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Scenarios for a Nordic Power System without Greenhouse Gas Emissions

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Abstract

The paper presents scenarios for power production without greenhouse gas (GHG) emissions in Denmark, Finland, Norway and Sweden by 2050. The Nordic region already has a high share of renewables in its power production portfolio (about 60% in 2010), and possibilities for further deployment are very good. The main target group of the scenario results is the Transmission System Operators (TSOs), but the results will also be relevant for the Nordic politicians and investment decision makers in the power industry. The scenarios will among other be used for the following purposes:

- Identify profitable investments in transmission grids with particular focus on the interconnections between the Nordic region and Continental Europe
- Technical simulations of the power system with focus on balancing of large shares of non-dispatchable renewable resources in a future system.
- Assess impacts on the power system with large-scale deployment of electric vehicles.
- Discuss necessary governance transformation related to the transmission grid development

The paper presents a scenario methodology where each scenario consists of a possible future and a strategy for how the decision maker (TSOs) can act within that future. Each future consists of a set of uncertainties which are factors/developments that cannot be directly controlled by the decision makers. Each strategy contains a combination of technical and non-technical options for decision makers.

Application of this methodology for the study of a Nordic power system free of GHG emissions is described. Furthermore, the paper describes the resulting scenarios and compares them with the Nordic Energy Technology Perspective (NETP). Finally, quantification of input data for technical analyses is given. The input data are mainly based on statistical data from the four countries and information about established and planned projects for new renewable power production in the Nordic region.

Key words: Demand Development, Development of Power System, High share of Renewable Production, Transmission Grid development

1. Introduction

All Nordic countries have presented long-term strategies for CO_2 emission reduction to be achieved by 2050 [1]. Sweden and Norway already have very high share of renewable sources in their power production, and Denmark aims to a have a 100% renewable energy supply by 2050. Furthermore, the Nordic region is often mentioned as an exporter of "green" power in the future European system. The Nordic region is also considered as a possible provider of flexible power outside its own borders due to the high share of hydropower in the production portfolio [1].

The paper presents a scenario methodology and application of the methodology on a Nordic power system without greenhouse gas (GHG) emissions by 2050. The main target group of the scenario results is the Transmission System Operators (TSO), but the results will also be useful for Nordic politicians and investment decision makers in the power industry. The scenarios will among other be used for the following purposes:

- Identify profitable investments in transmission grids with particular focus on the interconnections between Denmark, Finland, Norway, Sweden and the Continental Europe
- Technical simulations of the power system with focus on balancing of large shares of non-dispatchable renewable resources in a future system
- Assess impacts on the power system with large-scale deployment of electric vehicles
- Discuss necessary governance transformation related to the grid development

The Nordic Energy Technology Perspectives (NETP) was released in 2013 [1]. It provided useful information about possible carbon neutral energy systems in the Nordic region in a long term perspective. However, identification of the needs of transmission grids and balancing services require a higher spatial resolution than provided by the NETP which mainly presents information at a national level. The scenarios presented in this paper are developed in the Nordic Energy Research project "NORSTRAT", and they will bring further the knowledge basis established by the NETP.

Section 2 describes relevant characteristics of the Nordic power system. In Section 3 a methodology for the development of scenarios is described. Section 4 shows how the methodology is applied on the Nordic power system and presents the resulting scenarios. In Section 5 the scenarios are quantified. In the end, the conclusions are drawn.

2. The Nordic power balance

The power production in the Nordic region (including Denmark, Finland, Norway and Sweden) is already to a large degree based on sources without GHG emissions (Table 1). To completely remove all the GHG emissions would imply substituting the remaining 70 -100 TWh/y of fossil fuel based production with fossil fuel free generation sources. The Nordic high voltage electricity transmission grid integrates Eastern Denmark, Finland, Norway and Sweden into a synchronous system. There are several Direct Current (DC) connections to Western Denmark. Furthermore, there are DC connections from Denmark to Germany, from Finland to Estonia and to Russia, from Norway to the Netherlands and from Sweden to Germany and to Poland, shown in Fig 1.

Table 1. The Nordic power balance in 2010 [TWh/y] [2]

Source	Denmark	Finland	Norway	Sweden	Sum
Wind power	8	0	1	4	13
Hydro power	0	13	117	66	196
Other RES	3	10	0	12	25
Nuclear	0	22	0	56	78
Fossil fuels	26	31	5	8	70
Non identifiable	0	1	0	0	1
Production	**37**	**77**	**123**	**145**	**382**
Consumption	**36**	**88**	**130**	**147**	**401**

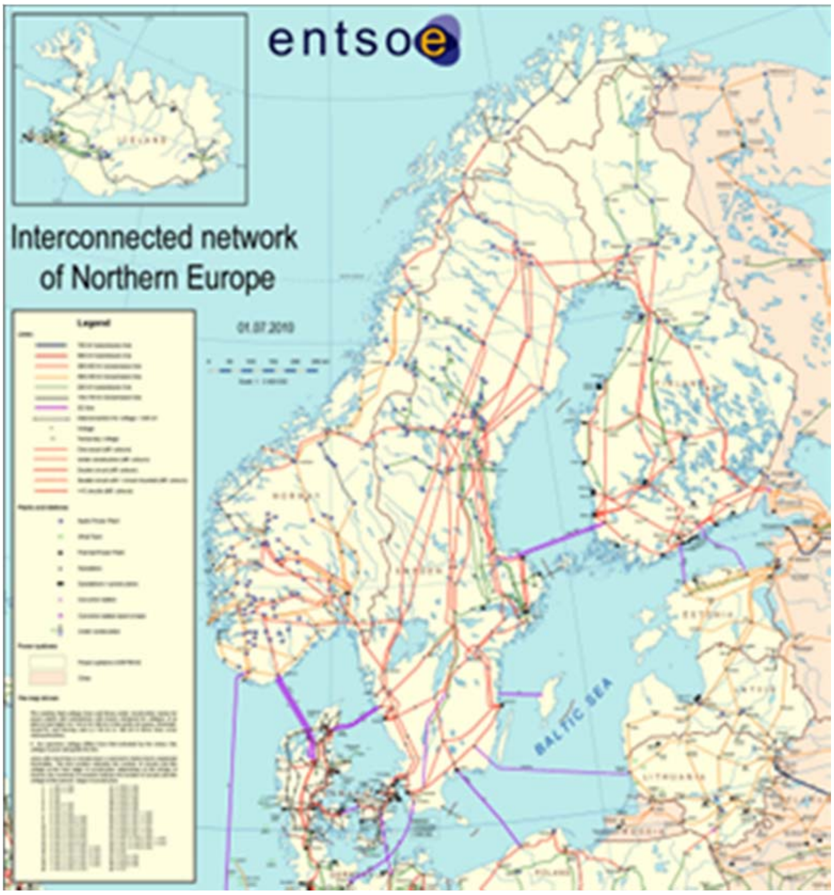

Fig. 1. The interconnected high voltage transmission grid in northern Europe[3].

3. Methodology for scenario development

The methodology for the scenario development is illustrated in Fig 2 and is also described in [4]. The first step in the development is to identify what is the key question/challenge the scenario analyses shall answer. Examples of questions are:

- How can a power system without GHG emissions be obtained?
- How can a totally self-supplied power system be obtained? (E.g. no power import from Russia to the EU region)

The second step is to decide who are the main target group/persons for the study? It may e.g. be national politicians, EU politicians, grid decision makers, technology vendors etc.

In the methodology each Scenario consists of a possible Future and a Strategy (Action Plan) for how to act within that Future. Each Future consists of a set of Uncertainties which are factors/development that will influence the Future but cannot be directly controlled by the target group. Each Strategy contains a combination of technical and non-technical Options which can be chosen/implemented by the target group. The maximum theoretical number of Scenarios is the number of possible Futures multiplied by the number of alternative Strategies. Ideally all possible combinations of Uncertainties and Options should be tested. However, such an approach requires a lot of resources. Therefore, to reduce the "room for analysis", the two most important Uncertainties for the project/activity objective are identified (see Section 4). These Uncertainties are used to span out a set of scenarios. Fig 2 shows the methodology applied on the key question in the NORSTRAT project: *What is the need for transmission grids and balancing services to develop a Nordic power system free of GHG emissions and what role can the Nordic power system have in a European context? What is the necessary governance transformations related to transmission grid development?*

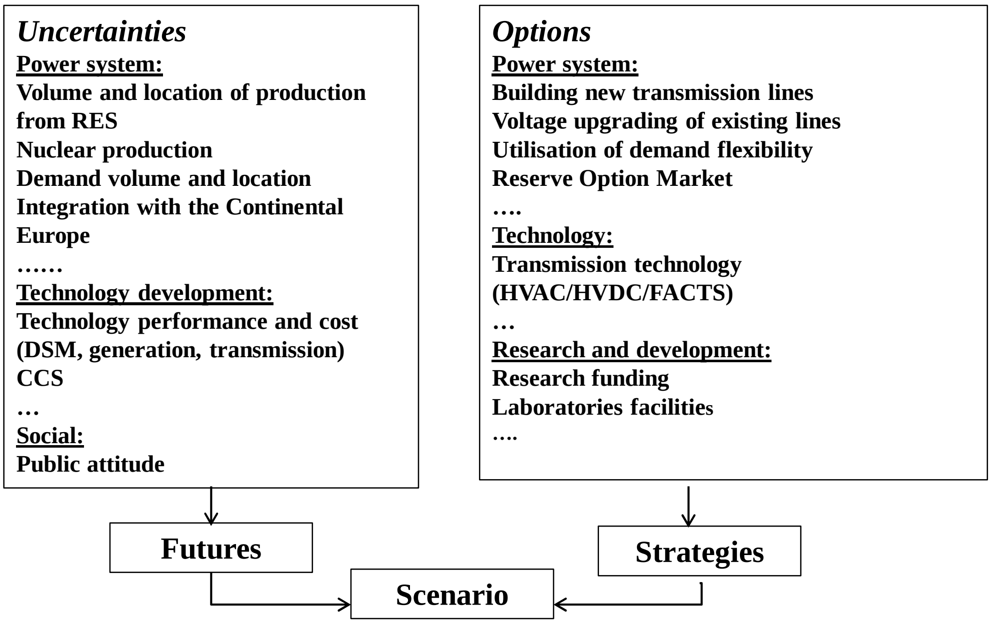

Fig. 2. Methodology for establishing scenarios applied on the NORSTRAT challenge and considered from a TSO perspective

4. Scenarios for the Nordic power system to 2050

4.1. Development of scenarios

The identification of relevant Uncertainties and Options depends on who the actual decision maker(s) are in the study. A controllable Option for one decision maker could be an Uncertainty for another. In NORSTRAT the Uncertainties and Options are seen from the TSO perspective, but with a focus on the more general political debate about the future Nordic power system. It is chosen to consider the Nordic power system as fully integrated in 2050. The system is already highly integrated physically through the grids and through common power markets. At a meeting between the Nordic energy ministers on the 25th of October 2010 they stated that transmission grid investments that are socio-economic profitable for the Nordic region as a whole shall be implemented [5]. Thus, Nordic integration is neither an Uncertainty nor an Option. Below are the Uncertainties and Options and their relevance to the scenarios discussed (ref Fig 2). The different Uncertainties and Options are *italicized*.

The TSOs shall at any time ensure balance between production and consumption, but the development of the generation system is an Uncertainty from their perspective. Factors like *Volume and location of production from RES* (Renewable Resources) and *Nuclear production* as well as development of *Demand volume and location* are outside their control. In a future Nordic power system without GHG emissions, the *Volume and location of RES* will be of particular importance. Share and types of renewables in the production system has a large impact on the grid structure, e.g. offshore wind parks far away from the demand centers will require new grids for connecting to shore as well as an upgrade of the onshore grid in many cases. Furthermore, production from variable resources like wind and solar will require that sufficient balancing sources are integrated into the system. Increase of nuclear production is not very likely except for in Finland. Thus, a possible increase in demand must be balanced with new production from RES unless fossil production with Carbon Capture and Storage (CCS) can be applied.

Integration with the Continental Europe is identified as an Uncertainty. It can of course be discussed if it is an Uncertainty or an Option for a TSO. On one hand it requires an agreement with the country which it is intended to connect with and also a governmental permission, i.e. it can be considered as an Uncertainty. On the other hand the TSO will impact the process, both the dialog with the country to connect with and through the decision basis for the governmental evaluation. Since establishing trans-national connections is not fully controlled by the TSO, it is chosen to regard it as an Uncertainty.

Technology performance and costs regarding energy efficiency, power generation and transmission are Uncertainties that probably will have several breakthroughs in the long period to 2050 and will impact design of the future power system. However, it is very difficult at this stage to assess what the breakthroughs will be and to design the scenarios according to it. One important possible breakthrough is CCS which is a very important technology for the GHG emission reduction options. In the NORSTRAT scenarios, we chose not to focus on CCS since the Nordic region has large unexploited RES resources and a low share of fossil production compared to many other regions.

Public attitude is an important Uncertainty for realising new grids. However, the NORSTRAT scenarios will mainly be used for discussions and decisions about future development of the power system. The NORSTRAT results may be used to impact the public attitude, e.g. to show that the GHG emissions can be removed with a specific development of the power system. It is therefore chosen not to focus on possible public attitude/resistance against grids at this stage.

Based on the above evaluation of uncertainties for the TSOs as well as through discussions with power sector actors in the four Nordic countries, the two most important uncertainties are identified and used to span out the scenario picture: *i) Volume and location of production from RES* and *ii) Integration with the Continental Europe*. These were selected on the basis of their major relevance to the geographically explicit transmission grid planning. Variation over development of demand and share of nuclear in the production portfolio were also included in the scenarios, but not as the key uncertainties.

When it comes to the Options for the TSOs (ref Fig 2) *Building new transmission lines* and *Voltage upgrading of existing lines* are important measures for the TSO to achieve balance between production and demand. The first stage of overall grid analyses in NORSTRAT will be with a power market model with transmission capacity between nodes, but without information about more technical aspects. Thus, it not possible to separate between the two mentioned Options in the first stage, and in the further discussions it is just focused on *Building new transmission lines*.

Another Option is *Utilization of demand flexibility* to reduce consumption in situations with production deficits. The measure could to some degree be used by the TSO, but will not be suitable for permanent imbalances. The Norwegian *Reserve Option Market* (RKOM) is a market created by the TSOs to ensure reserves solutions from both demand and production. Similar to *Utilization of demand flexibility* it does not represent a solution for permanent imbalances. Choice of *Transmission technology* is an Option for the TSOs and will to some degree be included in the NORSTRAT power system analyses which will distinguish between HVAC and HVDC transmission. Regarding the Options *Research funding and Laboratories facilities*, it is difficult to reflect them in the NORSTRAT type of work and they will not be considered further.

4.2. The Nordic scenarios

The NORSTRAT scenarios are described below (see Fig 3). The scenarios are based on the two main Uncertainties identified in Section 4.1 and will among other be used to analyze how the TSOs can have strategies related to *Building new transmission lines* (Option). The background of the numbers of new RES production is given in Section 5. The scenarios are:

- **"Carbon Neutral"** has the same transmission connection to the rest of Europe as today. The fossil production is phased out and substituted with 100- 150 TWh/y new RES based production.
- **"Purely RES"** has 200-250 TWh/y new RES based production and the same transmission capacities to the Nordic neighboring countries as today. The nuclear and the fossil production in the Nordic region are phased out.
- **"European Hub"** is based on 200-250 TWh/y new RES in the Nordic region and up to 20 GW new capacity in the Norwegian hydropower system. The transmission capacities between the Nordic region and the rest of Europe are increased.
- **"European battery"** has 100-150 TWh/y of new RES based production in addition up to 20 GW new capacity in the Norwegian hydropower system. Transmission capacities between the Nordic region and its neighboring countries are increased.

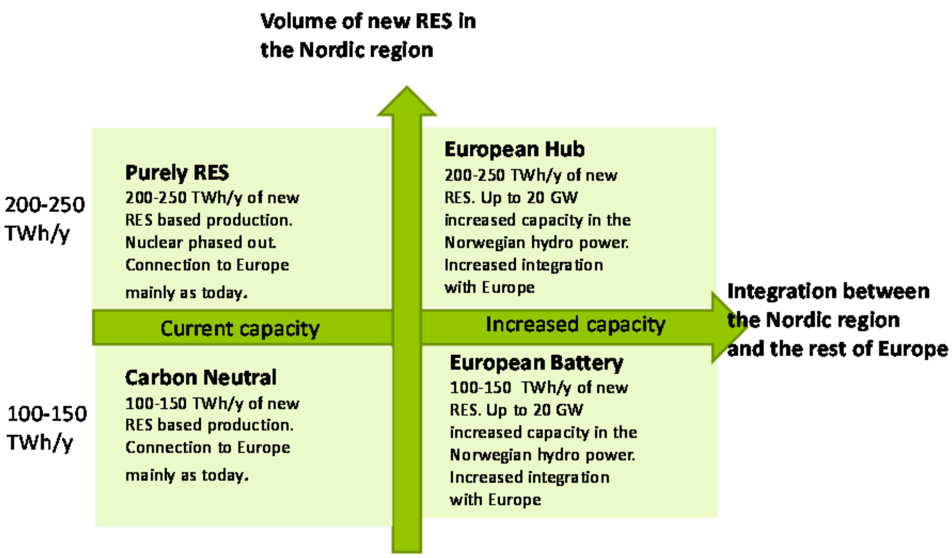

Fig. 3. The NORSTRAT scenarios

Except for in "Purely RES" nuclear production capacity is assumed to be unchanged from 2012 to 2050. Sensitivity analyses will include a "Purely RES" scenario where only Swedish nuclear production is phased out and also some variation in demand.

5. Quantification of the scenarios

As mentioned above, in a study about future need of transmission grids, both the volume and the location of the demand and production sources are important. In this section the quantification of these factors in the NORSTRAT scenarios are described.

5.1. Development of demand

There are several studies about the possible volume of demand in each of the countries, but no comprehensive study about the location of future demand in the whole Nordic region was found. In the NORSTRAT scenarios, both development of volume of demand as well of the location of it is important and need to be considered. The increase/decrease of demand is based on expected increase/decrease in population and location of the population in a long term perspective.

The population in the Nordic region is expected to increase in the period to 2050. Offices of statistical information in each of the countries provide estimations of expected development of population in the period to 2050. Based on information from Statistics Denmark [6], Statistics Finland [7], Statistics Norway [8], Statistics Sweden [9] and some own projections, the expected population in the Nordic countries in 2050 have been obtained and are shown in Table 2. For all the four countries, the main increases in population are in and around the largest cities. The details of calculations can be found in [10].

Table 2. Increase of population to 2050 in each of the Nordic countries

Country	Population 2012 (1000 persons)	Estimated population 2050 (1000 persons)	Difference population 2050-2012 (1000 persons)	Estimated demand increase 2050 [TWh/y]
Denmark	5 580	6 160	580	3.5
Finland	5 430	6 094	664	7
Norway	4 986	6 160	1 174	26
Sweden	9 483	11 291	1 808	21
Total	**25 479**	**29 705**	**4 226**	**57.5**

The expected increase of population may generate an increase in demand. The increase of demand is calculated based on the expected increase of population per region multiplied by the current consumption per inhabitant in the specific region. This rough estimation of demand development is based on expected energy efficiency from passive houses etc (demand reduction) and on the other hand an expected electrification i.e. in the transport sector (demand increase). Further studies in NORSTRAT may result in a revise of the estimate. The estimated total demand increase per country is shown in the column to the right in Table 2.

Fig 4 shows possible location of change of the demand based on the location of the expected increase/decrease of population multiplied by the current consumption in the region. The possible demand increase adds up to 57.5 TWh/y for the four countries together. The increase was added to the power consumption in 2012. The following consumption is assumed per year in the scenarios in 2050: Denmark 39 TWh, Finland 96 TWh, Norway 152 TWh and Sweden 158 TWh.

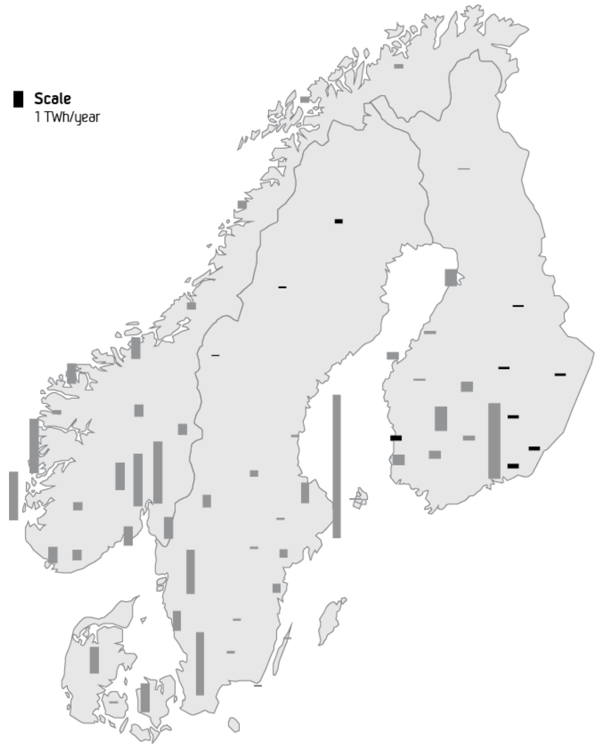

Fig. 4. Location of demand increase in 2050 based on expected increase in population (Grey shows increase, black shows decrease)

The scaling up results in 445 TWh/y in total power demand in Denmark, Finland, Norway and Sweden in 2050. This volume and the location shown in Fig 4 are used in all four NORSTRAT scenarios. However, there is specified a sensitivity variation of "Carbon Neutral" with demand reduction.

In [1] the final electricity demand in the Nordic region by 2050 is in the range of 430 TWh/y- 480 TWh/y. The Nordic region includes in that report Iceland with a yearly power consumption of about 18 TWh/y in 2012 [11]. Estimates for power consumption by 2030 are given in [12]. The estimate for Denmark, Finland, Norway and Sweden is 449 TWh/y already by 2030. Compared to these two studies, the NORSTRAT scenarios are in the same range as [1]. If the Eurelectric scenarios were projected to 2050, they would probably have ended up with a higher consumption than the NORSTRAT scenarios.

5.2. Development of new renewable production

In NORSTRAT, the estimation of potential new renewable production as well as the location of the new production is as far as possible based on already defined projects or plans from authorities, etc.

5.2.1. Wind power production

The wind projects defined are in different phases like "under construction", "Preparing for construction", etc. Several of the projects will probably never be realised, but anyway they give information about where investors find it possible/profitable to build wind power production, and as such the information is useful for the localisation of wind power production in the NORSTRAT scenarios. In Fig 5, the localization of all the identified projects is shown.

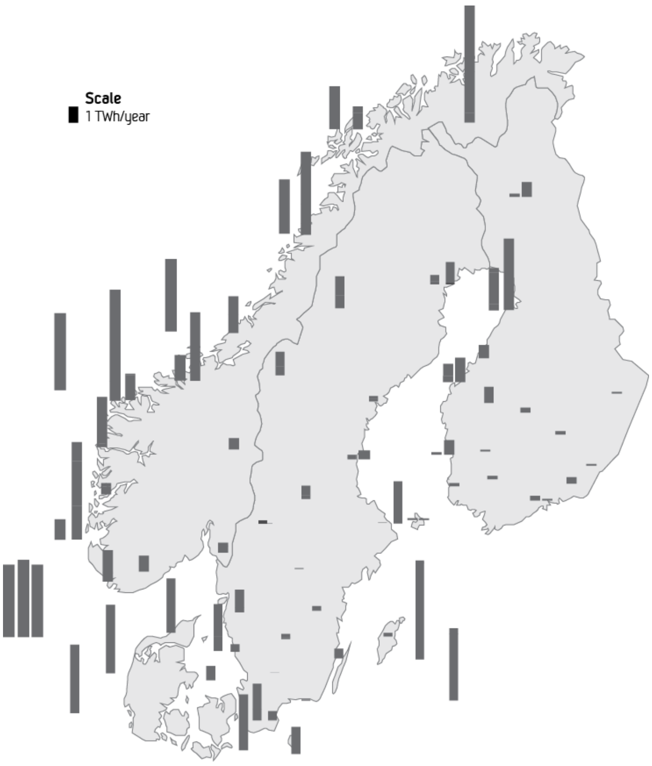

Fig. 5. Localization of identified wind power projects in the Nordic region in 2012 [13-15,17,18]

In Denmark, Energistyrelsen has identified possible locations for new offshore wind production in Denmark in the period to 2025. New capacity of 4600 MW is assumed to give about 18 TWh/y of new production [13]. Detailed information about possible new wind production in Finland is available on web [14]. By the end of January 2012, 7800 MW of wind power projects were published of which about 3000 MW is offshore. The Norwegian Water Resources and Energy Directorate (NVE) give detailed information of possible new wind production in Norway, both onshore as well as offshore [15]. In 2012 projects with a total of 37 TWh/y new onshore and 40 TWh offshore wind production were registered. In 2009 the Swedish Parliament decided to plan for 30 TWh/y power production from wind resources by 2020. 10 TWh/y should be based on offshore wind resources [16]. Svensk Vindenergi provides information of 17 GW or ca 35 TWh/y on already defined projects for onshore wind production [18]. According to [17], there are registered projects that may give another 23 TWh/y production from offshore turbines.

5.2.2. Hydro power production

New hydro power production will mainly be in Norway. Neither Sweden nor Finland is expected to have large increases in the hydro power production [12]. New capacity in Norway is identified by information available at [15]. NVE has the authority to give concession for all new hydro power projects in Norway. In 2012 there were registered projects for possible new hydro production for more than 20 TWh/y at the regulators web page.

Some studies have the recent years identified possibilities for increased of the capacity in the Norwegian hydropower system and also the possibility for installation of pumping capacity [19,[20]. By combining information in the studies potential for increased capacity of 20 000 MW can be identified. The information is used to increase the capacity in the Norwegian hydropower system in the scenarios "European Battery" and "European Hub".

5.2.3. Bio energy

Techno-economic potential for biomass resources is given in [25] and shown in Fig 6.

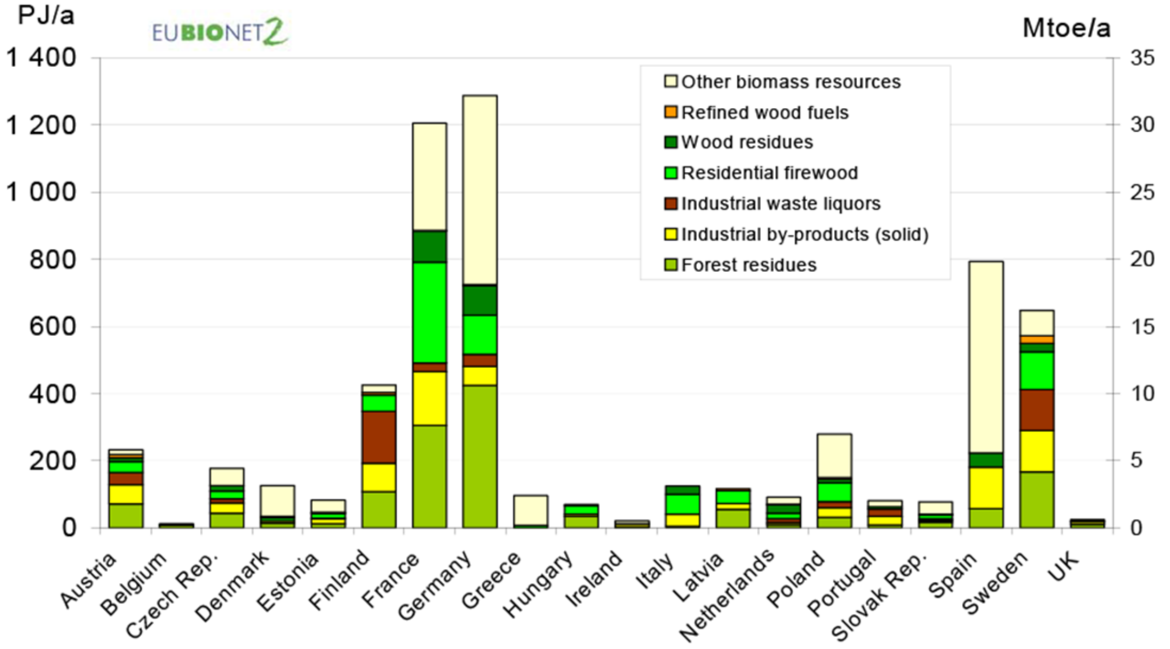

Fig. 6. Techno-economical biomass resources in 20 European countries [25]

We did not find any overview of potential power production from biomass for the Nordic region. If all the resources where used for power generation it would approximately represent 45-50 TWh/y for Denmark, 110 TWh/y for Finland and 180 TWh/y for Sweden. NORSTRAT is based of using a minor share of the potentials shown in Fig 6.

5.2.4. Other possible sources for new renewable production

There were no registered projects for future solar power production as it was for wind and hydro power production. For Sweden a review [21] indicates that the long term realistic potential of the roof top photovoltaic (PV) in Sweden is in the order of 5 TWh/y corresponding to a fifth of the long term technical potential on buildings. A rough estimate of a long term potential of 5 TWh/y was also made for Denmark. The potentials in Norway and Finland were assumed to be limited and set to zero. The potential of solar power production in the Nordic countries will anyway be very low compared to the potentials of production from wind, hydro and bio energy. The detailed description can be found in [10].

It is assumed that geothermal energy primarily will be utilized for heating in the Nordic region [22]. Thus, the geothermal energy will only impact the power system in terms of reduced consumption for heating. The wave resources for the Nordic region are mapped in [23]. The mapping shows theoretical possibilities in Norway and on the west coast of Denmark. However, the theoretical potentials are limited by different factors like competing use, lacking technologies, costs and water depths [24]. There are no registered wave projects of commercial size. In the scenarios, it is chosen not to focus on wave potentials.

5.3. Total possibilities for development of new renewable production in the Nordic region

There is huge potential for new renewable based power production in the Nordic region. A survey conducted in 2012 showed that there are registered projects with nearly 200 TWh/y of possible new production (see below). Among other there are registered about 80 TWh/y onshore wind projects and more 100 TWh/y offshore wind projects [10].

In Table 3 there are two cases for new renewable energy in the Nordic region. Both cases describe large potentials for new renewable power production. The lowest case includes "only" 152 TWh/y new renewable production while the highest case includes 248 TWh/y new production. The main difference between the volumes is offshore wind production. The two cases are used as basis for the scenario quantification. The "Low case" is the basis for the two scenarios "Carbon Neutral" and "European Battery" and the "High case" is the basis for the two scenarios "Purely RES" and "European Hub" in Fig 3.

Table 3. Potential for new production from RES in the Nordic region, "Low" and "High case"

Country	Technology	New prod. Low case [TWh/y]	New prod. High case [TWh/y]	Comments
Denmark	Offsh wind	25	40	Ca 20 TWh/y new projects at [17]
	PV	5	5	Same assumption as for Sweden, see [25]
	Bio		5	Potential 45-50 TWh/y according to [25]
Finland	Onsh wind	10	10	Applications for 5GW new capacity in [14]
	Offsh wind	14	30	Projects with 14 TWh/y registered in [17]
	Bio	20	20	Potential up to 110 TWh/ y, see [25]
Norway	Onsh wind	13	20	Projects for 37 TWh/y registered at [15]
	Offsh wind		30	Projects for ca 40 TWh/y registered at [15]
	Hydro	10	20	Projects for more than 15 TWh/y at [15]
Sweden	Onsh wind	20	30	Projects for ca 35 TWh/y already registered [18]
	Offsh wind	20	30	Registered project for 30 TWh/y in [17]
	PV	5	5	See [21]
	Bio	10	10	Potential up to 180 TWh/y, see [25]
Total		**152**	**248**	

5.4. Comparison with other relevant studies

5.4.1. Nordic Energy Technology Perspectives (NETP)

The NETP provides analyses of a low emission energy system in the Nordic region in 2050 [1]. There are three main scenarios which are very similar regarding the power system.

The development of power demand is already discussed in section 5.1. All NETP scenarios are similar at the production side. They include an increase in production from about 400 TWh/y in 2010 to 550 TWh/y in 2050. The main part of the increase is covered by wind and also some bio energy. Renewable resources like solar, wave and geothermal are not visible. The nuclear production is increased with 40% to 120 TWh/y in 2050. Nearly all fossil fuel based production is phased out except for 5 TWh/y equipped with CCS.

The NORSTRAT scenarios are at overall level very similar to the scenarios in the NETP. The demand is at the same level and the production portfolio is also very similar based on the same new renewable technologies. The only exception is that the NETP assumes increased nuclear production and also a small share of fossil fuel based production.

5.4.2. Towards a Low-carbon Finland

The Finnish government outlines targets and measures marking out the road to a thriving and low-carbon Finland in 2050 in the report [26]. According to report, one of the greatest climate benefits in reducing emissions in Finland can be achieved by among other integration of renewable and zero-emission energy sources. In the medium and long term, the greatest potential is from wind power. In 2009 there were wind farm projects being planned and investigated with a total capacity of more than 5000 MW. According to the report the technological potential are many times greater, and the largest limitations in the long run have to do with how to connect the wind power capacity to the national grid. Four scenarios for 2050 are described in the report:

- A: The efficiency of energy use is radically improved and final energy consumption in Finland is cut by half. All energy is produced using renewable sources.
- B: The regional structure has developed towards service centres located throughout Finland around which is building efficient. There is less focus on consumptions and services are replacing products. The use of nuclear has increased.
- C: The scenario aims at self-sufficiency and locality. Single-family houses produce most of their energy. RES count for a large share of energy consumption.
- D: This is a technology oriented scenario with concentration of the population in the southern Finland. Energy consumption is at present level. Much new nuclear has been built. Fossil fuels are still used with carbon capture and storage.

Table 4. Power production in scenarios in report from the Finnish government [26]

[TWh/y]	2007	A	B	C	D
Nuclear power	22.5	0	41.6	13.1	64.6
Hydro power	14.0	14.6	15.2	17.5	15.2
Wind power	0.2	22.9	18.6	20.3	22.1
CHP with renewable sources	9.2	17.4	4.0	16.6	27.2
CHP with other sources	17.4	0	0	1.3	7.3
Condensing power	14.5	8.4	0	5.0	8.5
Other	0	0.8	0	0.3	0
Imports (+) or exports (-)	12.6	4.8	0	0	-6.1
Total	**90.3**	**68.9**	**79.3**	**73.8**	**144.7**

Power demand in Finland is in NORSTRAT assumed to be 96 TWh/y, i.e. it is higher than three of the scenarios in the report from the Finnish government, but much lower than the demand in the fourth. Wind power production is in NORSTRAT "low case" at the same level as the scenarios from the government. In the "high case" it is much higher, but as already mentioned the potential is by the government assumed to be "many times higher than 5000 MW". "Other" in Table 4 is including among other production from solar resources. "Other" is in all scenarios lower than 1 TWh/y, and in NORSTRAT it is not included.

5.4.3. Danish Energy Strategy 2050

The Danish government released in 2011 an "Energy Strategy 2050" [27]. Relevant targets/visions for 2050 are:

- Denmark is independent of fossil fuels in 2050
- In 2050 the energy consumption could be more than 50% more efficient overall

- It is likely that wind production will count for very large amount of future electricity production. In principle, wind power could cover current levels of electricity consumption many times.
- In future, biomass will play an even more important role in the energy system than today.
- With the government initiatives for expansion of wind and biomass, Denmark is well on its way to having an energy and transport system based on RES in 2050.

The strategy is not very quantitative about 2050. The NORSTRAT scenarios are in accordance with the targets/visions from the Danish government.

5.4.4. Norway to 2050

In 2012 the Norwegian government released a report about Norwegian climate policy [28]. The report covers among other potentials for new renewable production in Norway. Potential for new hydro power production is about 30 TWh/y and for wind power production about 17,4 – 21,5 TWh/y in the period to 2025. The technical potential for wind power production is enormous, but among other economic and environmental factors are limiting the potential.

The power development in Norway to 2030 is estimated in [29]. The power demand is analysed in three scenarios with medium versus low and high price development. In the medium alternative the power prices are at the same level as today, in the high price alternative they are increasing with 20% and in the low price scenario they are decreasing with 30%. The different development of prices reflects different developments of primary costs for power producers like fuel costs and CO2 prices. In the three scenarios the total power demand in Norway is increasing from the 2005 consumption of approximately 126 TWh to between 140 TWh to 159 TWh in 2030.

The use of renewable resources in Norway in NORSTRAT is in "low case" lower than the potential to 2025. The assumed power demand in 2050 in NORSTRAT is at the same level as expected by the Statistical Office in the medium alternative in 2030 [29].

5.4.5. Sweden to 2050

The Swedish government has a target of a carbon neutral Sweden in 2050 [30]. The government has started to elaborate a Road Map to 2050, but it is not found any deadline for the finalization of the Road Map.

6. Discussions/conclusions

This paper has presented a scenario methodology and application of the methodology on a Nordic power system without GHG emissions by 2050. The scenarios will be used for the analyses of the power system with particular focus on the need for transmission grids and the future role of the Nordic power system in a European context. The target group for the analyses is TSOs but also politicians and decision makers in the power industries.

The scenarios are very similar to the Nordic Energy Technology Perspective scenarios which were released in 2013. However, NORSTRAT goes much further in spatial resolution related to localisation of demand and new renewable production. The quantification of the new production resources is to a large degree based on already defined projects and is derby probably reflecting the most profitable locations for the potential production. Furthermore, the NORSTRAT scenarios are mainly in accordance with possible developments described by the governments and authorities in the Nordic countries.

Based on the quantification results it can be concluded that the Nordic region has sufficient RES to develop a power system free of carbon emission. Further it can be concluded that based on the expected demographic changes it is likely that there will be a considerable increase in demand in the largest cities unless there is a focus on energy efficiency.

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