulikute toodangu prognoosivigadest tekkinud tarbimise ja tootmise vahelise ebabilansi tasakaalustamise kvantitatiivne analüüs ning tasakaalustamisvõimaluste analüüs.

## Süsteemihalduri järeldus tuulikute integreerimise võimalustest Eesti elektrisüsteemi

Arvestades võimalike muutustega elektritootmise struktuuris 2016. aastal on uuringu põhjal võimalik Eesti elektrisüsteemi ühendada tuuleelektrijaamu võimsusega kuni 900 MW , et aastane piiratav energia jääks aastani 2020 suure tõenäosusega üsna väikseks.
Praegu ei ole arvestatud naaberriikide võimalike energiapoliitiliste eesmärkidega tuuleenergia laialdaseks rakendamiseks, mistõttu oleks vajalik saavutada Läänemere regioonis konsensus süsteemiga liituvate tuulelektrijaamade koguvõimsuste ja aastase piirangute osas alates 2020. aastast.

Elering leiab uuringu tulemustele põhinedes ning Fingridi Estlink2 investeerimisotsusega arvestades, et praegune reservgeneraatori nõue ei ole majanduslikult põhjendatud. Leiame, et otstarbekas on asendada käesolev nõue:

- muutustega seadusandluses, et tagada toimiv süsteem tuulikute piiramiseks;
- seadusandluse muutustega, mille alusel süsteemihaldur omaks tuuleelektrijaamade toodangu prognoosi tsentraalset prognoosisüsteemi ning prognoosib tuuleelektrijaamade toodangut turuosaliste asemel ning omab prognoosivigade katteks piisaval hulgal reservvõimsusi.

## Järeldusi mõjutavanud asjaolud

Antud uuringu tulemused eeldavad, et Baltikumis on hästi toimiv reguleerimisturg, kus osalevad kõik olemasolevad jaamad..

Uuringu horisontaastateks olid 2013. aasta (elektrituru avamine Eestis) ja 2016. aasta (nelja ploki sulgemine Narva elektrijaamades ja Estlink 2 valmimine).

Käesolevas töös eesmärk oli uurida neid stsenaariume, mille rakendumine on tõenäoline kuni 2020. aastani. Seega on antud tulemusi võimalik tõlgendada aastani 2020, täpne hinnang peegeldab 2016. aasta seisu.

Eeldus oli ka, et süsteemihaldur omab tuuleelektrijaamade toodangu prognoosi tsentraalset prognoosimudelit ja prognoosib tuuleelektrijaamade toodangut turuosaliste asemel ning omab prognoosivigade katteks piisaval hulgal reservvõimsusi. Käesolevad ajal seadusandlik baas, vastav süsteem ning tariifikomponent puuduvad. Tulemused kehtivad vaid juhul, kui vastav süsteem rakendada Eestis ja teistes Baltimaades.

Elektrivõrgu läbilaskevõimed olid uuringus arvestatud aasta keskmiste näitajate järgi. Kuna reaalajas võimsusvood ja läbilaskevõimed kõiguvad suurtes piirides, siis teatavatel ajahetkedel võivad esineda piirangud, mida ei ole uuringus arvesse võetud.

Uuring põhineb eeldusel, et kõikides Läänemere regiooni riikides (sh Baltimaad) on toimiv elektriturg.

Uuringu horisontaasta oli 2016. Alates järgnevatest aastatest võib olukord muutuda kuna:

- Tuulestsenaariume Põhjamaades ei ole arvesse võetud – tuulelektrijaamade osakaalu suurenemisega piirkonnas kaasneb hüdroelektrijaamadel põhineva reguleerimisvõimsuse nappus Põhjamaades.
- Tuumastsenaariume (Soome, Leedu, Kaliningrad) ei ole käesolevas uuringus analüüsitud.
- Analüüse Põhjamaade võimalike stsenaariumide ja märja/kuiva aasta situatsiooni kohta pole tehtud.
- Eeldatud on, et Balti riikide elektrituru osalistel puudub ligipääs kolmandate riikide elektriturule – kolmandate riikidega säilib olemasolev olukord, kaubandus toimub läbi kahepoolsete lepingute.
- Ei ole arvestatud subsiidiumitega elektrituru modelleerimisel – säilib tänane olukord, kus elektriturg ja subsiidiumite turg on eraldiseisvad.
- Stsenaariumites analüüsitud madala marginaalkuluga elektritoodang vähendab elektriturul võimalusi olemasolevaid fossiilkütustel elektrijaamu kasutada, mistõttu ei pruugi majanduslikult otstarbekas neid jaamu töös hoida – jaamade võimalikku sulgemist ei ole analüüsitud.
- Täiendavad ühendused Põhjamaade ja Kesk-Euroopa vahel, mida kasutatakse tuuleenergia tasakaalustamiseks suurendavad tulevikus reguleerimisvõimsuse puudujääki Läänemere regioonis.

## Kommentaarid tulemustele

Tehniliselt on võimalik süsteemiga liita tuuleelektrijaamu suurel hulgal – küsimus on eelkõige selle majanduslikus jätkusuutlikkuses.

Olemasolevate soojuselektrijaamade kasutusaeg väheneb, mistõttu muutub nende käigushoidmine majanduslikult ebaefektiivseks ilma täiendavate subsiidiumiteta

Täna toetust saavate elektrijaamade (tõhus koostootmine, taastuvenergia (v.a tuul ja hüdro) kasutamine elektri tootmiseks) töötundide arv väheneb. Selliste jaamade opereerimise võimaldamiseks on vajalik mehhanism, mis katab tootmata jäänud elektri eest saamata jäänud subsiidiumite kulud

Suuremahuline tuuleenergia rakendamine alandab turuhinda, mistõttu ei muutu tuuleelektrijaam majanduslikult tasuvaks ilma subsiidiumiteta.

Tehnilise uuringu käigus analüüsiti võimalusi 2016. aastani – muutused elektritootmise struktuuris peale seda aastat omavad olulist mõju tuuleelektri integreerimise võimalustele.

# Contents

# 1 Executive Summary

## 1.1 Scope of the study

Wind power has developed as energy production technology during the last decade and today wind power turbines are mature and reliable as technology.

Advantages and disadvantages

The advantages of using wind power are a clean energy production, no $CO_2$ emission and low marginal costs. The disadvantages of wind power are the high investment costs and the fluctuating and less predictable nature of the wind power production, which make it more difficult to integrate into the power system.

Wind power deployment in Estonia

In Estonia, deployment of wind power has been encouraged by a favourable incentive scheme which has given birth to a large number of wind power projects. By the end of 2009 app. 140 MW wind power capacity was installed in Estonia, approx. 200 MW of new wind power capacity is being constructed and connection points have been completed for an additional approx. 380 MW. Permits have been given for an additional approx. 2600 MW of wind power. These projects are still in the planning process.

The potential high share of wind power in the Estonian power system gives reason for concerns regarding both the technical and the economical feasibility of the wind power integration and development. The Estonian power system is relatively small and the interconnectors to other areas are not full available for balancing the load and production.

Scope of this study

This report focuses on the system integration of wind power in Estonia and in the Baltic States as a whole.

The following questions are analysed:

- How much wind power capacity will it be technical possible to integrate into the Estonian power system and the Baltic power system?
- How to deal with uncertainty about forecasting of the wind power production?
- What are the additional costs for the system of wind power integration?
- How does wind power deployment influence the electricity prices in the region?
- What is the role of the electricity market in the integration of wind power?

Other aspects regarding wind power integration are the technical requirements for connection of wind power to the grid (grid code issues), and the economic viability of wind power deployment from a socio economical viewpoint and from a stakeholder viewpoint (economic evaluation). These aspects are not dealt with in detail in this study.

## Technical integration

Simulation of optimal system dispatch

The technical possibilities for integration of wind power in the Estonian power system is assessed by using the energy system modelling tool Balmorel which makes a detailed simulation of the hourly dispatch of the generation units in order to meet the load. With the given input the model finds the economic optimal solution to the dispatch for the whole system in consideration.

Curtailment as a measure for max. wind power

Normally the generation will be fitted to the load, second by second and hour by hour. But in some situations the system flexibility is too low in certain areas and production has to be curtailed in order to maintain the system balance and system stability. These situations might occur when wind power production is high, thermal generation unit cannot be ramped down quickly enough, units are on minimum load and cannot shut down because of minimum uptime constraints and transport capacity is insufficient to transport load out of a surplus area. In these situations curtailment of wind power production is the only solution to maintain system stability.

Curtailment of wind power is problematic because the financial viability of wind power project might be jeopardized by the missing revenue. From a socioeconomic point of view the wind power production has the lowest marginal cost (which compensates for the high investment costs) and the cleanest production which implies that curtailment should be avoided.

One measure for the maximum wind power capacity is therefore the wind power capacity which creates very little curtailment, measured on a yearly energy basis. The small amount of curtailment indicates that the maximum capacity of wind power has been reached.

In the present study three levels of curtailment is chosen as measures. The first level, 0.1% curtailment, is used as an indication of zero curtailment. The second level, 5.0% curtailment, indicates a curtailment level which normally will only have a small effect on the financial viability of wind power. The third level, 20.0% curtailment, will give an indication of a curtailment level, which will significantly influence the economic feasibility of wind power.

## Forecast errors

Accurate forecast important…

Forecasting wind power as accurately as possible is important to wind power producers bidding in their production in an electricity market as well as to the system operator.

for wind power producers

In a market based setup the wind power producers will normally pay for the costs of balancing the wind power (the cost of providing balancing power). Therefore the more accurate the forecast of wind power the lower will the balancing costs be to wind power producers. From a socio-economic perspective better forecasting will reduce the total generation costs due to more optimal dispatch of power plants.

and for the system operator

From a system operator point-of-view forecasting can be important to determine the amount of reserves needed in the system during the coming day. Moreover, during the course of operation forecasting is important to the system control-centre to prepare the system for changes in wind power generation in the short-term horizon.

Reserves to cover forecast errors

Due to the uncertainty of the forecasts of the wind power production (and the load) it might be necessary to have additional reserves available to cover the forecast errors. In this study focus is on forecast up to 24 hours before the operational hour and the need for reserves to cover forecast errors.

Up-regulating and down-regulating

Two different situations are analysed. In a situation where the actual wind power production is less than the forecasted production, *up-regulating* reserves will be activated. In a situation where the actual wind power production is bigger than the forecasted production, *down-regulating* reserves are needed.

Up-regulating reserves would typically be units which are running below their maximum production or import on interconnectors. The possibilities for using generating units or interconnectors for up-regulation (or down-regulation) depend on how their operation has been scheduled in the day-ahead market. In some situations new units have to be started up before the operating hour in order to ensure sufficient reserve capacity to cover for forecast errors.

Down-regulating reserves would typically be units operating above their minimum production and interconnectors with possibility to reduce import or to increase export. But also wind power units would be able to act as down-regulating reserves by curtailing the production from the wind power plants.

The “optimal” level of reserves will depend on the operational status of the power system, including the demand for electricity, the availability of interconnections and which generators are operating.

To the extent that forecast errors require special measures for ensuring reserves, the cost of these measures are estimated.

## 1.2 Scenarios

The flexibility of the electricity system and the dependency of interconnectors between Estonia and the neighbouring countries are illustrated with different scenarios as illustrated in Figure 1.

The Limited Market scenario and the Estonian Flexibility scenario are analysed in 2013 and 2016, while the Market Flexibility only is analysed in 2016. The main difference between the two years is the interconnector between Finland and Estonia. Today the connection, Estlink 1, has a capacity of 350 MW. A new interconnector, Estlink 2, is planned to be in operation in 2014 with a capacity of 650 MW.

| | |
|---|---|
| Limited Market | • Estlink used on market conditions<br>• Connectors to Russian and Latvia run according to rules for system operation – not market based<br>• 500 MWh/h fixed import from Russia to the Baltic States |
| Estonian flexibility | • Estlink used on market conditions<br>• Connectors to Russian and Latvia run according to rules for system operation – not market based<br>• 500 MWh/h fixed import from Russia to the Baltic States<br>• 400 MW gas turbine in Estonia for balancing purpose |
| Market flexibility | • All interconnectors are used on market conditions<br>• No fixed import from Russia<br>• No additional gas turbine in Estonia |

*Figure 1: Overview of scenarios*

Besides the main scenarios, a number of sensitivity analyses are carried out, illustrating the consequences of the NordBalt interconnector between Lithuania and Sweden, and illustrating the consequences of differences in hydro power production in Latvia.

## 1.3 Results of the study

Limits due to forecast errors

The analyses in the study show that forecast errors are not likely to imply technical constraints on the level of wind power capacity in Estonia, but they create costs in order to ensure sufficient reserves to cover for less wind power production than expected or costs to curtail wind power if wind power production are bigger than expected and no other measures are available. With the current regulatory framework in Estonia it might be difficult or even impossible for Elering OÜ to cover these additional costs by letting the wind power producer pay or by an increase in the system tariffs. If no extraordinary balancing costs are allowed the maximum wind power capacity in the Estonian system would be around 600 MW with Estlink 1 in operation.

Limits due to curtailment

If (reasonable) balancing cost is not a problem, the amount of curtailment could be a guideline for the maximum wind power capacity in Estonia. Using curtailment levels of 0.1%, 5% and 20% of the annual wind power production the result of the scenario analyses are summarised in Table 1.

*Table 1: Maximum wind power capacity in Estonia with different levels of curtailment and with different capacity of the interconnector between Estonia and Finland.*

| | With Estlink 1 | With Estlink 1 and 2 | | | |
|---|---|---|---|---|---|
| | | Normal | Dry year | Wet year | NordBalt |
| **0.1%** | 575 MW | 1100 MW | 1050 MW | 900 MW | 850 MW |
| **5.0%** | 1250 MW | 2050 MW | 2150 MW | 2100 MW | 2175 MW |
| **20%** | 2000 MW | 3200 MW | 3300 MW | 3200 MW | 3400 MW |

Cost of covering forecast errors

The cost of balancing load and wind power forecast errors is calculated to 4.4 to 4.8 EUR/MWh wind power production.

New flexible units

The consequences of investments in new flexible new power units (gas turbines) on the amount of curtailment has been analysed as part of the scenario analyses. The analyses show that such an investment cannot be justified from a curtailment point of view. A new flexible unit could however be part of a strategy for covering the need for reserves for forecast errors.

### Electricity prices

Increasing possible supply of wind power depresses wholesale electricity prices. With increased wind power the short-run operating costs of wind power is more frequently marginal in the market. Increased wind power also leads to more frequent price differences resulting from increased congestion as high levels of local wind power generation are transmitted to where it can displace the dearest form of generation. Conversely, at times of short term low levels of wind generation, it may be preferable to import instead rather than commit thermal units incurring commitment costs. These two effects increase bottlenecks in the system and therefore also the marginal benefit of transmission capacity, trade and well functioning markets.

The Market Flexibility scenario has both the highest levels of electricity prices (marginal short-run generation costs) and the lowest average regional variations. This implies that economical wind power generation is facilitated by an efficient and coordinated approach to transmission access and to unit dispatch.

### Wind power and electricity markets

The development of efficient electricity markets will benefit the integration of wind power in the system. The analyses is carried out with the assumption that the interconnector between Estonia and Finland at least partly will be used according to market rules – an assumption which seems justified by the opening of the Nord Pool Estlink price area in April 2010. No market between Russia and the Baltic States is assumed, but the analyses show that a market based flow between Russia and the Baltic States will allow for more wind power in the Baltic States.

### Development of wind power in the Baltic States

Besides the curtailment of wind power production in Estonia, the curtailment in the Baltic States as a whole has been analysed. A symmetric development of wind power has been assumed for all three Baltic countries in the scenarios, i.e. the 900 MW level means 900 MW in Estonia, 900 MW in Latvia, and 900 MW in Lithuania. Similar for the 1800 MW level: 1800 MW in each of the three countries. In the surrounding countries assumptions on wind power development have been made based on existing plans.

The analyses show a similar trend to the curtailment in the Baltic States as a whole as in Estonia alone. However the curtailment is generally higher for the Baltic States as a whole than for Estonia alone. These results give preliminary indication that Estonia is able to effectively integrate more wind power than Latvia and Lithuania respectively.  In the scenarios for 2013, without Estlink 2, the level of curtailment in Estonia and the Baltic States as a whole are similar.

This situation is changed in 2016 with the introduction of Estlink 2, which results in decreased curtailment in Estonia and a larger difference between the curtailment level in Estonia and the Baltic States as a whole.

**Socio economic viable deployment**

The optimal deployment of wind power in Estonia from a socio economic point of view has not been analysed. Deployment of large scale wind power in Estonia might be economically viable for the society as a whole, but it would have significant impact on the financial viability of existing thermal power plants. The distribution of cost and benefits between the different stakeholders has however not been analysed in this study.

## 1.4 Recommendations

Based on the analyses and the result in the study, the following recommendations seem justified:

- It is technical possible and it might be socio economically beneficial to develop wind power further in Estonia. It is recommended to develop wind power gradually in order to ensure that the regulatory and institutional framework is developed accordingly.
- It is recommended to conduct a study of the economic impact of a wind power development plan, including a socio-economic study as well as an analysis of the consequences for the different stakeholders in the Estonian energy sector. The study could also include an analysis of the current and possible future incentive schemes for wind power.
- It is recommended to develop mechanisms for allocating of balancing cost to the different stakeholders in the energy sector
- It is recommended that Elering continue to improve forecasting of wind power production
- It is recommended to introduce a system where Elering has the possibility to activate reserves for compensating forecast errors and load variations
- Rules for curtailment of wind power and other power generating units exist today, but it might be necessary to develop the rules further, including development of compensation mechanisms for economic losses in connection with curtailment
- The development of wind power in Estonia should be carried out in coherence with the development of the energy systems in the neighbouring countries, especially in Latvia, Lithuania and Finland. A close cooperation with the TSOs in these countries on an optimal development and use of the electricity infrastructure and development of common rules and agreement for the future use and cooperation is strongly recommended. Also a stronger and more market oriented cooperation with Russia should be pursued in order to benefit the development of wind power in the Baltic States.

# 2 Introduction

Recent years wind power has become more interesting as energy source in Estonia.

Estonia has had an incentive scheme for renewable energy, including wind power, since 2003. The current scheme ensures a fixed subsidy per kWh which will be added to the market price for the first 600 GWh electricity produced by wind power each year. Any excess production will be paid the market price of electricity only.

The favourable incentive scheme has given birth to a large number of wind power projects. By the end of 2009 app. 140 MW wind power capacity was installed in Estonia. Furthermore, approx. 200 MW of new wind power capacity is being constructed and connection points have been completed for an additional approx. 380 MW. Hence it is not unlikely that within a few years wind power generation capacity may increase to 720 MW. This corresponds to an annual generation of about 1500 GWh of electricity – significantly more than covered by the current incentive scheme.

Connection proposals have been given for an additional approx. 2600 MW of wind power. However, it is still uncertain how big a share of this potential will be realised. This will also depend on the possibilities for cost-effectively integrating the wind power in the Estonian electricity system.

The many new wind power projects have given reason to examine the possibilities for integrating wind power in the Estonian system. The Estonian electricity system is a rather small system, although connected to the other Baltic States and to Russia as synchronous area, and with an interconnector for Finland. Elering OÜ has therefore launched a study to investigate the technical limits for wind power capacity in Estonia in the coming 10 year. The study is carried out by Ea Energy Analyses. The study was launched in January 2010 and completed in May 2010. This report is the final report from the study. The analyses from the study are documented in two reports, *Scenario Report* and *Wind power forecast errors*.

# 3 The Estonian Power system

## 3.1 Electricity consumption and production

The electricity consumption in Estonia was app. 8 TWh in 2009 and it is expected to grow to app. 9 TWh in 2016.

Production of electricity in Estonia is predominantly based on a domestic fuel – oil shale. Electricity produced from this mineral approached 95% of the total electrical energy supplied to the Estonian electrical network in 2008. The largest oil shale mining company in Estonia is Eesti Energia Kaevandused AS.

*Table 2: Electricity production in Estonia, 2009 (preliminary figures)*

| Power plant | Net Installed Capacity MW | Electricity production TWh | Fuel |
|---|---:|---:|:---:|
| **Narva TP** | 2000 | 7,0 | Oil shale |
| **Iru CHP** | 156 | 0,1 | Gas |
| **Other TPP-s** | 146 | 0,3 | Oil shale, gas |
| **Wind turbines** | 140 | 0,2 | Wind |
| **Hydro PP-s** | 4 | 0 | Water |
| **Total** | **2446** | **7,6** | |

## 3.2 Interconnected Systems

The Estonian electricity system is well integrated with the other Baltic States and Russia. The strong integration gives on one hand better possibilities for integrating wind power into the system. On the other hand, the integration creates flows in the systems which are out of control from the Baltic TSOs. These flows will potentially limit the possibilities for wind power integration and the development of the electricity market in the Baltic States.

From the end of year 2006 a connection has been established with the Finnish energy system through an underwater cable ESTLINK. The new connection increases Estonia’s reliability substantially and also enables the export of electricity produced in Estonia to the Nordic countries.

Elering and Fingrid have agreed to establish a new interconnector between Estonia and Finland, Estlink 2. The connection will have a capacity of 650 MW and is expected to be in operation in 2014.

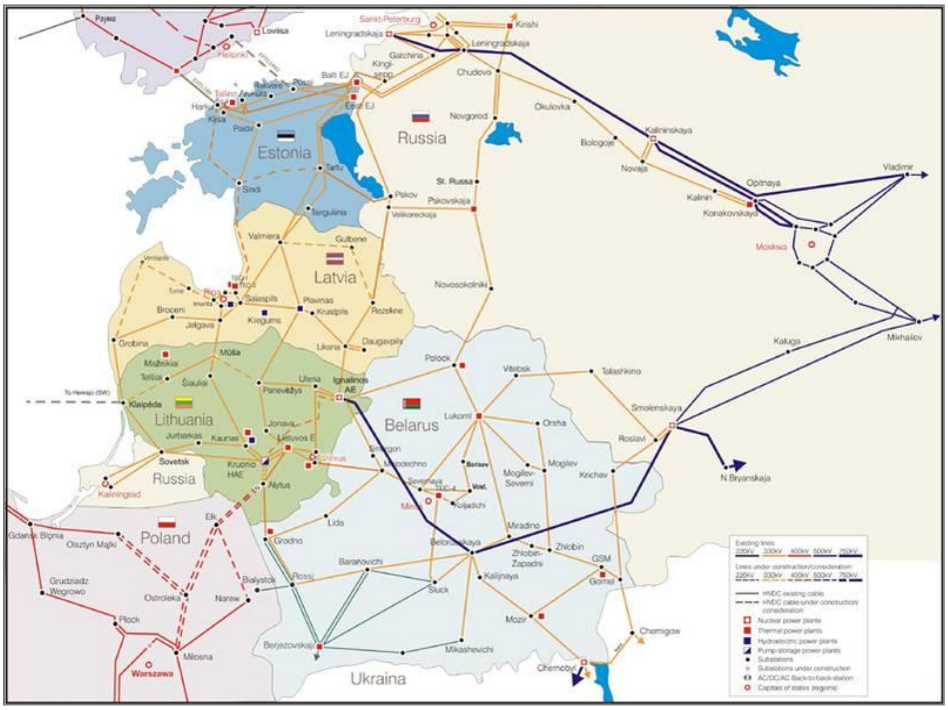

*Figure 2: The Baltic and the Western part of the Russian electricity system*

Within the interconnected systems (Estonian, Latvian, Lithuanian, and Belarussian and Russian electricity systems) the faults of one system have an instant effect on the other's performance in system operation, reliability and transmission capacity.

Although within the interconnections the operation of an element in one system affects the performance of the neighbouring systems, as a rule the consequences of a single short-circuit, an element turning off or a sharp change in load are essentially lighter in a large interconnected system. The interconnected systems also enable electricity trade and the possibility to obtain the necessary ancillary services (i.e. frequency control, managing power reserves etc.) to maintain system reliability with a favourable price.

## 3.3 Estonian electricity market

The market structure has similarities to Scandinavian model. All market participants are to have an open delivery contract and balance providers need a balance agreement with system responsible party. There are currently four balance providers active in Estonia. The trading in the market is carried out by bilateral contracts, and, starting from April 2010, via Nordpool Spot Estlink price area for eligible customers.

Customers with consumption over 2 GWh per year become eligible customers. Only eligible customers have a right to choose a supplier. They have also right to apply for an import license, which is issued by the Electricity Market Regulator. The opening of market is planned to be completed to the full extent by the year 2013.

Non-eligible customers can purchase their electricity from the grid company they are physically connected to or from the seller named by that grid company.

Grid companies and sellers selling energy to non-eligible customers can purchase that energy from power plants using oil-shale mines in Estonia as the primary energy source or from small producers with capacities less than 10 MW.

1 April 2010 Estonia joined the Nord Pool Spot market. From 2011, Estonia will also introduce the Nordic Intraday trading and the regulating information system NOIS.

The electricity market between the Baltic States is not well established yet. The prime ministers of the three countries signed in April 2009 an agreement on the creation of an open and transparent common Baltic electricity market and its integration with the Nordic electricity market within the dates foreseen by the EU legislation. The objective is to have a Nord Pool Spot area in 2011 in Latvia and Lithuania.

The agreement also includes a commitment to prepare a joint and common policy regarding import of electricity from third countries in close cooperation with European Commission and Member States concerned. This relates to the possibilities for exchange of power between Russia and the Baltic States, based on market principles.

## 3.4 Summing up

The power industry in Estonia was developed primarily to satisfy the needs of the former USSR North-West Region. In 1991, when Estonia restored its independence, it inherited from the USSR an advanced power sector, inclusive well developed and large oil shale fired power plants in Narva.

Today, Estonia is highly dependent on electricity production from the oil-shale fired power plants in the Eastern part of the country. Estonia is closely connected to Latvia and Russia, but the interconnectors are currently not used on market based conditions. A link between Estonia and Finland is operated on market conditions with the establishment of a North Pool Spot area in Estonia by 1 April 2010. The link will be further reinforced within the next three years. Wind power capacity in Estonia is currently below 150 MW, but a large number of projects are in progress, encouraged by a favourable incentive scheme for wind power plants.

# 4 Scenarios for wind power integration

## 4.1 Scenario analyses

The possibilities for integration of wind power capacity in the Baltic electricity grid in Estonia are dependent on a number of factors which again influences each other. In order to get a comprehensive assessment of the possibilities and constraints, the Baltic system has been modelled together with the surrounding system in the energy system model Balmorel. The analyses are detailed in the report *Wind Power in Estonia – Scenario Analyses*.

The model determines a least-cost solution for covering the electricity and district heating loads hour by hour with the given energy production system. Thereby the model simulates the detailed dispatch of the production units, taking into account electricity and heat demand, technical and economic characteristics for each kind of production unit, environmental regulation and transmission capacities between regions and countries. As output, the model derives production and transmission patterns on a total cost-minimizing basis. The model also account for violation of system constraints which will be of importance when evaluating the possible magnitude of installed wind power capacity in the system.

In order to analyse the inter-dependency between the different areas in the Baltic Sea Region the model includes the electricity system in the Baltic States, North-West Russia, the Nordic countries and Germany, as illustrated in Figure 3.

*Figure 3: The area modelled in the energy system analyses (except Poland)*

The energy system in Poland is not modelled due to the lack of interconnectors between the Baltic States and Poland.

The energy system is analysed for the year 2013 to illustrate the possibilities for wind power integration with the current energy system, and for the year 2016 to illustrate the situation after establishment of Estlink 2.

## 4.2 Scenario set up

### Different types of system flexibility

The flexibility of the electricity system and the dependency of interconnectors between Estonia and the neighbouring countries are illustrated with different scenarios.

| | |
|---|---|
| Limited Market | • Estlink used on market conditions<br>• Connectors to Russian and Latvia run according to rules for system operation – not market based<br>• 500 MWh/h fixed import from Russia to the Baltic States |
| Estonian flexibility | • Estlink used on market conditions<br>• Connectors to Russian and Latvia run according to rules for system operation – not market based<br>• 500 MWh/h fixed import from Russia to the Baltic States<br>• 400 MW gas turbine in Estonia for balancing purpose |
| Market flexibility | • All interconnectors are used on market conditions<br>• No fixed import from Russia<br>• No additional gas turbine in Estonia |

*Figure 4: overview of main scenarios in the study*

The first scenario, *Limited Market*, illustrates a situation where the interconnector between Estonia and Finland is operated on market conditions, while the connections to the other Baltic States and to Russia are run according to the rules for system operation, with a limited possibility of using these connections as balancing tools for variations in load and wind power production. In the scenario, a 500 MWh/h fixed import from Russia to the Baltic States is assumed.

The second scenario, *Estonian flexibility,* illustrates a situation where new gas fired capacity (gas turbine) is established in order to improve the possibilities for balancing load and wind power variations in Estonia. Other conditions are similar to the Limited Market scenario.

Finally, a third scenario, *Market flexibility,* shows a future situation where the market conditions between the Baltic States and Russia are improved. The interconnectors between the three countries and Russia will in this scenario contribute more to a market based balancing of the system, and no fixed import from Russia is assumed. This scenario is only applied for 2016.

In addition to the main scenarios, a number of sensitivity analyses are carried out. The first series of sensitivity analyses, *Island Operation,* illustrate a situation where the only available interconnector is the link to Finland. The connectors to Russia and Latvia are not used in these model runs.

The second series of sensitivity analyses, *NordBalt,* illustrate the consequences for the wind power development of the planned interconnector between Lithuania and Sweden.

Finally the sensitivity for variations in the production of hydro power in Latvia is illustrated.

### Wind power development

To illustrate different levels of wind power development two different levels have been selected – 900 MW and 1800 MW. It is assumed that the development is similar in the three Baltic States, i.e. 900 MW in each country or 1800 MW in each country. The two levels will be tested in each of the scenarios and for the two years in focus.

### Summing up

Table 3 gives an overview of the main scenarios carried out.

*Table 3: Overview of main scenarios in the study*

| | 2013 | | | 2016 | | |
|---|---|---|---|---|---|---|
| | Limited Market | Estonian Flexibility | Market Flexibility | Limited Market | Estonian Flexibility | Market Flexibility |
| 3*900 MW | **X** | **X** | | **X** | **X** | **X** |
| 3*1800 MW | **X** | **X** | | **X** | **X** | **X** |

In addition – the *Island Operation* scenario is carried out for 2013 and the *NordBalt* scenario is carried out for 2016.

In the following the results are described for each of the two years.

## 4.3 Wind power integration in 2013 (before Estlink 2)

### Wind power curtailment

As a first measure for the maximum wind power capacity in the Estonian system the yearly amount of energy curtailed from wind power plants is chosen. The curtailment is a proxy for how well wind power can be integrated into the system. If the system is not able to balance the load and production, wind power is curtailed until a balance is obtained. A small is generally allowed, but more curtailment would eventually jeopardize the economic viability of the wind power projects.

Figure 5 shows the results of the model runs for Estonia in 2013.

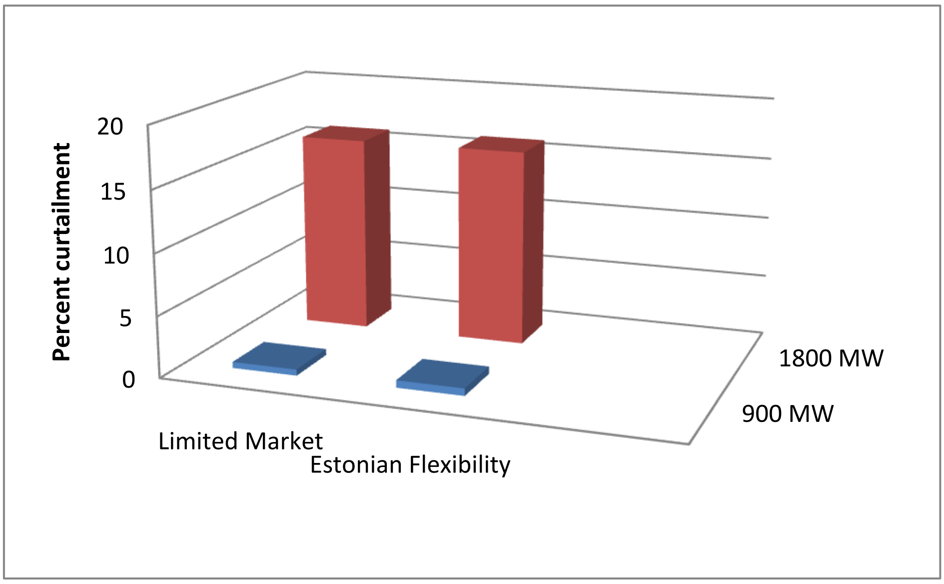

*Figure 5: Percent curtailment of wind power in Estonia in 2013 in the different scenarios*

The figure illustrates that it is technically possible to integrate 900 MW wind power in the Estonian electricity system without major curtailment (the curtailment is about 0.5 percent of the possible annual yearly production from the wind farms). Doubling of the capacity to 1800 will however result in a significant curtailment of wind power – app. 16 percent on a yearly basis.

Introduction of a flexible gas turbine (or other types of flexible balancing units) in Estonia has very limited influence on the amount of curtailment.

A more detailed look at the dispatch of the Estonian system and the neighbouring systems reveals that Estlink 1 is vital for balancing the wind power. Estlink 1 allows for a more smooth operation of the Estonian power plants.

Another way of looking at wind power integration is to examine the prices of electricity for wind power production. In general, more wind power in a system will tend to reduce the electricity price due to the low marginal costs of wind power. At some point the electricity price for wind power purchased will not make room for return of investments for the wind power projects.

The price of electricity from wind power production in the different scenarios is shown in Figure 6. The price is the electricity market prices weighted by the amount of wind power production for each hour of the year. The wind power electricity price will normally be lower than the system market price, as a high wind power production tends to depress the market price.

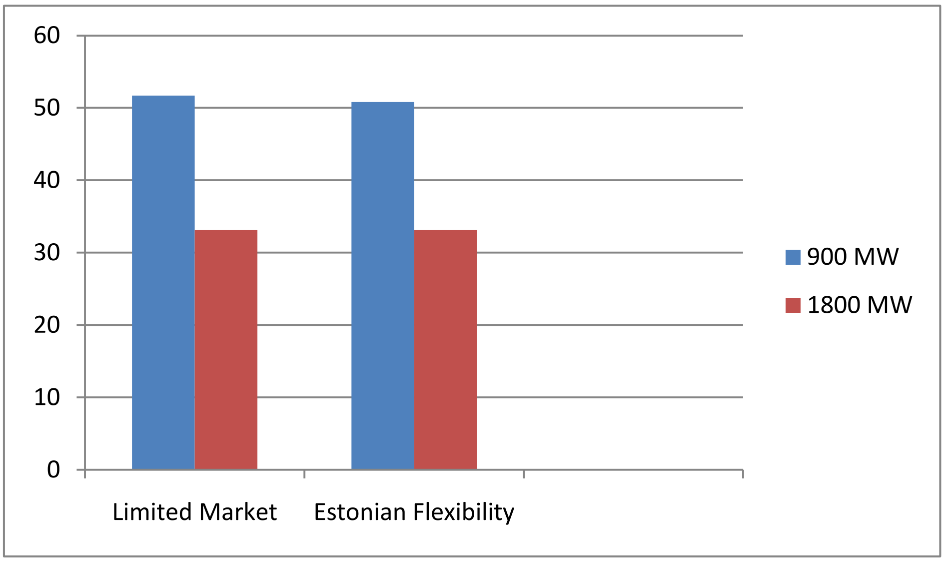

*Figure 6: Electricity price for wind power in Estonia in 2013 in different scenarios and different levels of wind power deployment*

The figure shows that deployment of 1800 MW wind power in Estonia in 2013 results in a significant reduction in the electricity price in both scenarios. This indicates that the 1800 MW level is too high for Estonia in 2013.

## 4.4 Wind power integration in 2016 (after Estlink 2)

In 2016, after Estlink 2 is put into operation, the situation changes. Figure 7 shows the amount of curtailment in Estonia in the three different scenarios with 900 MW and 1800 MW wind power capacity. The figure shows that Estlink 2 results in a significant reduction of the curtailment of wind power in the situation with 1800 MW wind power. In both the Limited Market and the

Estonian Flexibility scenarios the curtailment is 2.8 percent of the yearly wind power production. In the Market Flexibility scenario the curtailment is reduced to zero.

Looking at the electricity price for wind power shows the same picture, c.f. Figure 8. The difference between the electricity price at the 900 MW level and the 1800 MW level is smaller in 2016 than in 2013, implying a better integration of wind power in 2016, due to Estlink 2. Also more efficient market integration facilitates wind integration.

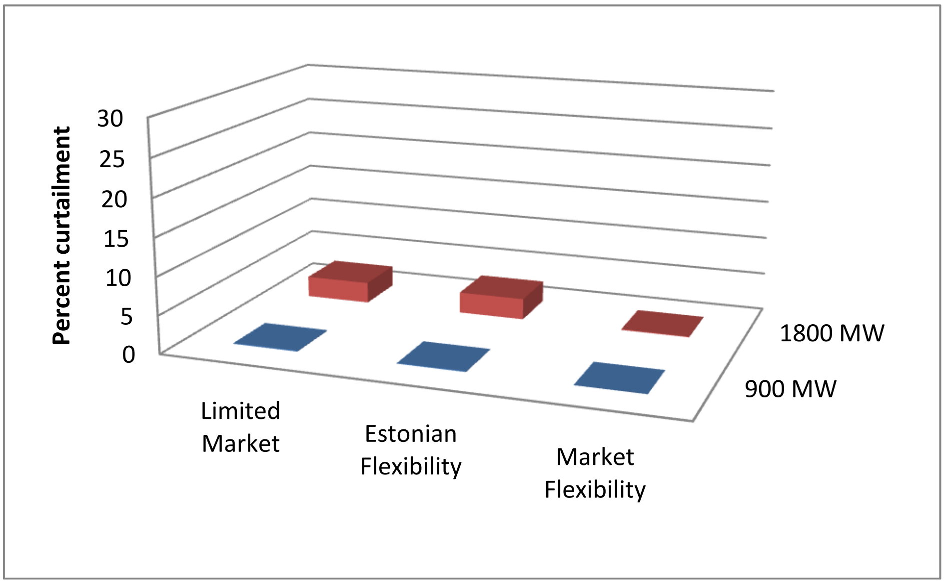

*Figure 7: Wind power curtailment in Estonia in 2016 for the three scenarios and the two levels of wind power deployment.*

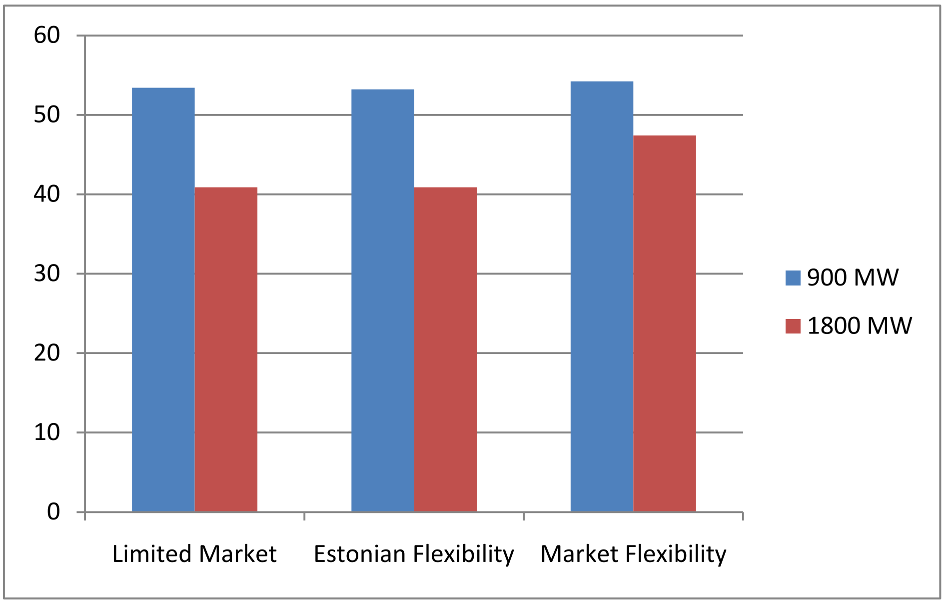

*Figure 8: Electricity price for wind power in Estonia in 2016 in different scenarios and different levels of wind power deployment*

## 4.5 Island Operation scenario

The Island Operation scenario in 2013 shows the same tendencies as the other scenarios, underlining the importance of the Estlink 1 as balancing measure. At a 900 MW wind power level, the curtailment is app. 1 percent; while the curtailment is around 15 percent curtailment with 1800 MW wind power capacity in Estonia.

## 4.6 Curtailment in the Baltic States

Besides the curtailment of wind power production in Estonia, the curtailment in the Baltic States as a whole has been analysed.

In the scenarios for 2013, without Estlink 2, the level of curtailment in Estonia and the Baltic States as a whole are similar. This situation is changed in 2016 with the introduction of Estlink 2, which results in decreased curtailment in Estonia and a larger difference between the curtailment level in Estonia and the Baltic States as a whole.

A symmetric development of wind power has been assumed for all three Baltic countries in the scenarios, i.e. the 900 MW level means 900 MW in Estonia, 900 MW in Latvia, and 900 MW in Lithuania. Similar for the 1800 MW level: 1800 MW in each of the three countries.

The analyses show a similar trend to the curtailment in the Baltic States as a whole as in Estonia alone. However the curtailment is generally higher for the Baltic States as a whole than for Estonia alone.

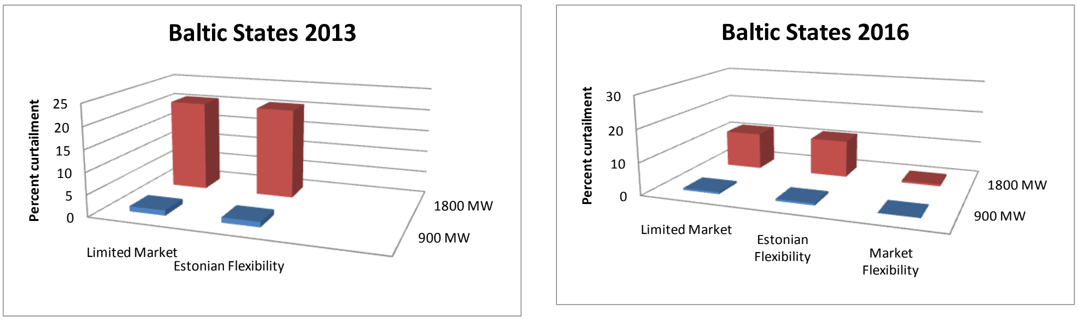

*Figure 9: Wind power curtailment for the Baltic States in 2013 and 2016 in different scenarios and with different levels of wind power capacity.*

## 4.7 The NordBalt interconnector

The impact of the planned connection between Lithuania and Sweden, NordBalt, on curtailment of wind power in the Baltic States has been analysed for 2016, as illustrated in Figure 10. NordBalt has a significant influence on the curtailment in a situation where the electricity market is developed towards the Nordic electricity market and not towards Russia (the Limited Market scenario). In a situation with full market opening towards both the Nordic and the Russian market, NordBalt is not important as a means for limiting curtailment in the Baltic States (but it will have influence on the flows and generation patterns in general).

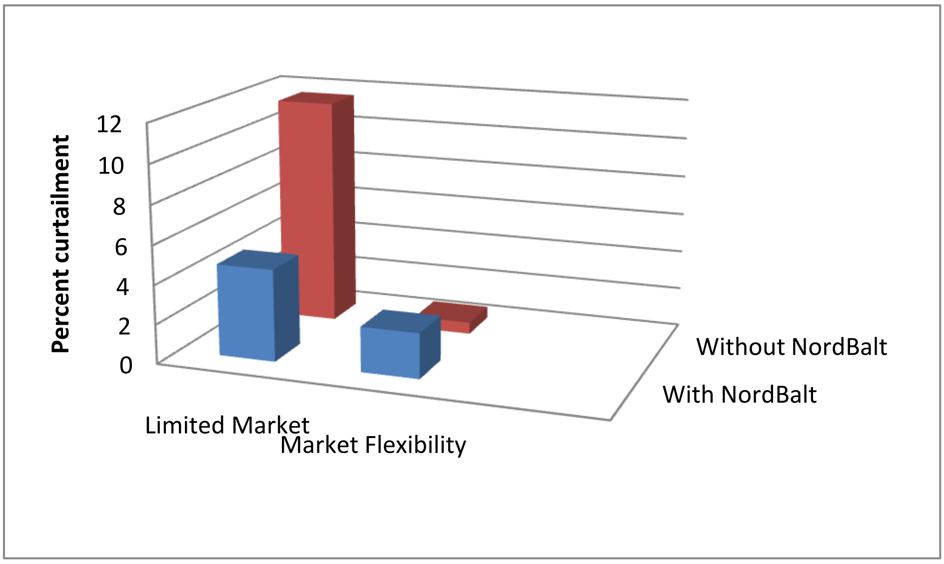

*Figure 10: Curtailment in the Baltic States in 2016 with and without NordBalt*

# 5 Forecast errors and reserve margins

Forecasting wind power as accurately as possible is important to wind power producers bidding in their production in an electricity market as well as to the system operator.

In a market based setup the wind power producers will normally pay for the costs of balancing the wind power (the cost of providing balancing power). Therefore the more accurate the forecast of wind power the lower will the balancing costs be to wind power producers. From a socio-economic perspective better forecasting will reduce the total generation costs due to more optimal dispatch of power plants.

From a system operator point-of-view forecasting can be important to determine the amount of reserves needed in the system during the coming day. Moreover, during the course of operation forecasting is important to the system control-centre to prepare the system for changes in wind power generation in the short-term horizon.

There is a variety of reserves, classified according to the response time required by those reserves:

a) *Frequency or regulation reserves* which are reserves that can be employed within a very short time frame after a surge in demand occurs.
b) *Disturbance or contingency reserve* consists of fast units that are able to respond to a contingency within seconds/minutes. This kind of reserve's size is determined by the size of the largest generator in the grid, allowing for a relatively smooth response to any unit in the grid tripping (also known as the n-1 principle).
c) *Load following reserves* consist of slower starting units that can be available and synchronized within approximately 10 minutes or more. These units are called upon to contribute to serving the load and relieving the regulating reserve units who can then go back to their predesigned point of operation to ensure they are available for another frequency perturbation.

Increased levels of wind power may increase the requirement for load following reserves as the forecast error associated with the change in net load variation is likely to increase. The demand for disturbance reserves will not increase as distributed wind power plants – unlike conventional thermal units - are not subject to sudden changes in generation.

The Estonian system's grid code already incorporates provisions for the separation of reserves into frequency and regulatory ones.

To determine reserve planning, two parameters are critical. The time that reserves are committed to the system and the speed they need to react to unforeseen imbalances. Another issue is the correct dimensioning of the system reserves according to those two guidelines.

Typically among TSO's, the n-1 principle applies, i.e. reserves are high enough that they can withstand the tripping of the biggest power generator or interconnector (with import).

In practice, TSO's often merge this disturbance reserves with load following reserves. For example Energinet.dk makes no separation between the two kinds of reserves and assumed the probability of a contingency and large wind/load variation occurring simultaneously is insignificant (or could be solved through interconnection use in the rare chance it occurs).

For this reason wind power is not determining the demand for disturbance reserves acquired by the Danish system operator Energinet.dk. In the both Eastern and Western Denmark – with approx. 900 MW and 2200 MW wind respectively – the amount of reserves is presently based on an n-1 criterion related to possible tripping of the largest generating unit (600 MW and 500 MW respectively).

## 5.1 Requirement for load following reserve capacity in Estonia

A common way to determine the level of load following reserves is to find the standard deviation of the forecast of wind and load. Since load and wind forecast errors tend to follow normal distribution (with a mean of zero), three standard deviations away from the mean should cover 99.7% of the possible outcomes.

In the case of Estonia, a large part of the generation capacity has long start-up time – up to 16 hours. Therefore, the day ahead forecast error of wind generation, has been used to determine the need for reserve capacity, to allow for the possible commitment of reserve capacity.

The requirement for load following capacity is mapped for two situations:

1) 2013 scenario with 900 MW wind in Estonia
2) 2016 scenario with 1800 MW wind in Estonia.

To estimate the forecast errors of wind production in the two scenarios the experience from the German and Danish wind forecast data is used.

The table below shows the subsequent requirement for reserves to deal with the wind forecast error in the cases with either 900 or 1800 MW wind (using the three times standard deviation method).

| Year | Wind | 0 – 20% | 20 – 40% | 40 – 60% | 60 – 80% | 80 – 100% |
|---|---|---|---|---|---|---|
| 2013 | 900 MW | 162 | 270 | 243 | 189 | 54 |
| 2016 | 1800 MW | 216 | 324 | 270 | 324 | 162 |

*Table 4: Requirement for reserves to deal with the wind forecast error in the cases with either 900 or 1800 MW wind. Calculated as a function of the wind power output*

Two different situations are analysed. In a situation where the actual wind power production is less than the forecasted production, *up-regulating* reserves will be activated. In a situation where the actual wind power production is bigger than the forecasted production, *down-regulating* reserves are needed.

Up-regulating reserves would typically be units which are running below their maximum production or interconnectors with possibility for more import or reduced export. In some situations new units have to be started up before the operating hour in order to ensure sufficient reserve capacity to cover for forecast errors.

Down-regulating reserves would typically be units operating above their minimum production and interconnectors with possibility to reduce import or to increase export. But also wind power units would be able to act as down-regulating reserves by curtailing the production from the wind power plants.

The “optimal” level of reserves will depend on the operational status of the power system, including the demand for electricity, the availability of interconnections and which generators are operating.

Using the load and wind time series from the Balmorel simulations for 2013 and 2016, it is possible to calculate the reserves required for each hour. An example for 2013 (900 MW wind) is shown in *Figure 11*.

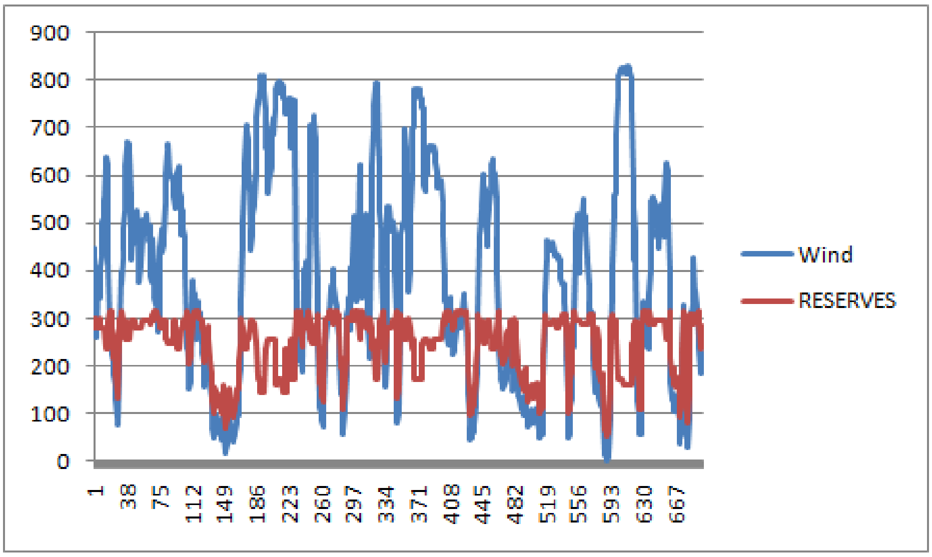

*Figure 11: Wind generation (blue) and Reserve requirement (red) time series for a 2013 (the 600 first hours of the year), 900 MW wind Estonia scenario. The figures concern only the requirements for up-regulation (lower wind power production than forecasted). The reserves cover both forecast errors in load and in wind power production.*

## 5.2 Available load following reserve capacity for up-regulation

The next step is to compare the requirement for reserves with the **available** load following capacity (up-regulation) in the system.

By this we mean the assigned capacity leftover by the simulation tool (Balmorel), i.e. the total unused capacity of the power plants that operate in the Estonian system and can be ramped up within an hour according to the optimization solution. This includes possibilities for importing power at Estlink 1, if the interconnector is not already fully utilized for import.
The interconnections to Russia and the other Baltic States have been not considered in the analyses, as Elering considers them inflexible and unavailable to provide regulating capacity in times of emergency (apart from existing agreements to deal with n-1 situations). However future agreements could augment their role in reserve planning.

### 900 MW in 2013

In Figure 12, the load following capacity reserves identified by the 3σ method are deducted from the BALMOREL leftover capacity that can be ramped up within at most one hour.

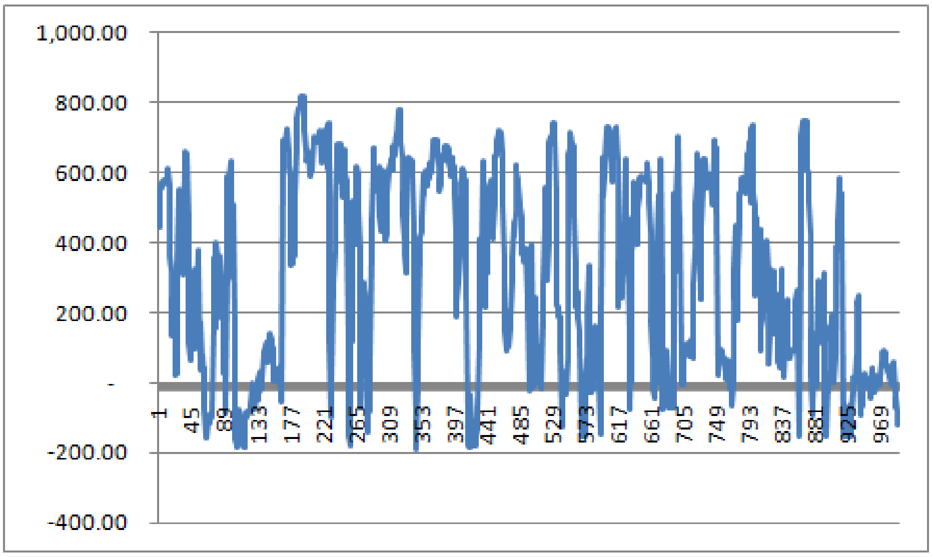

*Figure 12: BALMOREL leftover capacity minus reserves calculated by the 3σ method, Estonia 2013-900 MW wind scenario.*

Figure 13 shows the duration Curve of the net reserves (BALMOREL reserves minus reserves calculated by the 3σ method) for all hours in the 2013 scenario.

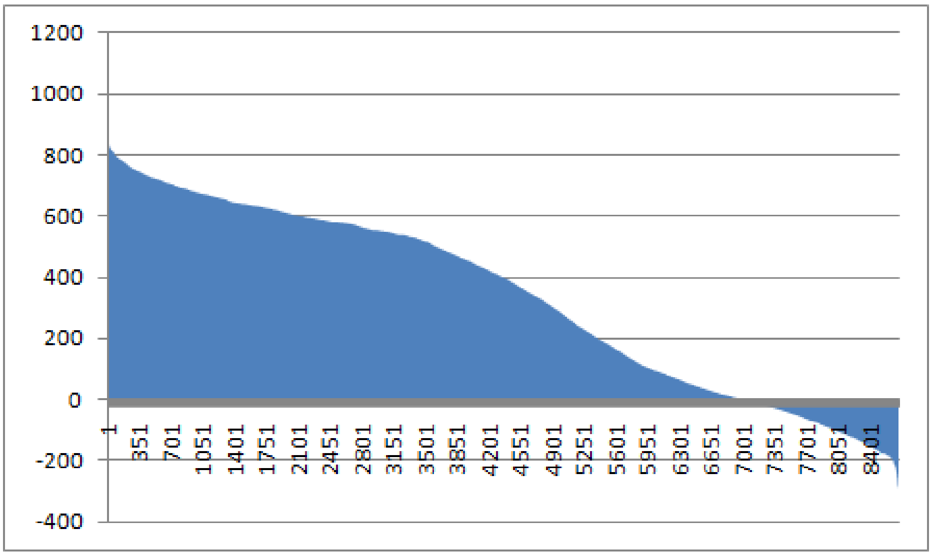

*Figure 13: Duration Curve of the net reserves (BALMOREL reserves minus reserves calculated by the 3σ method)*

The figures for 2013 with 900 MW show that for most cases, further resource allocation is not actually required since there is sufficient backup capacity available within an hour to cover any unexpected fluctuations. However there are cases where reserves are lacking and this could be worrying. The Estonian units are on average slow to start up and unless they are committed already, fluctuations that are big could unbalance the system.

It should be reminded that this reserve calculation is meant to cover 99.7% of possible outcomes and in combination with the low amount of hours for, which reserves are not enough, means that an unbalance is not very likely. Furthermore, the forecast error calculations are based on a 12-36 hour ahead prediction. If the time window is narrowed down to one hour, forecast errors are reduced drastically and the standard deviation of the net load is not expected to vary as much, reducing reserve requirements.

### 1800 MW wind in 2016

In 2016, the addition of a second interconnection line (Estlink 2) to Finland gives the potential to transmit almost instantaneously 1000 MW of power, compared to 350 MW for 2013.

The inclusion of Estlink 2 will however in some periods also lead to an increase of the contingency reserve, since n-1 will need to cover now the size of Estlink 2, if it is operated with full import to Estonia.

Figure 14 shows the net reserves for 2016 with 1800 MW installed wind power capacity.

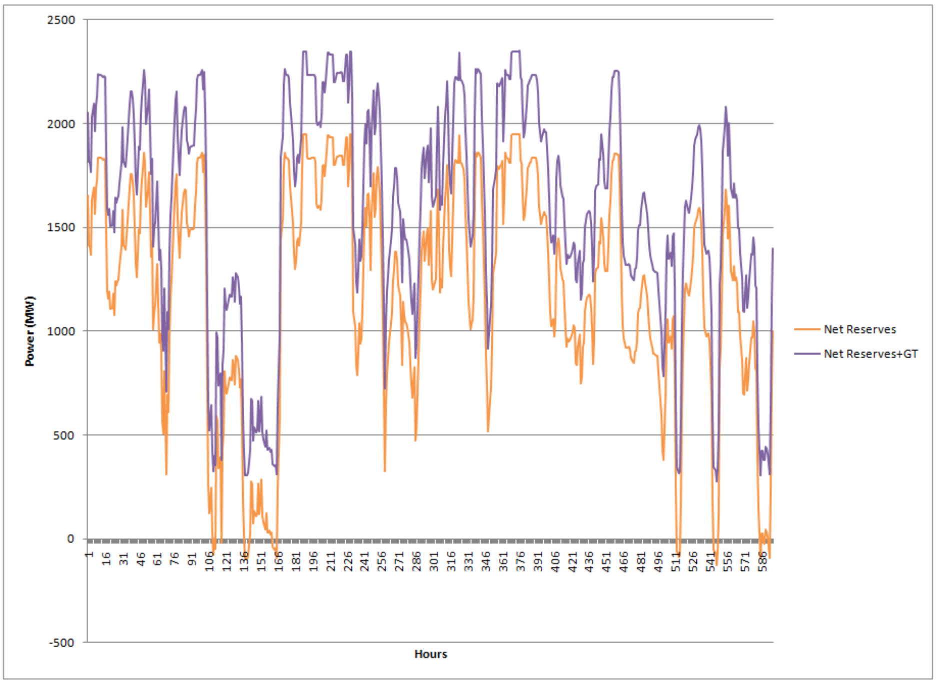

*Figure 14: Net Reserves (BALMOREL unused capacity minus calculated need for reserves) for 2016, with and without a 400 MW gas turbine*

The figure illustrates that also in 2016 there are a few occasions, when the Estlink 2 connection is committed for full import, where the load following capacity is not sufficient.

If a 400 MW gas turbine with a start up time of 10 minutes (and 10 minutes further to reach full capacity) is build, there will be sufficient load following capacity available in all stages of operation.

However it should be noted that the size of that power plant may be excessive and unnecessary and that a smaller gas based power plant would have sufficient effect.

## 5.3 Down regulation reserves

The next inquiry is on the effect of wind on down regulation. The same 1800 MW scenario will be examined. Unlike up-regulation, down-regulation does not require starting-up power plants and can be performed a lot closer to the event horizon. To account for the fact that down regulation can happen a lot closer to the event horizon, the reserve requirements calculated using the 1-hour variability of wind instead of the forecast error’s standard deviation for each interval of wind power (in effect assuming a 1 hour ahead persistence forecast). The calculations result in the duration curve of the net down regulation reserves.

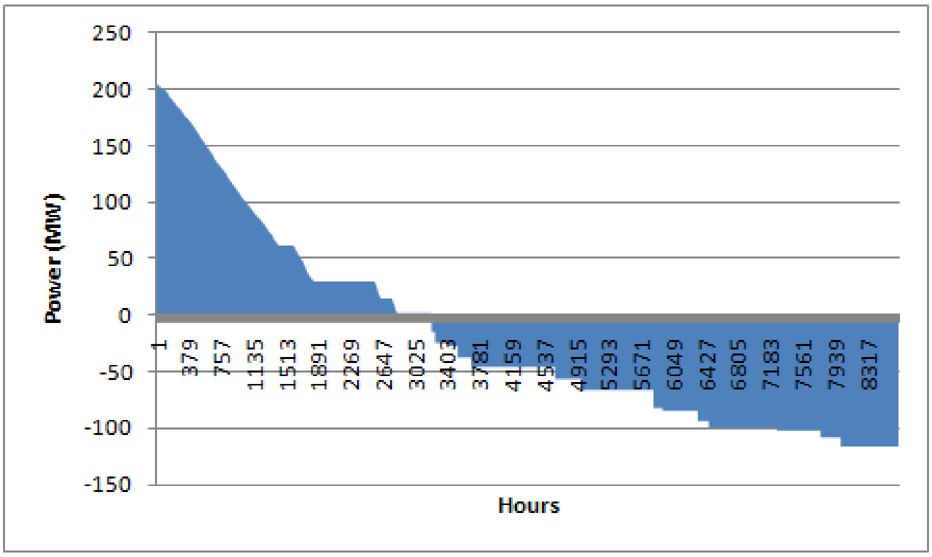

*Figure 15: Duration Curve of the net down regulation reserves (BALMOREL reserves minus reserves calculated by the 3σ method for the hourly wind variability)*

It should be taken into considerations that it is possible for wind turbines to contribute to down-regulation, a prospect that is not included in the graphs pictured above. This would just require the down-regulation of wind to the levels that the forecast predicted would be suitable.

## 5.4 Measures to increase load following capacity

The general conclusion of the analyses of the importance of load and wind power forecast errors in relation to the amount of load following reserves is that only in few hours additional reserve capacity is needed for up-regulation.

Down regulation reserves are needed in more than half of the year, but down-regulation do not require start up of units and can be performed much closer to the operating hour. Wind turbines could contribute to the down-regulation in a dynamic way.

A variety of different measures to improve the situation regarding up-regulating could be considered:

1. The probability of a large wind/load variation occurring could be treated as a contingency event, which could be handled with contingency reserves; a method applied by the Danish TSO, Energinet.dk. This would however imply a relaxation of the current security of supply standards.
2. Developing a common market for reserves between the Baltic countries and if possible Russia. In the longer term with the opening of Estlink2 and NordBalt such a market could be linked to the Nordic regulation power market..
3. The possibilities for import on Estlink in the day-ahead market could be limited when forecast indicate a need for reserve capacity (as updated information about forecast is available closer to the hour of operation this constraint could be released and the import possibility be made available for intraday trading).This is not possible according to current EU regulation.
4. Existing units could be required to start up to be available to provide reserve capacity.
5. New units (e.g. gas turbines) with short start-up time could be acquired.
6. In the longer term perspective it will be relevant to explore the possibilities for obtaining ancillary services – including up-regulation - from the demand side as part of a smart grid strategy. Electric heat pumps at consumers and electric vehicles or plug-in vehicles are examples of technologies, which may hold a significant potential in the coming decaded

# 6 Cost of wind power balancing

There are two levels of cost implications for wind power balancing.

1. The system-wide or societal costs of balancing are the net sum of costs less the benefits for all stakeholders involved.
2. The individual costs (or benefits) to a particular stakeholder or group of stakeholders.

In evaluating the cost of wind power balancing the first point is central in the decision to pursue or not to pursue promotion policies. The second point is a crucial point of consideration in practical implementation, especially since changes to the policy and regulatory framework are most likely necessary to ensure that stakeholders in legitimate pursuit of their own interests obstruct implementation and to protect interests where relevant.

## 6.1 Forecast errors cause disruptions to planning

The costs of forecast errors are stochastic and manifest themselves in the realised. Commonly used metrics for assessing the potential costs of disruptions involve calculating the expected value of perfect information (EVPI), i.e. the difference between the *expected costs under uncertainty* and the *ex post calculation of costs subject to realised values* of the underlying stochastic variables (possible wind power production). The Balmorel scenarios in this study use historical (realised) values for possible power generation and as such yield the later portion of the EVPI expression. In the previous section, a span is calculated for the uncertainty and with this as a base the costs can be estimated.

## 6.2 Costs calculated on the basis of “naive” dispatch

Since the Balmorel model does not take forecast errors into consideration the cost estimates should be considered and expected upper bound on the costs which should necessarily incur. With integrated planning of dispatch, which takes account of uncertainty, e.g. by incentivising reserves to be available prior to day-ahead scheduling based on wind power forecasts, the system costs of wind power uncertainty should be significantly lowered.

## 6.3 Cost components

There are two specific manifestations of costs from wind power uncertainty in wind power forecasts.

1. Additional units may need to be started to ensure that sufficient up-regulation capacity.
2. The realised dispatch is likely to commit units with higher running costs than the units originally dispatched.

From the system cost perspective it is important to note that on average the deviation in realised possible power as opposed to forecasted possible power should balance out over the year. Therefore there is only net waste (curtailment) of wind when realised possible power exceeds beyond what is possible to utilise by reduction generation on units with short-run costs in the system. As wind power curtailment can be effectuated in real-time it does not need to be carried out in anticipation of possible events. In terms of operational costs to the system the additional costs are therefore only the perceivably higher variable operating costs (fuel) of units ramped up when possible power falls short of the forecast to the variable cost savings when possible power exceeds the forecast and can be safely utilised.

When forecasts have a high (>1%) probability of overestimating possible power it may be necessary to commit an additional new unit prior to knowing whether or not that unit will been need to maintain the system balance. In the following illustration, it is assumed that whenever the system has a likelihood of being in deficit when the wind is realised, a unit must be paid to start-up even though it is not a part of the expected optimal dispatch as defined by the market. This unit will be maintained in operation until there is not another contingent situation in sight within a sufficient turn-around time of the unit. The start-up cost of the unit is considered to be entirely a cost attributed to forecast uncertainty. The cost is material, as it is incurred whether the contingent situation is realised or not.

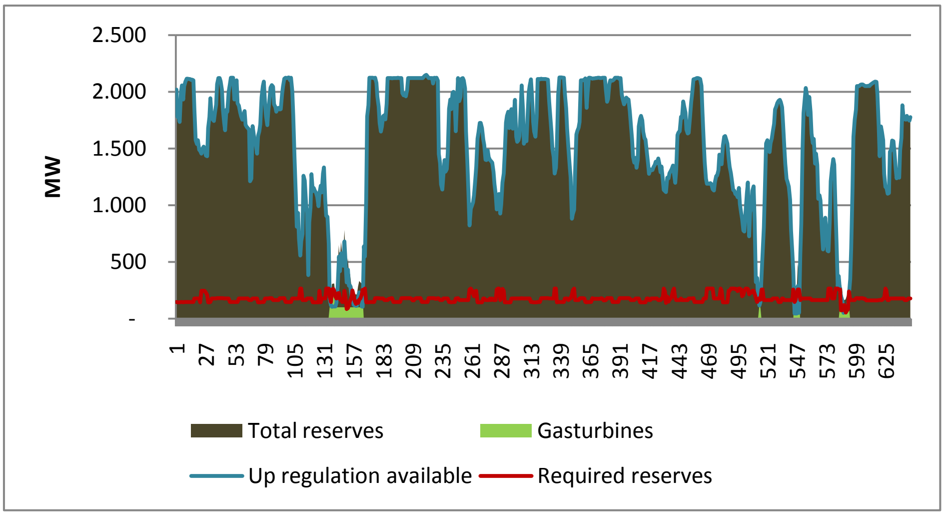

*Figure 16: Illustration of a situation where available up regulation power in the myopic dispatch falls short of the contingent reserve requirement (first 650 hours of the year).*

The scenario depicted on Figure 16 shows the commitment of the 400 MW gas turbines in the Estonian Flexibility scenario. For the sake of this calculation it is assumed that the gas turbine facility is comprised of 4x100 MW units, each with start-up costs of 6.000 EUR.

In the 2016 scenario with 1.800 MWs of wind power, gas turbine units are started 87 times in anticipation that the wind forecast may overestimate the possible wind generation. The first 100 MW units are in operation for 580 hours to be available for 303 hours with a possible up regulation contingency. In total they operate for 873 hours. Note that the units are kept online if successive contingent reserve requirements are close together.

- Total start-ups costs are estimated to 522,000 EUR/year which distributed on 5.3 TWh wind yields 0.1 EUR/MWh wind.
- Assuming conservatively the gas turbine units have a minimum generation level of 20%, they with generate 17.5 GWh from being committed to the system. The weighted average short-term marginal generation cost (sunken start-up costs) is 45.6 EUR/MWh compared to variable operating costs of the gas turbines of 65 EUR/MWh. The additional operating costs to the system are therefore calculated to 9.4 EUR/MWh generation on the gas turbines, 164.500 EUR in total which distributed over 5,3 TWh of wind comes to 0,03 EUR/MWh of wind.

The operational proportion of balancing costs when using new gas turbines gas thus be estimated to 0,13 EUR/MWh in this scenario. In comparison, the 400 MW gas turbines could be expected to cost in the area of 200 mEUR, which in annual terms over 20 years with a 10% interest would yield 4.4 EUR/MWh of wind.

The gas turbines, or other reserve units, are committed when there is not sufficient up regulation capacity available from the myopic dispatch. This coincides with other units operating at their maximum rates. Committing an additional unit to run at its minimum level will require another unit to ramp down. Thereby the total potential for ramping up is increase by the ramping capacity of both units, should the contingency situation arise.

A similar calculation of the balancing cost in 2013, using existing oil shale units as balancing units shows cost of 4.8 EUR/MWh of wind.

## 6.4 Recovering costs incurred from forecast errors

The costs described in the previous sections are designed to provide conservative estimates based on the existing practice supplemented with minimal necessary development of operational strategy. Therefore costs figures are inflated in relation to possible actions which can be put in place by the TSO. These include, but are not limited to, the following:

- Consider allowing use of N-1 contingency reserves for wind power balancing, rather than investing in dedicated gas turbines, or committing ill-suited oil shale units for balancing. This is however not possible with today's agreement between the TSOs in the Baltic States, Russian and Belarus.
- Delay activation of decision to get greater accuracy on the forecast before putting reserve units in play.

# 7 Max wind power capacity in Estonia

## 7.1 Technical integration

The technical possibilities for integration of wind power in the Estonian power system is assessed by using the energy system modelling tool Balmorel which makes a detailed simulation of the hourly dispatch of the generation units in order to meet the load. With the given input the model finds the optimal economic solution to the dispatch for the whole system in consideration.

Normally the generation will be fitted to the load, second by second and hour by hour. But in some situations the system flexibility is too low in certain areas and production has to be curtailed in order to maintain the system balance and system stability. These situations might occur when wind power production is high, thermal generation unit cannot be ramped down quickly enough, units are on minimum load and cannot shut down because of minimum up-time constraints and transport capacity is insufficient to transport load out of a surplus area. In these situations curtailment of wind power production is the only solution to maintain system stability.

Curtailment of wind power is problematic because the financial viability of wind power project might be jeopardized by the missing revenue. From a socioeconomic point of view the wind power production has the lowest marginal cost (which compensates for the high investment costs) and the cleanest production which implies that curtailment should be avoided.

One measure for the maximum wind power capacity is therefore the wind power capacity which creates very little curtailment, measured on a yearly energy basis. The small amount of curtailment indicates that the maximum capacity of wind power has been reached.

In the present study three levels of curtailment is chosen as measures. The first level, 0.1% curtailment, is used as an indication of zero curtailment. The second level, 5.0% curtailment, indicates a curtailment level which normally only will have a small effect on the financial viability of the wind power project. Finally the maximum wind power with 20% curtailment is shown. 20% is a very high level of curtailment, and the financial viability of the wind power projects might be jeopardized with such a high level.

To illustrate the limits for wind power capacity in Estonia the scenario Estonian Flexibility has been chosen. The Limited Market and the Estonian Flexibility scenario are very similar regarding curtailment of wind power, and the Market Flexibility scenario with a market based flow on the interconnectors between Russia and the Baltic States is not expected to reflect reality in the coming years, although it might be a vision for the long term development of the cooperation in the Baltic Sea Region.

In Figure 17 and Figure 18 the amount of curtailment of wind power production is shown as function of the installed wind power capacity in a situation with Estlink 1 is in operation and a situation where both Estlink 1 and Estlink 2 is in operation.

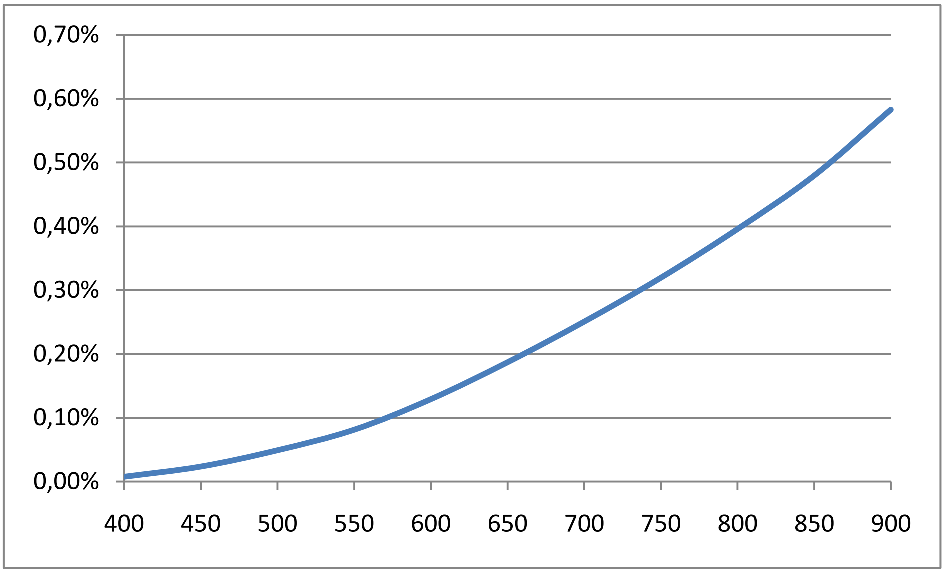

*Figure 17: Curtailment as a function of installed wind power capacity in 2013, based on the Estonian Flexibility scenario with 900 MW wind power*

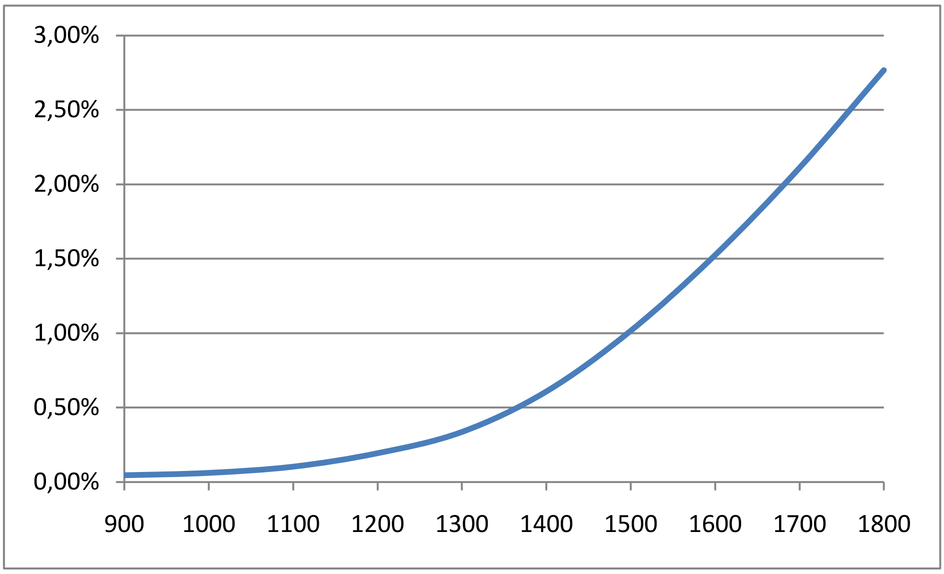

*Figure 18: Curtailment as a function of installed wind power capacity in 2016, based on the Estonian Flexibility scenario with 1800 MW wind power*

Similar figures can be made for the other scenarios and sensitivity analyses. In Table 5 the maximum wind power capacity in Estonia is summarised for curtailment levels of 0.1%, 5% and 20%.

*Table 5: Maximum wind power capacity in Estonia with different levels of curtailment and with different capacity of the interconnector between Estonia and Finland.*

| | **With Estlink 1** | **With Estlink 1 and 2** | | | |
|---|---|---|---|---|---|
| | | Normal | Dry year | Wet year | NordBalt |
| **0.1%** | 575 MW | 1100 MW | 1050 MW | 900 MW | 850 MW |
| **5.0%** | 1250 MW | 2050 MW | 2150 MW | 2100 MW | 2175 MW |
| **20%** | 2000 MW | 3200 MW | 3300 MW | 3200 MW | 3400 MW |

## 7.2 Limits due to forecast errors

As shown in Chapter 5 and 6 forecast errors do not imply technical constraints on the level of wind power capacity in Estonia, but they might create costs in order to ensure sufficient reserves to cover for less wind power production than expected or costs to curtail wind power if wind power production are bigger than expected and no other measures are available. The cost of balancing load and wind power forecast errors is calculated to 4.4 to 4.8 EUR/MWh wind power production.

With the current regulatory framework in Estonia it might be difficult or even impossible for Elering OÜ to cover these additional costs by letting the wind power producer pay or by an increase in the system tariffs. It might therefore be of interest to analyse the amount of wind power capacity which the system could accommodate without extra costs for the system operator.

The reserve margins calculated in Chapter 5 are reserves needed to cover both forecast errors from wind power production and from load variations. Analyses of the load variations without any wind power in the system reveal that the maximum reserve margin for the load alone is 160 MW. These reserve margins are in some way or the other covered today in the Estonian system.

Furthermore, 350 MW disturbance reserve are covered by the system operator without specific costs for the producers which have a total production of 8 TWh per year. The power plants benefit from the disturbance reserves if they have a forced outage. If 900 MW wind power is installed, the total wind power production would be around 2 TWh per year accounting for ¼ of the total production. It might be fair to let the wind power producer benefit from a reserve margin of ¼ of the total disturbance reserve (= app. 80 MW) without labelling the costs from these reserves as extraordinary.

Using the method from Chapter 5 it can be calculated that the maximum wind power capacity in 2013 should not exceed 600 MW if the reserve margins is to be lower than 240 MW (160 MW plus 80 MW) as the total for load and wind power forecast errors together.

## 7.3 Summing up: Max wind power in Estonia

The analyses in this study show that it is technical possible to further develop wind power in Estonia in the coming years without severe balancing costs.

With the current regulatory framework the expansion of the wind power capacity is limited by the lack of possibility to curtail wind power and the missing regime for allocating balancing cost to the various stakeholders. With these limitations, wind power capacity should not exceed 600 MW before Estlink 2 is put into operation and 900-1100 MW after Estlink 2 is in operation.

If these limitations are removed it will be possible to accommodate up to 1200 MW wind power with Estlink 1 and up to 2000 to 2200 MW with both Estlink 1 and Estlink 2 in operation, as summarized in Table 6.

*Table 6: Maximum wind power capacity in Estonia with different levels of curtailment and with different capacity of the interconnector between Estonia and Finland.*

| | **With Estlink 1** | **With Estlink 1 and 2** | | | |
|---|---|---|---|---|---|
| | | Normal | Dry year | Wet year | NordBalt |
| **0.1%** | 575 MW | 1100 MW | 1050 MW | 900 MW | 850 MW |
| **5.0%** | 1250 MW | 2050 MW | 2150 MW | 2100 MW | 2175 MW |
| **20%** | 2000 MW | 3200 MW | 3300 MW | 3200 MW | 3400 MW |

The cost of balancing load and wind power forecast errors is calculated to 4.4 to 4.8 EUR/MWh wind power production.

The results in this study are based on the technical limitations for wind power in the Estonian power system and the surrounding power systems as well as estimations of the costs for reserves to balance forecast errors in load and wind power production.

An economic assessment of the wind power development in Estonia for the society as a whole and for the individual stakeholders has not been carried out as part of the study. It is recommended to conclude such a study as part of the further decisions on the future development of wind power in Estonia. Such a study should also include different scenarios for the development of the power system in the Baltic States as well as in Nordic countries (especially in Finland) and in North West Russia, including Kaliningrad. The development of new power plants in the area will have great influence on the financial viability of new power units in Estonia, including wind turbines. Also the financial viability of the existing power plants in Estonia will be influenced by the development in the region.

The analyses show that wind power development in Estonia is highly depended on an efficient and market based use of the interconnector between Finland and Estonia. A further development of a common Nordic-Baltic electricity market including an intraday market would be valuable for the wind power development in the region. Also a more market based flow on the interconnector to Russia would be important for an efficient use of the power infrastructure in the region and for the further development of wind power.